Pathway Study on Demand Side Management and Energy Storage in Ottawa

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

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January 2019

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Executive Summary

This paper examines the role of demand side initiatives in electricity and thermal energy, including demand response, conservation and time of use pricing, with a particular focus on electrical and thermal energy storage.

Electricity production has lower GHG emissions in Ontario than in many other jurisdictions. However, conservation demand management (CDM) and electricity storage can further reduce greenhouse gas emissions in multiple ways. Electricity demand peaks—which are met by natural gas generation in Ontario—can be reduced through demand response, conservation and time of use pricing. Electricity storage can also time-shift renewable electricity generation to displace natural gas electricity generation at peak periods, further decreasing the GHG intensity of typical grid-supplied electricity.

In heating systems, natural gas Demand Side Management (DSM) reduces energy demand. Thermal energy storage supplements low carbon fuel sources to displace natural gas heating as an aspect of district energy or other systems.

Currently, Ontario has a surplus of baseload electricity generation, which can be used in power-to-gas or power-to-thermal storage applications to displace natural gas heating demands. The electrification of heating and transportation systems will also displace fossil fuel use, which will reduce their associated emissions. The resulting increased electricity demands will reduce the surplus baseload periods. CDM and electricity storage will be required to mitigate future peaks by reducing demand, as well as increasing the inclusion of variable renewable energy generation.

Section 1: Present Assessment of DSM and Energy Storage

Pathway Description

This paper examines the role of Demand Side Management (DSM) and energy storage in a low carbon future for the City of Ottawa.

Energy DSM programs reduce greenhouse gas (GHG) emissions by reducing overall energy consumption through conservation and energy efficiency. DSM includes technologies, policies and strategies that reduce or modify energy demand, targeting energy efficient devices, time-shifting energy loads and energy conservation. DSM also includes energy storage, innovative energy pricing structures, and policies that target efficient buildings, appliances and processes. In the context of electricity in Ontario, DSM is referred to as Conservation and Demand Management (CDM), and this term will be used in this document when discussing electricity.

This paper has a particular focus on the role of energy storage. Energy storage technologies store energy for use at a later time. In traditional electricity systems, electricity must be used as it is generated, requiring considerable system oversight and ongoing processes to turn generation on and off to ensure that supply meets demand at a given moment. Electrical storage technologies transform electricity into other forms of energy (chemical, mechanical potential, magnetic), a process which is then reversed to release electricity at a later time, either injected back into the electrical grid, or to be used directly in applications. This process enables the capture of excess thermal or electrical energy at certain times, storing it for use at other times, thus avoiding additional generation.

Energy storage enables increased use of variable renewable energy (VRE) in heating and electricity systems by reducing the time discrepancy between VRE generation and actual energy demand.[1] Electricity storage increases the utilisation of each unit of electricity generating capacity, while also reducing the overall electricity capacity required to address spikes in demand. Additionally, surplus electrical energy can be transformed into thermal energy and stored for periods during which heating and cooling services are required.

Electricity storage technologies can also encourage the electrification of the transportation and heating sector, by providing flexibility in the supply of electricity, and alleviating the impact of potential demand spikes associated with new demand from electric vehicles and electric heating systems.

Energy storage and DSM strategies add complexity to energy distribution, but can provide many benefits including potential cost savings, supply reliability, resilient distribution, and emissions reductions.

Pathway Boundaries

This pathway examines the role of DSM, CDM and storage within thermal and electricity energy systems in Ottawa, including system benefits, drivers and barriers to uptake, and opportunities to reduce GHG emissions. The study provides background information, focusing on high level descriptions of technologies and policies and noting the relevance of these systems to the context of Ottawa. The current pathway section explores existing deployment in Ontario and Ottawa and identifies the opportunities which are most significant locally. Finally, this paper examines the future pathway, using modelling to explore and potential DSM, CDM and storage options for the City.

[1] IEA. (2014). Technology Roadmap: Energy Storage.

Background Information

Demand Side Management

DSM is a broad term that incorporates strategies and technologies that modify or reduce energy demand. In Ontario, electricity and natural gas providers are required to provide DSM programs to customers.

Electricity

DSM is referred to conservation and demand management (CDM) in relation to electric utilities in Ontario, and includes the following program structures:

Demand response (DR) seeks to reduce electricity use at a given moment, often at peak demand. DR programs often allow energy customers to sell a reduction in energy use at peak demand, referred to as 'negawatts' by Hydro Ottawa.[2] The key principle is to encourage peak demand reductions, rather than increase supply. DR is more easily achieved with large consumers of electricity which can individually cause considerable peak load reductions by curtailing their energy demand and can easily compete in auctions for energy use reductions. Currently, class A accounts (users that exceed 5 megawatts for the applicable base period) and any organization with a peak demand of more than 1 MW are eligible for DR.[3] DR strategies for residential or small commercial customers rely on intermediaries that pool a group of residential customers in the sale of energy reductions. Examples of DR strategies include adjusting temperatures to draw less electricity during peak heating/cooling periods, turning off production processes in industry during peak demand, and using "behind the meter" generation or storage during peak periods. DR will become increasingly critical to managing costs as the share of intermittent renewable energy in the electrical system increases.[4]

Innovative pricing structures also provide incentives for energy customers to reduce use, often at peak times. Time-of-Use pricing structures make electricity more expensive during peak demand periods, encouraging consumers to shift energy use to low demand periods. Examples of time of use pricing structures include variable pricing for on and off peak and prices that include seasonal critical peak pricing.[5] One study found that pricing strategies combined with solar PV battery storage can result in mean peak net demand reductions between 46% - 64%, reducing mean net demand fluctuations by 25% - 49%, and increasing the mean solar PV self-consumption between 24% - 39%.[6]

Electricity CDM programs also encourage uptake of energy efficient appliances, buildings and materials. Utilities frequently provide rebates and incentives to consumers who purchase energy efficient lights, appliances and other electrical plug loads.

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[2] Hydro Ottawa. (2016). Strategic Direction 2016-2020.
[3] IESO (2017) Demand response: A smart approach to energy management.
[4] The value of electricity and reserve services in low carbon electricity systems. (n.d.). https://doi.org/10.1016/j.apenergy.2017.05.094
[5] Ministry of Energy. (2017). Ontario's Long-Term Energy Plan: Delivering Fairness and Choice. Government of Ontario.
[6] Babacan, O., Ratnam, E. L., Disfani, V. R., & Kleissl, J. (2017). Distributed energy storage system scheduling considering tariff structure, energy arbitrage and solar PV penetration. *Applied Energy*, *205*, 1384–1393. https://doi.org/10.1016/j.apenergy.2017.08.025

Natural Gas DSM

Natural gas utilities in Ontario are required to provide customers with tools to reduce natural gas consumption, predominantly through energy efficiency upgrades.[7] For residential and commercial customers, this includes incentives for high efficiency heating and cooling systems, building retrofits, as well as energy management devices (ex, programmable thermostats) that encourage conservation by the building occupant. Industrial DSM programs range from energy management advice to specific system upgrades.

Demand Response programs can also be applied to natural gas systems, but are mostly used to minimize the impacts of gas shortages. Many natural gas suppliers have interruptible service contracts for large consumers that use natural gas for industrial processes, rather than heat. In signing an interruptible supply contract, natural gas customers may have their supply interrupted in exchange for lower distribution fees. Customers with over 340,000m^3 of natural gas use are eligible to sign an interruptible service contract with Enbridge.[8] Natural gas DR programs can also include smaller and residential customers using energy management systems. An example program is the Advisory Thermostat Program by Southern California Gas, where participants agree to adjustments to their programmable thermostat for a $50 rebate.[9]

Natural gas DSM is critical to an energy evolution in the City of Ottawa. Natural gas consumption is a major contributor to Ottawa's greenhouse gas emissions, as most residential, commercial and industrial heating needs are met by natural gas.

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[7] Ontario Energy Board (2017). 2018 to 2021 Business Plan. Retrieved from: https://www.oeb.ca/sites/default/files/OEB-2018-2021-business-plan.pdf

[8] Enbridge. (2019). Handbook of Rates and Distribution Services.

[9] Navigant. (July 25, 2017). Natural Gas Demand Response – Current Utility Programs: Part 3. Retrieved from: https://www.navigantresearch.com/news-and-views/natural-gas-demand-response-current-utility-programs-part-3.

Energy Storage

Electricity Storage

Electricity storage technologies influence electricity supply and demand in a variety of ways, performing various grid services that benefit the electricity system.

Figure 1: Services provided by electricity storage technologies.[10]

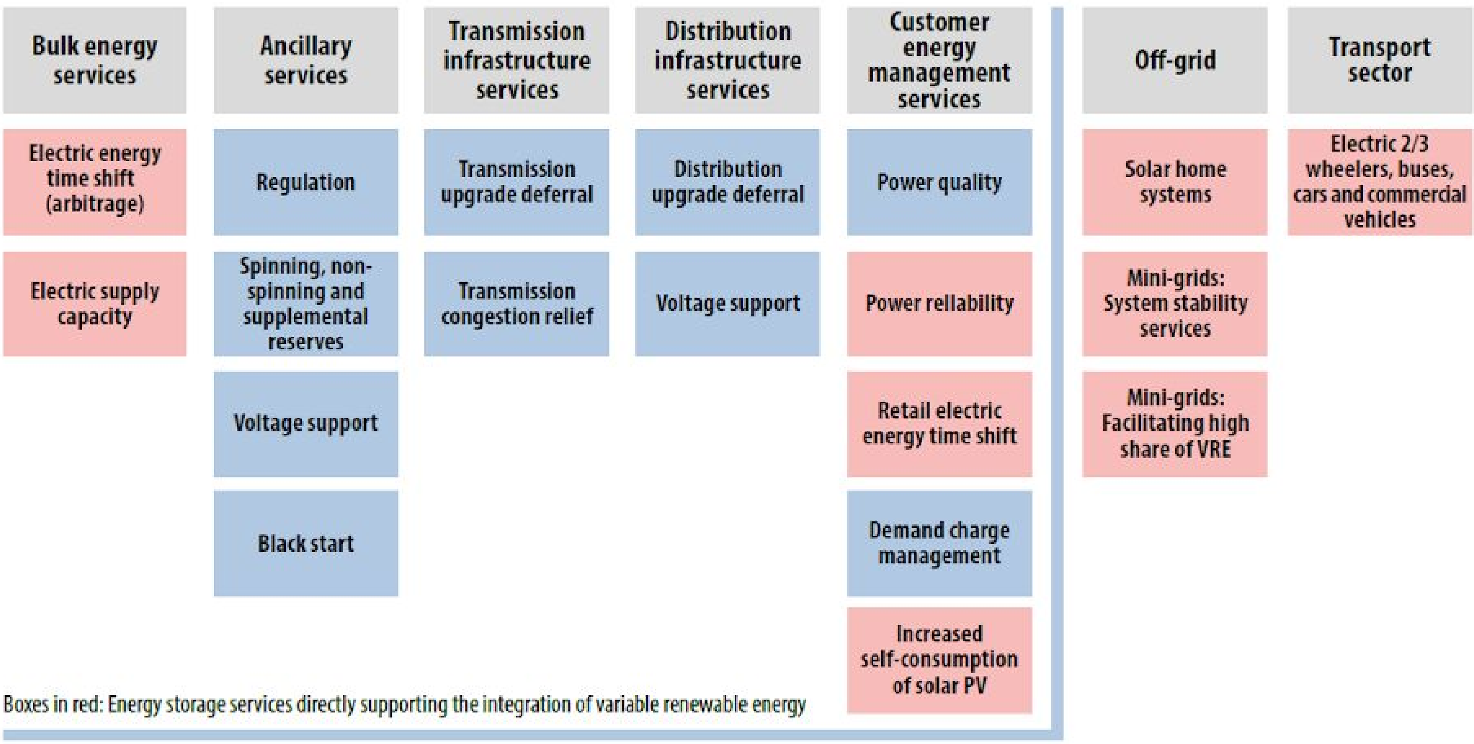

Figure 1 illustrates some of the services provided by energy storage:

- Bulk energy services refer to the role of storage in balancing energy supply and demand at a system level. As an example, seasonal storage systems store energy for days to months in order to reduce the discrepancy between seasonal supply and demand.
- Ancillary services refer to maintaining an ongoing balance between electricity supply and demand on a minute-to-minute basis, providing additional voltage support and system reliability.
- Transmission and distribution infrastructure services refers to the ability of storage to alleviate congestion in transmission and distribution infrastructure and to locally shift demand at peak hours. In this context, energy storage can be used to defer investments in transmission and distribution infrastructure.[11]
- Customer energy management uses energy storage to provide reliable supply to consumers. Generally, more relevant to larger industrial loads, it is increasingly being used at the residential level, when coupled with rooftop solar PV systems. This can allow customers to

[10] IEA. (2017). Electricity and storage costs 2017.
[11] Department of Energy. (2013). DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA. Sandia National Laboratories.

engage in time-shifting activities, often to reduce energy demand at peak times to reduce costs.[12]

- Off-grid services refer to the use of storage to provide for off-grid or micro-grid systems that provide enhanced system reliability and reduce overall system costs. Off-grid storage can better incorporate renewables services to replace diesel, natural gas and propane generators.

- Electrification of transportation refers to the use of storage to support the electrification of transportation vehicles.

The services described above can be achieved through various storage technologies, each of which has different characteristics and capabilities.

Batteries: Electricity charges chemical reactions within electrochemical cells, transferring electrical energy to chemical energy. Batteries have terminals of different chemicals, often metals. Electrolytes separate the two terminals but allow for the flow of ions between the cells. Wiring attached to the terminal connects the flow of ions to be used as electricity.

Solid state batteries are at the commercial phase, including lead-acid and lithium-ion batteries, the latter used in electric vehicles. Flow batteries are still in development and rely on chemical anodes dissolved in liquid. Flow batteries can be instantly recharged by replacing the battery liquid and are considerably more energy dense than solid state batteries.

Batteries range considerably in scale and can be placed at various points in the electricity system, depending on the service they are providing. A large-scale battery connected to the transmission system can provide time shift services controlled by the electricity system operator. Smaller scale battery storage at the distribution level is also becoming increasingly common. These smaller modules are often paired with rooftop solar PV, and can reduce overall electricity demand for electricity customers, and can increase reliability in remote areas.[13] Decentralized batteries at the distribution level can also re-inject electricity back into the distribution system, acting as distributed energy resources.

Batteries are used in transportation electrification, where electricity is used as a substitute for fuel. Deployment of electric vehicles can also act as distributed energy resources for local electricity distribution systems, releasing electricity from vehicle batteries back into the grid as required. This integrated vehicle-to-grid storage model is still in development, but greater integration of EVs both as loads and as sources could provide further flexibility to the grid, while displacing transport fuels and their associated emissions. Vehicle-to-grid storage raises concerns of battery life and degradation, as EV batteries would be charged and discharged more frequently than if used only for driving.[14] EV grid integration will also require sufficient smart grid communications to be effectively deployed.

The wide range of applications and declining module costs have created momentum for the application of batteries in electricity storage. Batteries make up a considerable portion of the projects already developed in Ontario, as procured by Ontario's Independent Electricity System Operator (IESO), including a lithium ion module that was installed by Canadian Solar for Hydro Ottawa at the Ellwood Energy Storage Project.

[12] Weniger, J., Tjaden, T., & Quaschning, V. (2014). Sizing of Residential PV Battery Systems. *Energy Procedia*, *46*, 78–87. https://doi.org/10.1016/j.egypro.2014.01.160
[13] IRENA. (2015). Battery storage for renewables: market status and technology outlook.
[14] Uddin, K., Dubarry, M., Glick, M. (2018). The viability of vehicle-to-grid operations from a battery technology and policy perspective. Energy Policy, 113, 342-347.

Batteries are suitable for deployment in Ottawa for a variety of reasons. First, there are few geographical limitations, and batteries can be scaled up and down, depending on the service it is providing. This means that batteries can be placed in various places in Ottawa, from rooftop storage to large grid storage applications. Rural and vacant industrial lands can provide suitable locations for grid scale projects. Ongoing declining costs also makes battery deployment increasingly viable.

There are some concerns that widespread deployment of batteries may have adverse environmental and emissions impacts from mining and manufacturing battery components.[15] Successful decarbonization of energy systems will mean that life cycle emissions will become an increasingly important contribution to total emissions over time.

Power-to-thermal energy: This approach uses electricity during low cost periods to generate thermal energy using either a boiler or air or ground source heat pump. A relatively small volume of storage, which is typically hot water, can displace subsequent periods when natural gas is lower cost than electricity. Additional benefits include redundancy in the building heating system, the simplicity of the technical approach and the ability to act as a bridge to a broader electrification strategy. The system also provides flexibility for capturing the surplus power from renewable electrical generation in periods of low demand, thus encouraging additional renewable generation. Power-to-thermal is currently feasible in Class A accounts with real time response to hourly prices and the payback can be under ten years.[16]

Hydrogen: Electricity can be used to produce hydrogen through electrolysis. Hydrogen can be used directly in transportation, injected into the natural gas grid, or can be re-converted back to electricity. North America's first grid scale hydrogen storage project is in Mississauga, a collaboration between Hydrogenics and Enbridge. Electricity is converted to hydrogen gas at periods of low demand, which can be injected into local natural gas networks, for use in heating and industrial processes. This process is an example of power-to-gas technology. Hydrogen power-to-gas systems can displace a portion of natural gas use, which can reduce the associated GHG emissions. However, safety and feasibility studies are still required prior to widespread deployment.[17] It is estimated that local natural gas distribution networks could safely accommodate hydrogen injection rates of 5%-15%, with local case by case variation.[18]

Hydrogen storage can also be used in passenger vehicles, using fuel cell technology. Hydrogen vehicles are only just reaching commercialization, with one available model in Canada, the Hyundai Tucson Fuel Cell Electric Vehicle (FCEV). Major automakers are pushing forward on hydrogen FCEV models, but vehicle availability and filling station networks are sparse. There are also safety concerns associated with hydrogen storage, and safety standards have not been widely established.

Hydrogen storage and power-to-gas have important relevance in Ottawa. There are no geographical constraints, and power-to-gas applications target GHG emissions reductions from natural gas use, which are a critical lever for Ottawa. As one of the first commercial operations is in Ontario, there is opportunity to leverage expertise from project successes within a similar regulatory environment.

Ice Storage: Ice storage systems use electricity to create ice during periods of low demand, to be used for cooling in periods of high demand, often in the summer. This approach is often used in commercial air conditioning systems, with approximately 1,000 MW of ice storage capacity in the United States.[19] Ice storage can also be classified as thermal energy storage because it influences heating and cooling systems. Ice storage has relevance to power-to-thermal applications by

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[15] Rohmare, M. Dahllof, L. (2017). The Life Cycle Energy Consumption and Greenhouse Gas Emissions from Lithium-ion Batteries. No. c243.

[16] Personal communication with the City of Ottawa, 2018.

[17] Melaina, M., Antonia, O., Penev, M. (2013). Blending Hydrogen into Natural Gas Pipeline Networks: A review of Key Issues. National Renewable Energy Laboratory.

[18] Ibid.

[19] IEA. (2014). Technology Roadmap: Energy Storage.

providing short term storage for cooling resources, and time shifting electricity demand from cooling.

Pumped storage: Pumped storage uses electricity to pump water from a lower elevation reservoir to a higher elevation reservoir in periods of electricity surplus, storing electrical energy as gravitational potential. In periods of electricity demand, the water is then released back down to the lower reservoir to spin a turbine, to produce electricity to be re-injected back into the electrical grid. Pumped storage is the most mature energy storage technology, and accounts for over 99% of global energy storage capacity in 2014.[20] There is only one pumped storage facility in Canada, located on the Niagara River in Southwestern Ontario. The Sir Adam Beck Pump Generating Station is a 174 MW storage facility.[21]

Pumped storage is limited by regional geography, requiring an elevation differential of at least 100m and a large surface area for effective system design, and therefore is limited in the City of Ottawa.

Compressed Air Energy Storage (CAES): CAES uses electricity at periods of low demand to compress air in underground or pressurized storage tanks or caverns. When electricity is needed, air is released to a combustor to generate electricity. As air is pressurized, it must be cooled, releasing waste thermal energy; the air must be reheated (often by natural gas) in order to be used, which results in lower system efficiency and thermal energy loss. Advanced adiabatic compressed air energy storage (AA-CAES) addresses the use the of natural gas during heating phase by using waste heat generated during the initial air compression, resulting in greater efficiency and lower associated emissions. Simple CAES technology has a much lower system efficiency, with estimates at approximately 25-40%, while adiabatic CAES can see efficiencies of up to 70%.[22]

One of the world's first underwater AA-CAES storage facility is operated by Toronto Hydro, NRStor and Hydrostor in Lake Ontario. Electricity is used to compress air into accumulators at the bottom of Lake Ontario. When electricity is required, the pressure of the lake water forces air back up to the surface into an expander, which drives a generator.[23] Hydrostor is also moving forward on a similar system in an abandoned mine in Goderich, Ontario.

CAES is also limited in the City of Ottawa because it has few, if any, accessible underground or deep-water resources for tank pressurization. Hydrostor's Lake Ontario AA-CAES system is at a depth of approximately 54m.[24] The Ottawa River could be a potential site for an underwater CAES, with the deepest point of the river at 90 m, although feasibility studies would be required to assess site viability.

Other electricity storage technologies are more suited to ancillary services and electricity system regulation. These include flywheels, supercapacitors and other electricity storage technologies that provide short bursts of energy. These projects are generally associated with transmission infrastructure. While these can potentially have relevance to the City, they do not directly influence emissions reductions.

[20] IEA. (2014). Technology Roadmap: Energy Storage.
[21] Ontario Power Generation. Sir Adam Beck Pump Generating Station. Retrieved from: https://www.opg.com/generating-power/hydro/southwest-ontario/Pages/sir-adam-beck-pgs.aspx
[22] Elmegaard, B., & Brix, W. (2011). Efficiency of Compressed Air Energy Storage. In The 24th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems: The 2011 conference motto: International Smart Energy Networks of Cooperation for Sustainable Development.
[23] Toronto Hydro. Compressed Air Energy Storage Project. Retrieved from: https://www.torontohydro.com/sites/electricsystem/gridinvestment/powerup/pages/compressedairenergystorageproject.aspx
[24] Tweed, C. (November 25, 2015). Toronto Hydro Pilots World's first Offshore Compressed Air Energy Storage. Greentech Media. Retrieved from: https://www.greentechmedia.com/articles/read/toronto-hydro-pilots-worlds-first-offshore-compressed-air-energy-storage#gs.6ohWI0s

Thermal Energy Storage

With the exception of some buildings in rural areas which are outside the natural gas grid, most heating needs in Ottawa are met by natural gas, an inherently storable fuel. Thermal energy storage technologies are used to reduce supply variability from low carbon sources of heat, which can displace natural gas use. Thermal energy storage is effective when included in district energy systems, and there are examples of thermal energy storage technologies at the building level. Renewable heating sources such as industrial waste heat, biomass, solar thermal, geothermal and renewable electricity can be combined with storage in district energy systems. District energy with thermal storage is well developed in Denmark, Netherlands, Sweden and Germany, and there are a growing number of successful projects in Canada. The following thermal energy storage technologies have relevance to emissions reductions in Ottawa.

Underground Thermal Energy Storage (UTES): A heated or cooled working fluid, often water, is pumped underground into aquifers or boreholes for later use. Underground thermal energy storage is most applicable to medium temperature thermal requirements, such as building heat. UTES can effectively store heat seasonally, by collecting solar thermal energy for use in the winter. It can also improve the efficiency and feasibility of ground source heat pumps by improving system feasibility in the winter. The technology is well developed in Sweden, where 20% of heat demand is associated with borehole thermal energy storage.[25] UTES systems are used in both individual buildings and in district energy systems.

The Drake Landing Solar Community in Okotoks, Alberta is a key Canadian example of UTES. In this district energy system, solar thermal energy is generated in periods of high solar insolation. The heated water is pumped below ground in boreholes, to be used later and throughout the year. The system provides enough space heating for 52 detached high efficiency homes. Five years into its operation, the system is still performing at high efficiency.[26] The Drake Landing example represents an important example for Ottawa, because it experiences a similar annual temperature profile, and has similar residential development patterns.

In addition to a solar thermal storage operation, a system which stores excess thermal heat in the ground from a variety of energy sources such as low-cost electricity, solar thermal and waste head can be used to increases the performance of a geothermal system. University of Ontario Institute of Technology developed such a system to heat eight buildings on campus with three hundred and eighty-four boreholes.[27]

Pit storage: Heated or cooled water is pumped into shallow pits filled with gravel and covered in insulating materials. Pit storage is frequently used in conjunction with district energy systems. It has been deployed successfully in Denmark, storing solar heating during the summer for use in the winter. In Denmark, pit storage is fairly simple to build and is relatively low cost, making it an attractive option.[28] Pit storage could be feasibly introduced in Ottawa with a connection to district energy systems or large buildings if there is sufficient surface area. The space requirements for pit storage limits this type of system in urban areas.

Snow storage: Snow storage systems use waste snow to provide cooling to buildings. In Ottawa, snow is collected and left to melt in disposal sites and facilities. Because snow is considered a waste stream, snow storage can have lower operating costs, while displacing energy for cooling. The first

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[25] Harris, M. (2011). Thermal Energy Storage in Sweden and Denmark Potentials for Technology Transfer. Lund University, thesis.
[26] Sibbit, B., McClenahan, D., Djebbar, R., Thornton, J., Wong, B., Carriere, J., Kokko, J. (2012). The performance of a high solar fraction seasonal storage district heating system – five years of operation. Energy Procedia, 30, 856-865.
[27]University of Ontario Institute of Technology (2003). Canada's newest university has one of North America's largest geothermal well fields. Retrieved from: https://news.uoit.ca/archives/2003/11/20031107_1.php
[28] Ibid.

commercial snow energy storage operation is a cooling system at a hospital in Sundvall, Sweden.[29] Collected snow is stored in an insulated tank, and as it melts, the water is fed through a heat exchanger, which cools circulating air in the building.

Snow storage is technically feasible in Ottawa, as the City receives 175 cm of snowfall annually.[30] However, there are technical concerns with declining or variable snowfall in relation to changing climate conditions.

Hot water storage: Insulated tanks are used to store hot water on a short-term basis. A common example of this technology is domestic hot water heaters, which are commonly used across Ottawa and North America. Natural gas hot water heaters do not contribute to GHG emissions reductions. However, when heat is generated using low carbon or renewable energy sources, such as solar insolation and waste heat, short term storage can maintain hot water supply, avoiding the need for natural gas and the resulting greenhouse gas emissions.

In particular, hot water storage has applications in power-to-thermal electric heating. Hot water can be generated by electricity in low demand periods and stored to provide thermal energy for heating, reducing the need for natural gas. The City of Ottawa has successfully pioneered this approach with a mock operation study, which predicted reduced GHG emissions and costs.

Costs

Capital costs for many electricity storage technologies are high, but are rapidly changing and are expected to decline with further uptake. The International Renewable Energy Agency (IRENA) estimates that by 2030, stationary battery costs could fall by 50-60%.[31] Actual project costs are very site, technology and jurisdictionally specific, which makes cost estimates difficult to apply at the local level.[32] The costs of grid-scale batteries range based on the technology, system and size of application.

The most cost-effective electrical energy storage technologies are those that can provide multiple applications. Under IESO planning, DSM and energy storage technologies are procured based on the services the storage provides, rather than the technology type and the cost of the solution. This principle fits in within the IESO's Market Renewal Initiative, in which generation, storage and DR compete in one market auction.

Once installed, grid scale electricity storage can provide economic benefits. The avoided costs of purchasing electricity at peak times is dependent on the time of system charge and discharge times. When storage is used to defer investments in new transmission or distribution investments and development, or defer the development of new generation infrastructure, energy storage often presents financial savings from a grid operation perspective. The avoided costs of purchasing electricity at peak times can also provide financial benefits for system owners.

In contrast, thermal energy storage technologies are generally more mature, and have lower capital costs.

[29] Region Vastlnorrdland. Snow Cooling in Sundsvall. Retrieved from: https://www.rvn.se/v1/In-english1/In-english/Environment-and-energy/Energy-Factor-2/Snow-cooling-in-Sundsvall

[30] Environment and Climate Change Canada. 2018. Canadian Climate Normals 1981-2010 Station data. Retrieved from: http://climate.weather.gc.ca/climate_normals/results_1981_2010_e.html?searchType=stnName&txtStationName=Ottawa&searchMethod=contains&txtCentralLatMin=0&txtCentralLatSec=0&txtCentralLongMin=0&txtCentralLongSec=0&stnID=4333&dispBack=0

[31] IRENA. (2017). Electricity Storage and Renewables: Costs and Markets to 2030.

[32] Ibid.

Technologies examined in this report are summarized in Table 1. It should be noted that system costs are case specific, and the values shown are for illustrative purposes.

Table 1: Characteristics of sample energy storage technologies.[33,34]

Technology	Location	Suitable storage duration	Output	Energy Capital Cost ($USD/kWh)	Efficiency	Maturity
Pumped Hydro	Supply	Long term; hours-months	Electricity	$5-100	50-85%	Mature
CAES	Supply	Long term; hours-months	Electricity	$2-120	27-70%	Commercial (AA-CAES in demonstration)
Lead-acid batteries	Supply, Demand	Minutes-days	Electricity	$50-400	75-95%	Mature
Lithium-ion batteries	Supply, Demand	Minutes-days	Electricity	$600-3800	75-95%	Commercial
NaS batteries	Supply, Demand	Long term	Electricity	$300-500	75-95%	Early Commercial
Hydrogen	Supply, Demand	Hours-months	Electricity	$15	22-50%	Demonstration
Underground Thermal Energy Storage	Supply	Long term; hours-months	Thermal	$2.6[35]	50-90%	Mature
Pit Storage	Supply	Medium term	Thermal	$1-7[36]	50-90%	Mature
Ice / snow storage	Demand	Short term; hours-days	Thermal; low temp	$2-5[37]	75-90%	Commercial
Hot water storage	Demand	Short-term; hours-days	Thermal	--	50-90%	Mature

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[33] Luo, X., Wang, J., Dooner, M., Clarke, J. (2015). Overview of current development in electrical energy storage technologies and the application potential in power system operations. Applied energy, 137, 511-536.

[34] IEA. (2014). Technology Roadmap: Energy Storage.

[35] Lanahan, M., Tabares-Velasco, P. (2017). Seasonal Thermal energy Storage: A Critical Review on BTES Systems, Modelling, and System Design for Higher System Efficiency. Energies, 10, 743, doi:10.3390/en10060743

[36] IEA. Task 45: Seasonal pit heat storages - Guidelines for materials & construction. IEA-SHC TECH SHEET 45.B.3.2. Retrieved from: http://task45.iea-shc.org/data/sites/1/publications/IEA-SHC%20T45.B.3.2%20TECH%20Seasonal%20storages%20-%20Water%20Pit%20Guidelines.pdf

[37] Lanahan, M., Tabares-Velasco, P. (2017). Seasonal Thermal energy Storage: A Critical Review on BTES Systems, Modelling, and System Design for Higher System Efficiency. Energies, 10, 743, doi:10.3390/en10060743

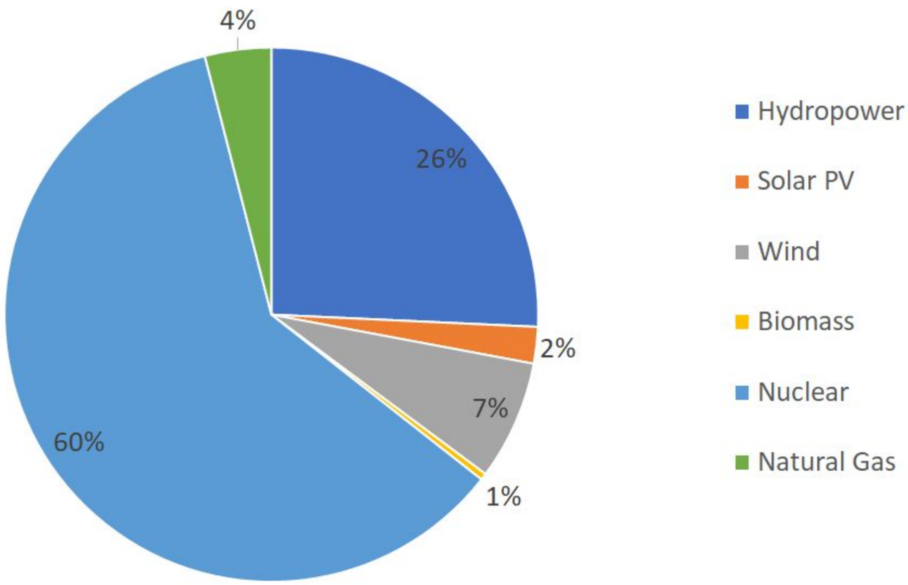
Evaluation of Current Pathway

The following section outlines the ways in which DSM and energy storage can contribute to emissions reductions in the City of Ottawa. Electricity pathways are examined first, followed by thermal energy pathways. Ongoing developments in DSM and energy storage are also considered, highlighting major opportunities for emissions reductions in Ottawa.

Electricity pathway

Ontario's electricity mix is made up primarily of nuclear, followed in order of prominence by, hydropower, natural gas, wind, solar and biomass, displayed in Figure 2. While Ontario is increasing its capacity of renewable electricity, it is also adding increasing amounts of natural gas fired generation to address electricity peaks and system reliability.[38]

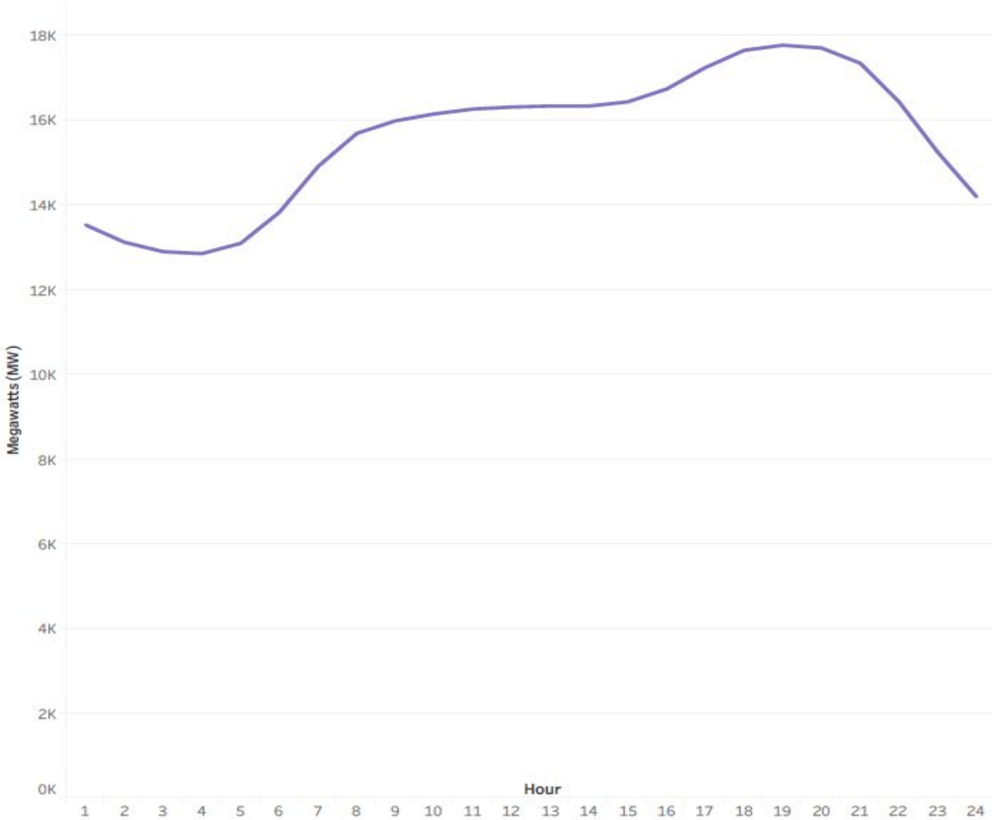
Figure 2: Ontario electricity generation mix in 2017.[39]



Ontario's electricity baseload comes primarily from carbon-free sources. During peak periods when demand is greater than Ontario's baseload generation, natural gas fired generators are deployed because natural gas generators can ramp up quickly and can provide stable supply. As a result, marginal emissions factors can be nearly four times the average emissions factor for electricity.[40] Peak demands occur daily, with critical peaks in the summers and winter, due to heating and cooling needs. Ontario's annual average hourly electricity demand in 2016 is displayed in Figure 3. Electricity demand increases over the course of the day, with the greatest demand in the early evening.

[38] IESO. (2016). IESO Report: Energy Storage.
[39] Ontario Energy Board. 2018. Ontario's System-Wide Electricity Supply Mix: 2017 Data. retrieved from: https://www.oeb.ca/sites/default/files/2017-supply-mix-data.pdf
[40] The Atmospheric Fund. (2017.). A clearer view on Ontario's emissions: Practice guidelines for electricity emissions factors. Retrieved from http://taf.ca/wp-content/uploads/2017/08/TAF_Guide_Ontario_Emissions_Factors_Digital_2017-08-03.pdf

Figure 3: Average Annual Hourly electricity demand.[41]



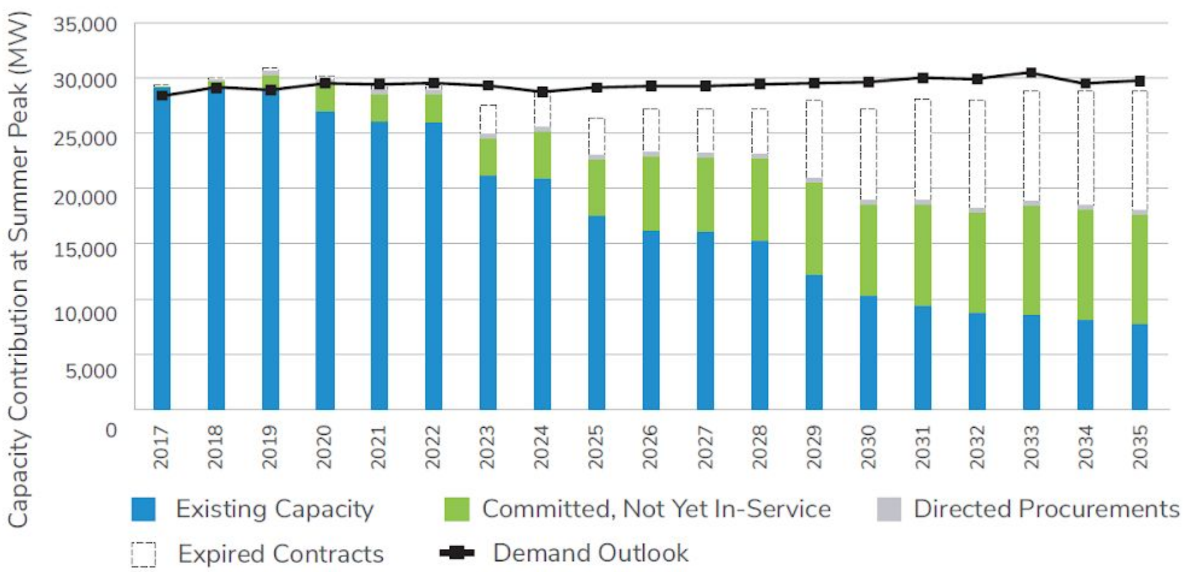
Electricity storage and electricity CDM can displace the need for natural gas peaking generation. If energy storage technologies can store variable renewable energy over the day or seasonally, and that storage technology can quickly inject power into the grid at peak demand periods, then there is some opportunity for displacing natural gas use.[42] Electricity conservation and DR programs can also reduce electricity demand, which decreases the need for natural gas fired generation. However, Ontario's ramping requirements can be as high as 10,000 MW, which will make the complete elimination of natural gas use difficult.[43]

Baseload supply is often greater than electricity demand for many hours of the day, and at multiple times of the year.[44] This is referred to as surplus baseload generation (SBG). Ontario is in SBG 66% of the time, most frequently in the spring and fall seasons.[45] In these periods, electricity is often exported, wind and solar generation are curtailed, or water spillover is enabled at hydropower stations.[46] Electricity storage presents an opportunity to mitigate differences in supply and demand in SBG periods. Seasonal storage technologies in particular will be useful to store excess electricity in the spring and fall, for use in the summer and winter.

[41] National Energy board (2018). Market snapshot: Why is Ontario's electricity demand declining? https://www.neb-one.gc.ca/nrg/ntgrtd/mrkt/snpsht/2018/03-03ntrlctrctdmnd-eng.html
[42] IESO. (2016). IESO Report: Energy Storage.
[43] Ibid.
[44] Ibid.
[45] Ibid.
[46] Environmental Commissioner of Ontario. (January 20, 2017). Surplus Baseload Electricity Generation in Ontario. Retrieved from https://eco.on.ca/blog/surplus-baseload-electricity-generation-in-ontario

According to the IESO, Ontario is expecting to be in frequent SBG periods up until the mid 2020s.[47] After this, declining SBG in the coming years is partially because of planned changes in nuclear generation: the Bruce, Pickering and Darlington Nuclear Generating Stations provide the majority of electricity in province, but the Pickering station is slated for retirement and the Bruce and Darlington generating stations are undergoing refurbishments over the coming decade.[48] Future supply and demand at peak hours is shown in Figure 4.[49]

Figure 4: Supply and demand outlook in Ontario.[50]



In order to keep the emissions associated with electricity relatively low, this supply gap will need to be met with continual operation of plants whose contracts have expired, or with new renewable electrical capacity. Electricity storage will become an important tool to ensure that variable renewable energy can feasibly meet capacity requirements. The intermittency of wind and solar is a barrier to high levels of renewable electricity deployment, as energy supply must consistently match energy demand. IRENA estimates that storage will be needed to provide stable baseload electricity when variable renewable electricity exceeds 30% of system capacity, or 20% if the grid infrastructure is constrained.[51] Electricity storage technologies that can provide short term storage of minutes to hours to 'smooth' out differences between variable renewable electricity supply and demand will be important in Ontario, but because Ontario experiences large seasonal peaks in the summer and winter, IESO estimates that seasonal storage will be even more critical for the province.[52]

Additionally, the Ottawa electrical zone is considered a congested load zone, meaning that at peak demand, electricity needs to be imported from other regions of the province and transmission lines are often at maximum capacity.[53] This has implications for electricity storage technologies for multiple reasons. According to the IESO, this can potentially limit the uptake of storage technologies where electricity is not re-injected into the grid, such as EVs, power-to-gas and power-to-thermal applications, as these forms of storage can increase electricity demand if they draw electricity at peak times.[54] In relation to increasing EV uptake, this makes vehicle-to-grid two-way charging and

[47] IESO. (2016). IESO Report: Energy Storage.
[48] Ministry of Energy. (2017). Ontario's Long-Term Energy Plan: Delivering Fairness and Choice. Government of Ontario.
[49] Ibid.
[50] IESO. (2016). Ontario's Long Term Energy Plan.
[51] IRENA. (2015). Renewables and Electricity Storage: A technology roadmap for Remap2030.
[52] IESO. (2016). IESO Report: Energy Storage.
[53] Ibid.
[54] Ibid.

vehicles as distributed energy resources an important system design feature to ensure successful EV uptake.

Ottawa's congested transmission infrastructure also presents a need for local time shifting energy storage to increase local electricity available at peak demand,[55] while DSM activities such as time of use pricing and DR programs can reduce overall peak loads when congestion is greatest.

Electricity CDM Deployment

At the highest level, the Government of Ontario has committed to a conservation first approach to energy planning in the province, a low-cost option for reducing emissions and matching electricity supply and demand.[56] The government has also required that all utilities in the province have mandatory DSM targets, in an effort to reduce consumer loads. CDM efforts are projected to cover 5% of Ontario's electricity demand by the year 2025.[57]

Demand response and time of use pricing specifically target electricity conservation at peak demand periods. Because Ontario's peaks are generated primarily by natural gas, demand response activities disproportionately reduce natural gas fired generation in comparison to Ontario's lower carbon baseload electricity.[58]

CDM initiatives at the provincial level are ongoing at multiple agencies. The Ontario Energy Board approves electricity prices and has set Ontario's time of use pricing structure. Currently, time of use pricing in the province has two separate pricing structures for summer and winter, with differing prices for off-peak, mid-peak and peak demand. Figure 5 displays TOU pricing as of May 1, 2018. The Ontario Energy Board is currently examining the Regulated Price Plan and reviewing time of use pricing structures to ensure fairness and alleviate peak demand periods.[59]

Figure 5: Time of use electricity pricing for residential customers, as of May 1, 2018.[60]

Off-Peak: 6.5 cents/kWh	Mid-Peak: 9.4 cents/kWh	On-Peak: 13.2 cents/kWh

The Industrial Conservation Initiative (ICI) is a demand response tool that encourages the largest consumers (referred to as Class A) to reduce electricity consumption at peak periods by offering financial incentive on global adjustment (GA) costs. Eligible participants must have an average monthly peak demand of over 500kW at an individual load facility, averaged over a twelve-month period.[61] Participants pay GA costs related to their contribution (as a percentage) to the largest five hourly peak demand periods over one year. This incentivizes large consumers to reduce demand, especially during critical annual peak demand periods. Global adjustment costs are paid by all customers and include charges for infrastructure, debt repayment and other charges.

In one example provided by the IESO, a Class A consumer could save approximately $31,801 in one year on GA rates by significantly reducing demand at peak load periods.[62] The ICI program is estimated to have reduced peak demand by over 1,400 MW in 2017.[63] The program has been

[55] Ibid.
[56] Ministry of Energy. (2017). Ontario's Long Term Energy Plan: Delivering Fairness and Choice. Government of Ontario.
[57] Ibid.
[58] The Atmospheric Fund. (2017). A clearer view on Ontario's emissions: Practice guidelines for electricity emissions factors.
[59] Ibid.
[60] Hydro Ottawa. Time of Use Pricing. Retrieved from: https://hydroottawa.com/accounts-and-billing/residential/time-of-use
[61] IESO. (2018). Industrial Conservation Initiative Backgrounder April 2018.
[62] Ibid.
[63] Ibid.

successful because it combines effective cost reductions for consumers to critical peaks. Alleviating critical peaks in Ontario reduces generation infrastructure requirements.

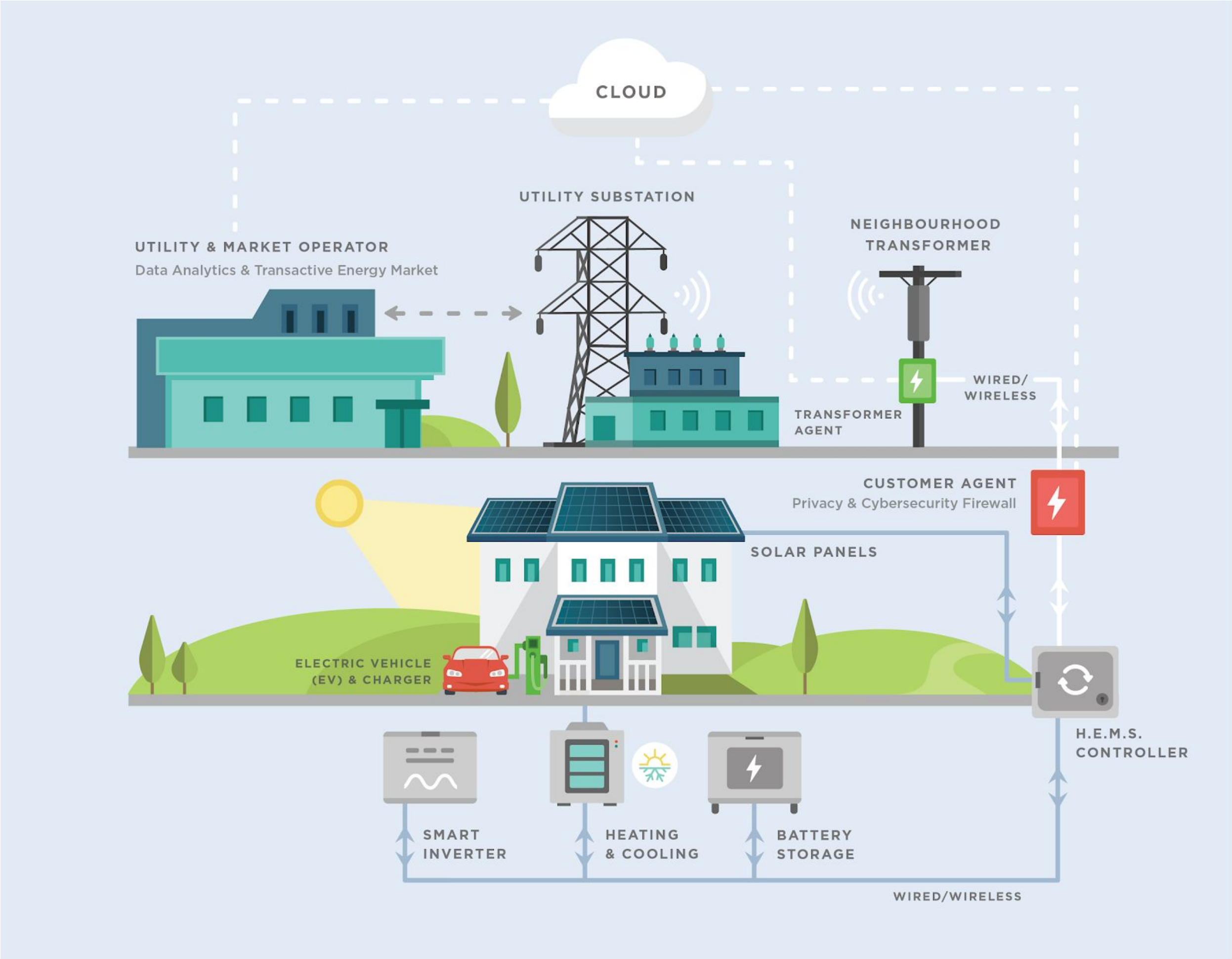
The IESO also recently piloted 100 MW of DR resources.[64] The DR pilot engaged three large electricity consumers in the province in load-following, where the participants could adjust electricity demand on an hourly basis, in return for financial payments. Ongoing uptake of DR fits within the IESO's vision for the Market Renewal Initiative, where storage, demand response, generation and other grid operations participate in an inclusive auction, based on the service provided. IESO's market renewal initiative aligns with Order 745 by the US Federal Energy Regulatory Commission (FERC), stating that demand response is allowed to bid on the same terms as generation in electricity markets.[65]

Hydro Ottawa administers IESO funded CDM programs, including various financial incentives for conservation. For Hydro Ottawa, CDM activities conserved 414.9 GWh of electricity between 2011 and 2014, reducing the energy use of approximately 54,000 homes in the City.[66] The estimated cost of such activities is placed at $0.044/kWh, which is a lower cost than electricity generation.[67]

Hydro Ottawa is also piloting a decentralized and automatic demand response program for residential customers, outlined in Figure 6.

[64] IESO. (2015). IESO Demand Response Pilot Program.
[65] Hydro Ottawa. (2016). Strategic Direction 2016-2020.
[66] Ibid.
[67] Ibid.

Figure 6: Great DR program design.[68]



The Grid Edge Active Transactional Demand Response (The Great DR) program is connecting residential customers to demand response activities, including the ability to control electricity use based on periods of demand.[69] The program will optimize transformer level electricity use between customers using a device (transactive agent) placed at the transformer to allow transactions between customers. The Great DR is to have 30 participants, with each participating home receiving an energy management system, solar panel, smart inverter, lithium ion battery and a bi-directional meter. The program will provide information on optimizing local electricity loads, solar PV, stationary home batteries and EV's in one integrated system.

As a complementary approach to managing the electricity peaks, the City of Ottawa also has a power-to-thermal pilot project which takes advantage of low electricity costs during periods of surplus generation. Electric boilers are dispatched, displacing natural gas consumption, resulting in reductions in GHG emissions and energy costs. The feasibility study, Supplemental Use of Electric Water Heating for Environmental and Cost Reduction, mock operated such a system at City Hall and has demonstrated a viable opportunity in heat electrification.

[68] Hydro Ottawa. (2018). The Great-DR. Retrieved from: https://hydroottawa.com/save-energy/residential/great-dr
[69] Hydro Ottawa. The Great DR. https://hydroottawa.com/save-energy/residential/great-dr

Electricity Storage Deployment

Agencies in Ontario are actively pursuing electricity storage development. The IESO brought electricity storage pilot projects online in 2012, through the Alternate Technologies for Regulation program. The first round procured a capacity of 6 MW, piloting a battery project and a flywheel project, which were used successfully for regulation.[70] IESO also performed a 50 MW Grid Energy Storage Procurement to investigate energy storage across multiple regions of Ontario. Technologies procured in the program included flow and solid-state batteries, hydrogen, and a compressed air project.

The Government of Ontario Smart Grid Fund provided support to 45 grid modernization projects across the province, including support to electricity storage developments. This included funding for battery energy storage projects in Niagara, Toronto, Sudbury and Ottawa. The fund also supported EV integration and automated grid developments. Hydro Ottawa is associated with multiple projects that were awarded funding under Ontario's Smart Grid Fund, including a battery storage project with eCamion, piloting a secure payment system for EV charging with the University of Ottawa, the Great-DR program as mentioned above, and a study on inverter technology.

Deployment of energy storage in Ottawa is currently small but growing. Hydro Ottawa is committed to grid innovation and sustainable energy services, as outlined in its Strategic Direction Report.[71] This is apparent in the involvement of Ottawa Hydro in projects associated with the Smart Grid Fund. Other energy storage initiatives in Ottawa include the deployment of Level 2 electric vehicle chargers across the City, as well the residential batteries in its Great DR Program. Hydro Ottawa is also involved in the Ellwood Energy Storage Project, a pilot facility for transmission-connected lithium-ion battery storage, procured through the IESO.[72]

Heating Pathway

Natural gas represents one of the largest sources of emissions in Ottawa, due to heating requirements in the winter. Natural gas DSM works by reducing overall natural gas use to reduce emissions. Thermal energy storage influences GHG emissions reductions because it allows for feasible use of renewable and waste sources of heat in district energy systems or in individual buildings.

Natural Gas DSM Deployment

Natural gas utilities are required to provide demand side management activities for customers under the Ontario energy Boards' Demand Side Management Framework for Natural Gas Distributors.[73] Enbridge Gas Distribution supplies Ottawa's natural gas.

Enbridge's programming for DSM is separated into three groups: Resource Acquisition, Low Income and Market Transformation. Resource acquisition and low-income programming are comprised of financial incentives for retrofits and efficient heating systems. Market transformation programming relates to shifting energy markets and consumer behaviour through information and support. Energy savings related to Enbridge's DSM activities are displayed in Table 2.

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[70] IESO. (2016). IESO Report: Energy Storage.
[71] Hydro Ottawa. (2016). Strategic Direction 2016-2020.
[72] Association of Power Producers. (2016). Canadian Solar Installing for Hydro Ottawa.
[73] Ontario Energy Board. (2014). Demand Side Management Framework for Natural Gas Distributors. EB-2014-0134.

Table 2: Enbridge DSM results in 2015.[74]

Program	Energy savings in 2015 (m^3)	Program Cost
Resource Acquisition		
Residential	6,762,791	$9,362,295
Commercial	25,646,715	$6,211,724
Industrial	12,289,466	$2,166,706
Low Income		
Part 9	1,129,070	$4,444,616
Part 3	3,143,515	$2,111,746
Market Transformation		
Savings by Design Residential	n/a	$2,032,022
Savings by Design Commercial	n/a	$890,464
Home Labelling	n/a	$121,241
Total	**48,971,556**	**$35,220,594**

In total, Enbridge's DSM programs saved just over 48 million m^3 of natural gas consumption in Ontario in 2015. In comparison to total natural gas consumption in the province, this represents a small reduction in energy use. With total natural gas consumption in Ontario in 2017 at over 22 billion m^3,[75] Enbridge's DSM savings makes up approximately 0.22% of total natural gas consumption in Ontario.

However, according to a report to the OEB, DSM programs have the technical potential to reduce gas consumption by 46.1% by 2030, which could reduce GHG emissions by 24.0 Mt CO2/yr. in 2030; achievable potential could see gas consumption decrease by 9-17.8%, which represents a reduction of 4.7-9.3 Mt CO2/yr. in 2030.[76]

Key barriers to natural gas DSM programming in Ontario are the total funding limit on DSM initiatives, as well as a freeze on financial incentives paid to shareholders for effective conservation, which provided incentive for effective DSM program uptake.[77]

[74] Enbridge. (2017). 2015 Demand Side Management Annual Report.
[75] Statistics Canada. Table 25-10-0055-01 Supply and disposition of natural gas, monthly (data in thousands) (x 1,000). Retrieved from: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2510005501
[76] ICF International. (2016). Natural gas conservation potential study. Submitted to Ontario Energy Board.
[77] The Atmospheric Fund. (January 23, 2015). The Good, the Bad and the Ugly: Ontario's New Natural Gas Framework. Retrieved from: http://taf.ca/good-bad-ugly-ontarios-new-natural-gas-conservation-framework-2

Thermal Storage Deployment

Currently, there is little development of thermal storage in Ottawa. Most buildings in the City use some form of hot water storage tank. However, at this time, heat needs are met mostly by natural gas. Therefore, although the technology is widely deployed, it does not contribute to emissions reductions.

Thermal energy storage has the greatest potential to contribute to emissions reductions if it is included in district energy systems in Ottawa, because district energy systems can more readily incorporate low carbon sources of thermal energy. One option is to include thermal storage in existing district energy systems at federal buildings in the downtown core, the University of Ottawa, Carleton University and other existing systems.

Another possibility would be to encourage district energy systems with thermal storage in new developments in the City. Ideally, these developments would also use low carbon source of thermal energy. One potential site for inclusion of district energy with thermal storage would be at future developments at LeBreton Flats. The site, which is overseen by the National Capital Commission, and is slated for mixed-use redevelopment. The potential for high energy intensity uses of this area makes it suitable for district energy that could use borehole thermal energy storage, similar to that deployed by University of Ontario Institute of Technology. The system could also theoretically connect to the federal buildings district energy system, or to the proposed district energy system at the Zibi development, although feasibility studies and development agreements would be required.

Other potential sites would be related to redevelopment and intensification along the new LRT corridor. Mixed-use, transit-oriented development at LRT stations could likely have sufficient density for district energy that uses thermal energy storage to use low carbon heat. Transit oriented development sites at Blair Station or around the Trainyards redevelopment could also support district energy combined with thermal energy storage. A program similar to the Toronto Green Standard could require or incentivize district energy with thermal storage as a condition of redevelopment.

Another application for thermal energy storage relevant to the City of Ottawa is the use of snow for cooling applications at City buildings. The use of snow storage was explored at the Mary Pitt Centre in Nepean, however, the City has chosen not to move forward with the project.[78] As urban intensification continues in the City, snow storage could be explored for new developments, especially for buildings with high cooling loads that are in proximity to snow storage disposal sites.

Electrification

Because of the low carbon profile of electricity in Ontario, electrification is a critical tool to reduce emissions in transportation and heat. Although there is less activity ongoing in natural gas DSM and thermal storage deployment, the role of electricity storage and demand management will play an important role in decarbonizing heat systems in the medium to long run. Electricity storage and CDM will be important to ensure there is sufficient supply to meet the increasing demand, and that the electricity supply is from and can support low-carbon sources.

Heating electrification through the use of heat pumps or district energy systems that use electric boilers or heat pumps will increase electricity demand, especially in winter and summer months, when critical electricity peaks already occur. Similarly, as electrification of transportation systems

[78] City of Ottawa. (May 11, 2010). Planning and Environment committee Minutes. Retrieved from: https://ottawa.ca/calendar/ottawa/citycouncil/pec/2010/05-11/minutes73.htm

increases within the city and across the province, electricity demand will increase, potentially disrupting current load patterns throughout the day, week and year.

Up until the mid-2020s, additional electric loads from electrification can be advantageous in Ontario in managing surplus baseload power, alleviating the need for the province to sell electricity at a reduced cost, or curtailing renewable generation.[79] This is an important consideration for power-to-thermal applications, where electricity is used for heating and cooling, to alleviate electricity demand and displace natural gas use. This aligns closely with the City of Ottawa's power-to-thermal pilot.

If increasing electrification results in higher than expected electricity demand, especially as nuclear supply is decreased over the coming decade, electricity storage and CDM programs may be required to mitigate system demand requirements.

Large scale grid electricity storage and other CDM programming could reduce the need for additional electrical supply additions by effectively load shifting existing supply to match a new demand profile from electrification. If new capacity is required, electrical storage can also better incorporate variable renewable electricity sources to ensure that Ontario's electricity supply remains from low carbon sources. As mentioned, using EVs as distributed energy loads in two-way vehicle-grid charging systems will be important. CDM programming that effectively reduces overall heating demand from buildings will also be necessary to alleviate the impacts from heating electrification.

Hydro Ottawa is actively engaging in EV readiness for electrification disruption. In a partnership with FLO, an EV charging network, Ottawa Hydro is piloting the use of level 2 chargers at the residential level within the City, gaining data to better understand the impact of EVs on the electricity grid.[80] Other utilities in Ontario are examining vehicle charging habits to better understand the impact of EV's on distribution systems, including Burlington Hydro and Oakville Hydro. A pilot program run by FleetCarma examined the role price signals in influencing charging behaviour, as well as charging optimization based on grid availability.[81] Ottawa could continue to examine the impacts of electrification, especially as it relates to energy storage requirements.

[79] IESO. (2016). IESO Report: Energy Storage.
[80] Hydro Ottawa. April 24, (2018). Hydro Ottawa and FLO to pilot residential charging stations in Ottawa. Retrieved from: https://hydroottawa.com/media/news-releases?nid=201
[81] Government of Ontario. Smart Grid Fund. Retrieved from: https://www.ontario.ca/document/projects-funded-smart-grid-fund/electric-vehicle-integration

Section 2: Growth Projections for DSM and Energy Storage

Methodology

There are four imperatives that support the deployment of energy storage and demand side management for the City of Ottawa:

1. To reduce GHG emissions from thermal energy consumption, primarily natural gas.
2. To optimize the use of low or zero carbon electricity within the city; using storage to match production with demand.
3. To minimize the burden (or congestion) on the existing electric grid as a result of extensive deployment of decentralized renewable electricity generation.
4. To enable the grid to support electrification of transportation and heat.

Description of approach

A key strategy in any low carbon scenario is the deployment of decentralized renewable energy. Energy storage can be installed alongside renewable energy deployment. This study models energy storage deployment as installations in tandem with decentralized renewable energy that improve the performance of the renewable energy system. There are two core strategies applied to evaluate pathways for energy storage for the City of Ottawa.

1. Thermal storage is modelled as "enhanced" geothermal as a component of district energy systems. In other words, the efficiency of geothermal is increased to reflect heat pumped into the ground during the summer. As a result, the Coefficient of Performance (COP) of the system increases from 3.0 to 5.0.[82]
2. Electrical storage is modelled as "enhanced" solar PV and hydropower, in which the capacity factor of solar PV and hydro is increased to reflect the ability of storage to capture energy that would otherwise be lost. Without storage the curtailment rate is assumed to be 15%; with storage this declines to 10%.[83] Using this calculation, energy storage capacity can be approximated to an energy storage capacity.

With this approach, energy storage is not associated with emissions reductions directly, but it influences the emissions reductions of the renewable thermal and electricity pathways.

Uptake projections

Uptake projections will be driven first by the rate of introduction of decentralized generation and second by the requirements for a seasonal storage system. The modelling approach relies on the introduction of additional actions (ground-source heat pumps, solar PV and hydropower) in order to capture GHG and energy benefits associated with storage. Table 4 describes the increase in storage capabilities associated with each energy system, assuming first the increase in decentralized energy generation. Table 5 describes cumulative emissions reductions from electricity and thermal energy systems from 2018-2050, with assumptions included.

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[82] Foulds, E., Abeysekera, M., & Wu, J. (2017). Modelling and analysis of a ground source heat pump combined with a PV-T and earth energy storage system. Energy Procedia, 142, 886–891. https://doi.org/10.1016/j.egypro.2017.12.142
[83] Denholm, P., & Mai, T. (2017). Timescales of Energy Storage Needed for Reducing Renewable Energy Curtailment. Renewable Energy, 33.

Table 4: Low carbon pathway action parameters.

Action	Conservative scenario	Moderate scenario	Aggressive scenario
Thermal storage	District energy: 16% of existing commercial buildings; 16% of apartments; 3% of residential buildings: 14% of the system low carbon Storage increases coefficient of performance to 5.0	40% of existing commercial buildings; 40% of apartments; 8% of residential buildings: 40% of the system low carbon Storage increases coefficient of performance to 5.0	80% of existing commercial buildings; 80% of apartments; 15% of residential buildings; 70% of the system low carbon Storage increases coefficient of performance to 5.0
Electricity storage: residential solar PV	3.92 MW storage by 2050	7.06 MW storage by 2050	25.10 MW storage by 2050
Electricity Storage: commercial solar PV	10.20 MW storage by 2050	25.10 MW storage by 2050	58.04 MW storage by 2050
Electricity storage: utility solar PV	14.90 MW storage by 2050	30.59 MW storage by 2050	48.63 MW storage by 2050
Electricity storage: hydro	6.80 MW storage by 2050	7.58 MW storage by 2050	9.41 MW storage by 2050

Table 5: Cumulative emissions reductions related to renewable energy deployment, with energy storage assumptions (2018-2050).

Action	Conservative scenario	Moderate scenario	Aggressive scenario
District energy	2,006	4,922	10,077
Residential solar PV	45	78	270
Commercial solar PV	112	270	620
Utility solar PV	162	329	521
Hydropower	75	83	102

Constraints

Costs are a primary barrier for uptake of energy storage. For electricity storage, the cost of most technologies prohibits widespread uptake at this point in time. However, costs are falling for technologies as they move through the development phase. Lithium-ion batteries are experiencing rapid declines in module costs.[84] Other technologies - including sodium-sulfur batteries and CAES - are also expected to see a decline in system costs.[85]

Thermal storage and natural gas demand side management are limited by the low cost of natural gas. Because natural gas prices are low, there is less incentive for consumers to engage in natural gas DSM programming, and little incentive for developers to pursue district energy systems with thermal storage. While a carbon price could help correct the impact of low natural gas prices, there is political uncertainty surrounding Ontario's carbon pricing regime. Additionally, with the recent cancellation of Ontario's Green Ontario Fund and the Cap and Trade Program, there is uncertainty in the availability of provincial funding for energy storage projects.

Other barriers to electricity and thermal storage deployment are utility acceptance, performance, safety as well as regulatory uncertainty.[86] While there is some momentum on storage uptake in Ontario, the regulatory environment differs across Canada, internationally, as well as at the utility level.[87] Hydro Ottawa has stated its intention to move forward with electricity storage, but this is not the case across all utilities in Ontario, which provides difficulties for individual companies as they progress through commercialization. Where feasible, Ottawa can act as a first mover through ongoing pilot projects and research to establish a solid foundation for energy storage and demand side management initiatives.

DR programs and many electricity storage technologies are also limited due to their maturity. Many technologies are still in the piloting phase, which cannot be widely adopted until there is greater technology and system certainty.

There are also concerns for data security. Widespread deployment of energy storage and demand response will require smart grid infrastructure that can communicate between the consumer and the wider electricity grid and natural gas networks, such as two-way electric meters, programmable thermostats, and natural gas meters. There are ongoing concerns across Ontario in the mandatory roll-out of smart-meters, and it is likely that further roll-out of communicating grid devices will be met with public scrutiny. There are similar concerns relating to the electrification of energy services with communication abilities as targets of disruption.

A final, yet critical barrier for uptake of electricity storage in Ottawa is that most energy planning falls within provincial jurisdiction. The development of large grid scale storage falls more closely into the role of the IESO. However, Hydro Ottawa has already been an active player in IESO procurements for storage as a project partner and could continue to partner on projects and bid on procurement allocation. The City of Ottawa, through Hydro Ottawa, has an influence over distributed electricity storage development. This includes the development of decentralized batteries at the building level and encouraging EV uptake. Ottawa also could encourage the use of thermal energy storage in district energy in new developments through rezoning and planning applications. The City can also actively encourage uptake of utility led electricity CDM and DSM programming in the natural gas sector.

[84] IRENA. (2017). Electricity Storage and Renewables: Costs and Markets to 2030.
[85] Ibid.
[86] IRENA. 2015. Renewables and Electricity Storage: A technology roadmap for Remap2030.
[87] Jang, D., Lafontaine, L., Tuck, A. (2015). Developing Stronger Links: Summary Report of the Canadian Energy Storage Supply Chain Workshop, April 9, 2015, Toronto. National Research Council.

Ways to Advance this Pathway

Policy set provincially by the Ministry of Energy, Ontario Energy Board and the IESO have considerable influence on energy storage and DSM deployment, funding capacity and overarching policy direction. The City of Ottawa and Ottawa Hydro can encourage energy storage uptake through incentives, advocacy and funding.

Hydro Ottawa could continue to be an active partner in energy storage pilot projects. Hydro Ottawa's subsidiary, Energy Ottawa, is also an owner of multiple renewable energy projects, and could pursue a portfolio that could be complimented or expanded by pursuing ownership of energy storage projects in the future.[88] The City of Ottawa or Hydro Ottawa can also provide incentives or low interest loans for consumer who chose to pilot home connected energy storage projects, similar to the Great DR program.

To successfully champion energy storage pilot projects, the City of Ottawa could develop key partners in well-established industries that can help financially support projects, such as banking and communication sectors, or partners that can benefit from electricity or thermal storage projects, such as manufacturing and industrial partners. [89]

The City of Ottawa and Hydro Ottawa play a role in consumer advocacy and informing customers on electricity system operations and costs. Hydro Ottawa could continue to inform customers on electricity system information and explain the role of electricity storage to mitigate cost and security concerns. It could also continue to work proactively with the IESO and other utilities to support standardized energy storage regulations in the industry.

Finally, Hydro Ottawa could continue to make smart and resilient grids a priority, which can ensure that energy storage technologies can be easily integrated in the future.[90] Energy storage technologies have the potential to considerably impact traditional electricity systems, and Hydro Ottawa could leverage its commitment to innovation to prepare for the future.[91]

[88] Navigant. (2015). Ontario Smart Grid Assessment and Roadmap. Prepared for Ontario Ministry of Energy.
[89] Jang, D., Lafontaine, L., Tuck, A. (2015). Developing stronger links: summary report of the Canadian Energy Storage Supply Chain Workshop, April 9, 2015, Toronto. National Research Council.
[90] Navigant. (2015). Ontario Smart Grid Assessment and Roadmap. Prepared for Ontario Ministry of Energy.
[91] D'Aprile, P. (2016). The new economics of energy storage. McKinsey & Company.

Pathway Study on Existing Non-Residential Buildings in Ottawa

Presented to:
The City of Ottawa
110 Laurier Ave W
Ottawa, ON K1P 1J1

In relation to:
The City of Ottawa's Energy Evolution Strategy (Phase 2)

By:
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Tatamagouche, NS

January 2019

Contents

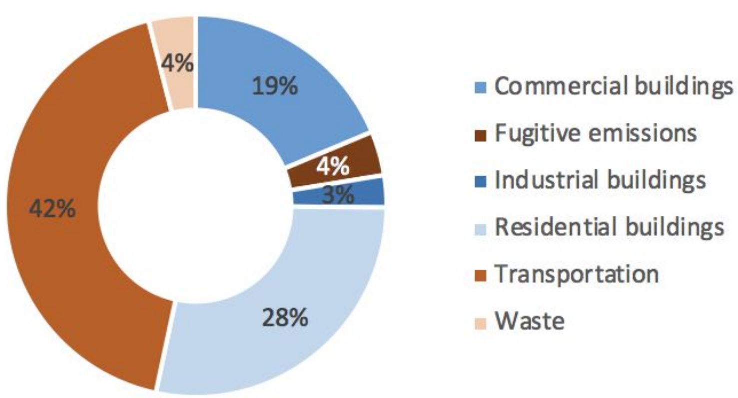
Executive Summary

This pathway profiles existing non-residential buildings in the City of Ottawa and details strategies to reduce their energy use and emissions in order to meet the goals and objectives of the City's Energy Evolution Strategy. Building types covered in this paper include industrial, commercial, institutional, and mixed-Use. These buildings can generally be considered larger than residential buildings.

Measuring and evaluating building energy use is an important first step in determining actions to make larger non-residential buildings more energy efficient. Recommissioning buildings ensures that building systems such as heating, and ventilation are operating efficiently. Retrofits update building components to minimize energy loss and can also replace GHG-intensive heating systems for lower carbon alternatives such as heat pumps or district energy—a strategy described as fuel switching.

The Canada Green Building Council (CaGBC) estimates that buildings in Canada currently contribute up to 35% of the country's annual carbon emissions.[1] In Ottawa, buildings represent the largest source of community GHG emissions, generating approximately 2.4 million tonnes of CO2e emissions annually and accounting for roughly 50% of the city's total emissions in 2016 (see Figure 1). Given the large impact of this sector on the city's emissions profile, any pathway to achieving an 80% reduction in GHG emissions by 2050 will require a transformation in energy supply and demand in Ottawa's existing building stock.

Figure 1. Emissions by Sector, Ottawa 2016.



[1] Canada Green Building Council (2017). A Roadmap for Retrofits in Canada: Charting a Path Forward for Large Buildings. Toronto. Retrieved from: www.cagbc.org/cagbcdocs/advocacy/CaGBC_Roadmap_for_Retrofits_in_Canada_2017_EN_web.pdf

The CaGBC has identified four major strategies to cut GHG emissions from large buildings in half in its “Roadmap for Retrofits” paper:[2]

1. Recommission buildings that have yet to achieve high performance status by optimizing existing building systems for improved control and operational performance;

2. Undertake deep retrofits in buildings to high-performance standards such as LEED,™ focusing on energy reduction and ensuring that key building systems such as lighting, HVAC and envelopes are upgraded;

3. Incorporate solar or other on-site renewable energy systems in buildings; and

4. Work with jurisdictions and the private sector to switch to low-carbon fuel sources in buildings.

This pathway study aligns with the four-step approach recommended by the CaGBC, while considering three scenarios of energy efficiency efforts: conservative, moderate, and aggressive. The conservative scenario reflects a Business-as-Planned outlook, moderate reflects interventions on the largest buildings and municipal/government buildings, and aggressive includes enhanced rates of recommissioning, deep energy retrofits, and fuel switching.

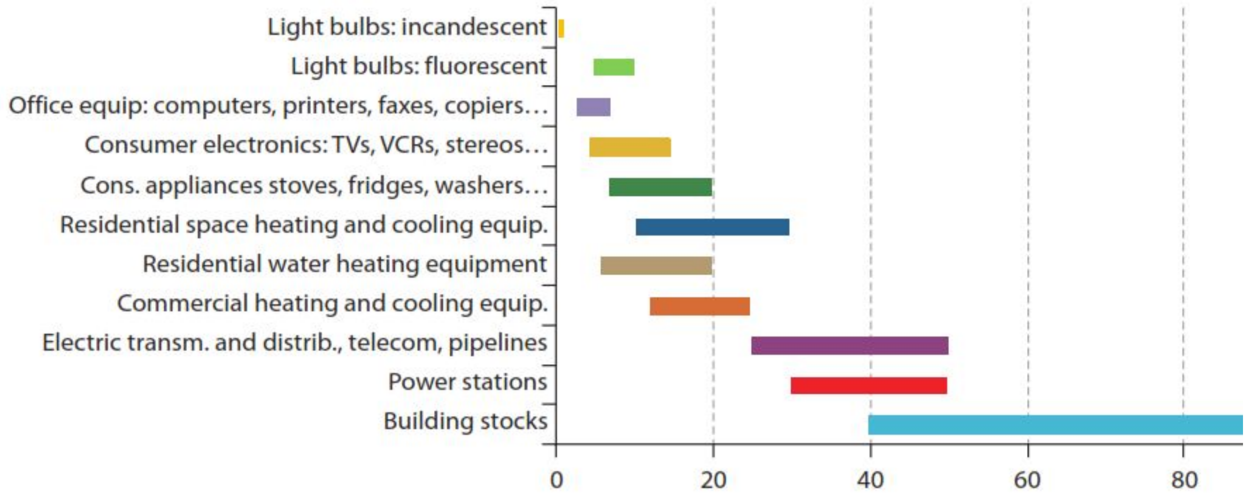
[2] Ibid.

Section 1: Present Assessment of Large Existing Buildings

Pathway Description

This pathway study focuses on increasing the efficiency of existing non-residential building stock in Ottawa, which is complementary to the New Non-Residential Buildings Pathway Study. The city's existing building stock has developed over the course of more than 100 years and accounts for much of Ottawa's current and future (projected) GHG emissions, thus presenting a large opportunity to reduce emissions community-wide. Each building is a system that includes very large components—such as the building shell—and very small components—such as light bulbs. All components combined determine the energy performance and GHG emissions associated with a building. The lifetime of each building component varies and there are opportunities to incrementally improve efficiency through natural replacement cycles. However, in order to achieve deep energy and emissions reductions (defined as a reduction of 50% or greater) a more proactive or interventionist approach is required, involving great uptake of new technologies and quick turnover in building energy systems. Almost all of Ottawa's current buildings will still exist in 2050.

Figure 2. Natural replacement cycle of different aspects of the building energy system.

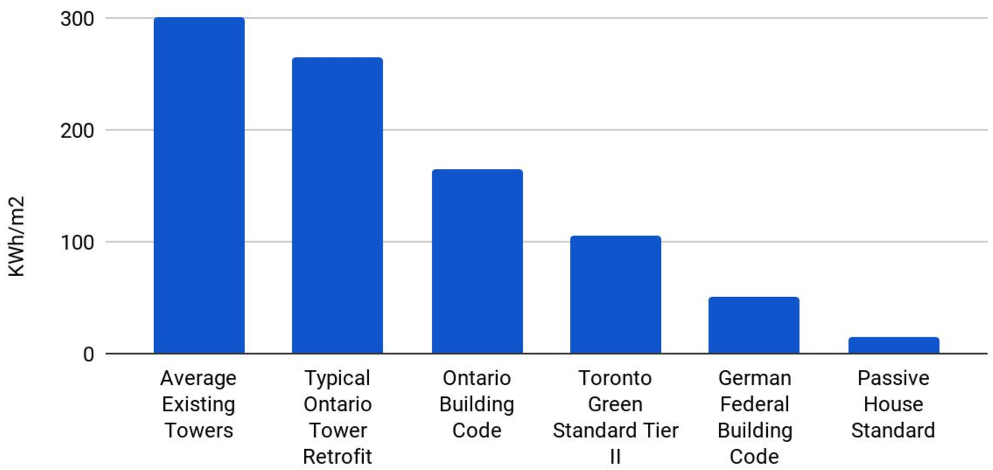


Addressing larger non-residential buildings as a class is important because they require distinct retrofitting approaches, policies and financing strategies in comparison to single family homes or other smaller residential buildings—a function of the complexity and scale of the systems, and differing ownership models.

The retention and retrofit of existing buildings have additional benefits beyond the reduction of GHG emissions. Improvements to the existing residential building stock can provide financial savings to building owners, tenants, or agencies through reduced spending on energy, for example. A major building retrofit program is an economic stimulus to the local economy through increased activity in the construction and contracting sector. Reducing energy use in residential buildings can also reduce demand burdens on electricity and natural gas providers, reducing issues with peak demand and therefore requirements for additional investments in new demand. Reduced demand for fossil fuels can also benefit the local economy as less money is spent on non-local energy sources, such as natural gas. When retrofits include on-site renewable energy such as solar, local businesses can also benefit. Retrofits can also improve household living conditions, improving indoor air quality and providing consistently comfortable temperatures.

Building size, choice of energy for operations (fuel source), GHG intensity from the electrical grid, and building type all determine a building's GHG emissions volumes. Older buildings that have been operating for 20 years or more may have degraded in performance and become leaky, for example, requiring greater energy for heating and cooling. Previous building codes were less stringent, and did not require window, wall, or roofing standards that provided the insulation performance that is possible today. Older large buildings may also use less efficient appliances, lighting, ventilation, or heating, ventilation and air conditioning (HVAC) systems. Figure 3 illustrates the difference between a "typical" tower in the Greater Golden Horseshoe, versus new construction standards that result in 83% to 95% energy savings.

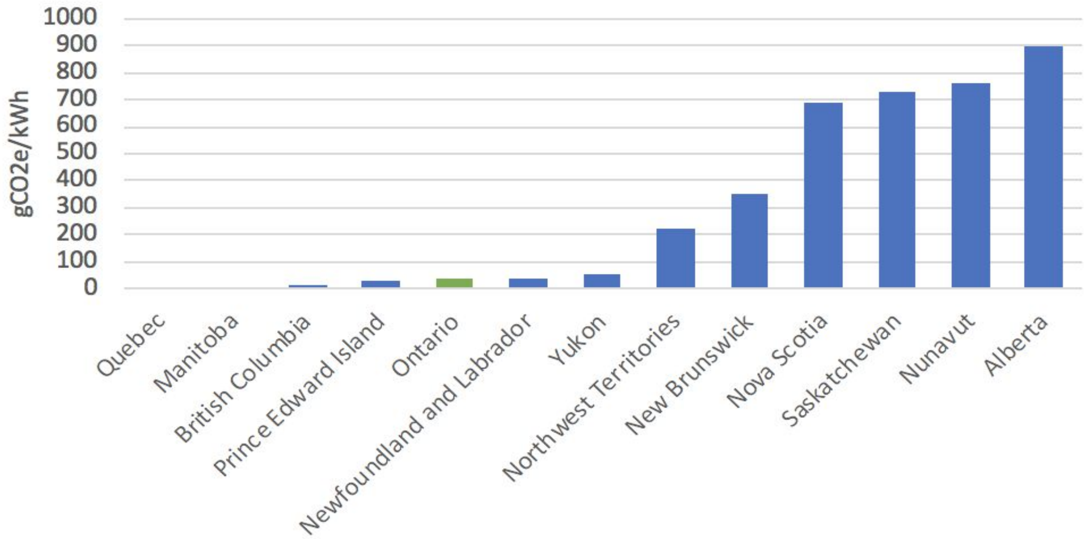
Figure 3. Comparison of the average energy performance of existing towers in the Greater Toronto area versus other standards.[3]



Although Ontario's electrical system has comparatively low GHG emissions intensity (Figure 4), the dominant source of space conditioning in buildings is natural gas—a major source of GHG emissions. Fuel switching to low carbon energy sources for heating is therefore a key GHG reduction opportunity.

[3] Tower Renewal (n.d.). Deep retrofit Towers and surrounding communities for a low carbon future. Retrieved from: http://towerrenewal.com/impact-areas/ghg-reduction

Figure 4. Provincial electrical grids emissions factors.[4]



Pathway Boundaries

This pathway identifies and contextualizes low carbon pathways for existing non-residential buildings in Ottawa that would benefit from upgrading or retrofitting of complex systems present in larger buildings with high energy demands. Table 1 identifies strategies reviewed in this paper for their effectiveness in reducing emissions, in the Ottawa context. This pathway examines policies that encourage uptake of the energy efficiency upgrades. Options for financing retrofits for large buildings are also discussed.

Table 1. Parameters and definitions for large existing buildings pathways study.

Parameter	Definition
Recommissioning	Recommissioning involves detailed energy and building systems performance audits resulting in recommendations for corrections. Recommissioning ensures that building systems such as heating, and ventilation work as required.
Retrofits	Retrofits update building components to minimize energy loss, reduce the thermal proportion of space heating fueled by a natural gas system, or replace natural gas heating systems. Retrofits can be small or extensive in scope.
Benchmarking	Benchmarking gathers energy use data including sources of energy, total energy use, and what activities use that energy in order to make comparisons to similar buildings or a building energy efficiency standard.
Fuel Switching	Switching of the fuel or energy source used in powering or heating a building.

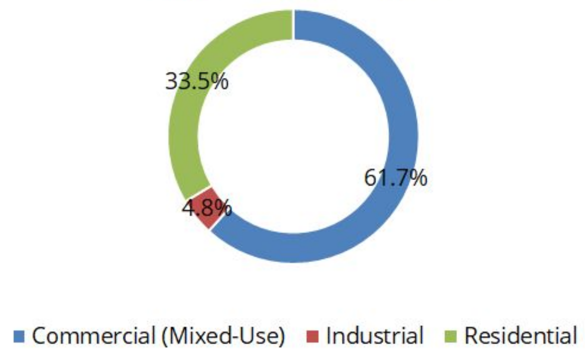
[4] Environment Canada (2018). National and Provincial/Territorial Greenhouse Gas Emission Tables. Retrieved from: http://data.ec.gc.ca/data/substances/monitor/national-and-provincial-territorial-greenhouse-gas-emission-tables

Background Information

Large Buildings in Ottawa

As of 2016, Ottawa had 2,944 large buildings in its inventory (greater than 2,323m^2). These large buildings totaled 27.7 million square metres of floor area, compared to 49.9 million square metres of small buildings. Of the 27.7 million square metres, commercial buildings represented 62% of the large building stock which is inclusive of mixed-use buildings, large residential buildings represented 33.5%, and large industrial buildings represented approximately 5%. Figure 5 represents the breakdown.

Figure 5. Large building stock by type, 2016



Ottawa's Historical Building Stock

Ottawa has 7,623 non-residential buildings which comprise 21 million square meters of floor space. The average building area is 2,800 square meters. Figure 6 illustrates the city's non-residential building stock by age and type (excluding industrial). For details on how specific buildings are assigned to these categories, see Appendix 1. There were three major building periods for non-residential buildings: before 1950, 1985-1990, and 2010-2015. More than 60% of the non-residential building floor space (m^2) is 20 years old or older and a quarter of the building floor space (m^2) is 50 years old or older.

Commercial buildings account for 45% of the current non-residential building floor space, followed by institutional buildings (32%), and retail space (25%).

Figure 6. Floor area of non-residential building stock by era and by class in Ottawa.

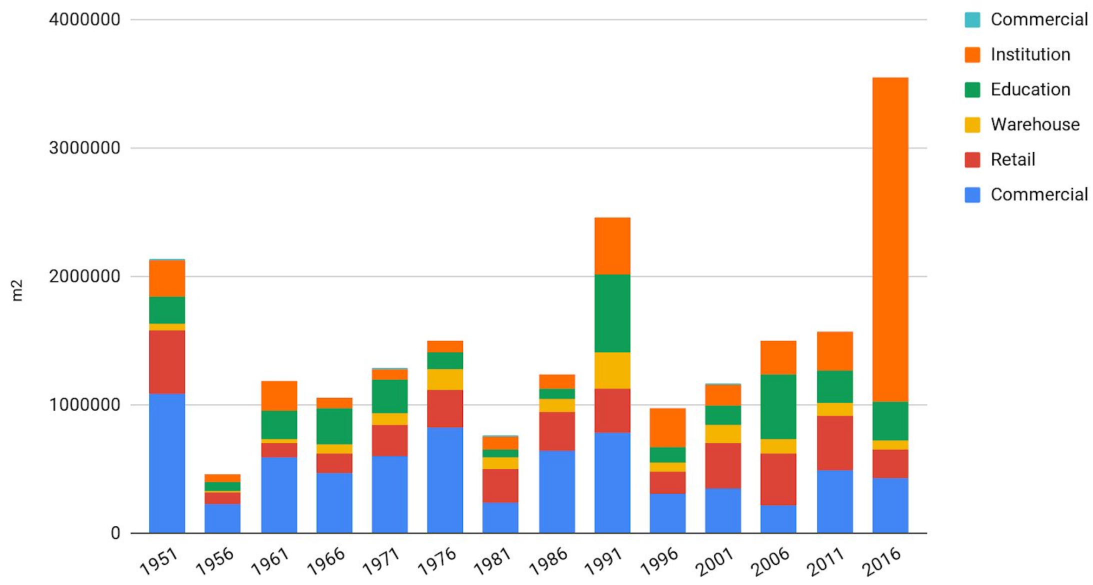
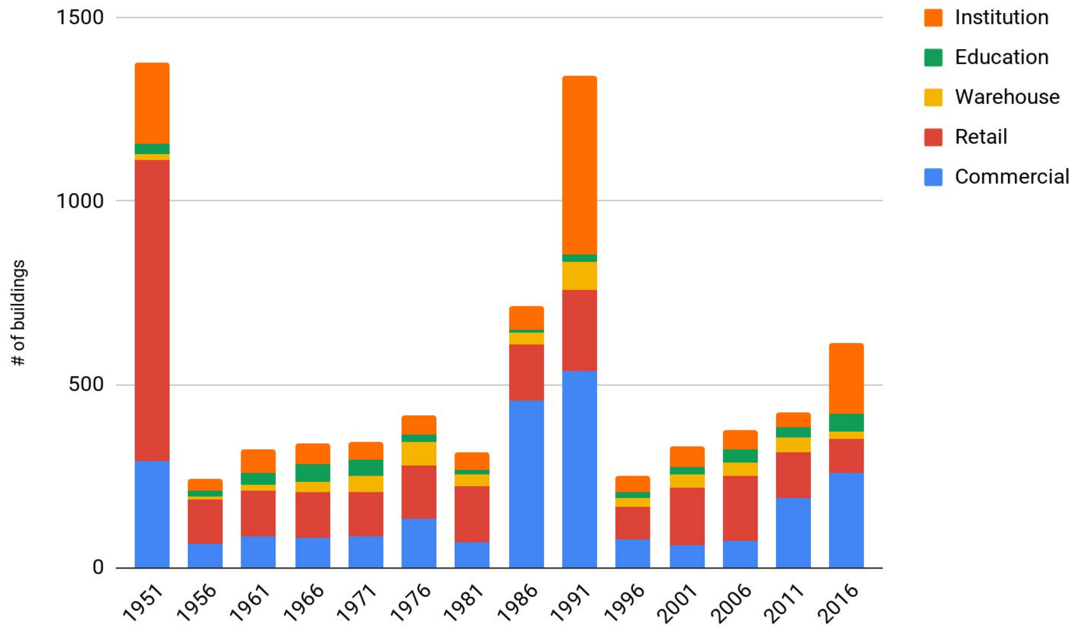


Figure 7 illustrates the number of buildings, as opposed to floor space, by the same categories in Figure 6. There are many pre-1950 retail buildings, indicating that they are relatively small in floor area, on average. There is a significant increase in institutional floor space between 2010 and 2015.

Figure 7. Number of non-residential buildings by era and by class in Ottawa.



Energy Consumption

Total energy consumption in buildings was 75,790 TJ (approx. 76 million GJ) in 2016. Of this total, commercial buildings used 29,618 TJ (approx. 30 million GJ). Residential buildings accounted for 52% of total building energy consumption in Ottawa in 2016, followed by commercial buildings at 39% and industrial buildings at 9%. Industrial buildings are separated from the rest of the non-residential building stock so that their unique patterns of energy consumption do not influence the broader non-residential sector tallies. Just over half of the energy used by all the buildings (54%) was provided by natural gas, while 38% was provided by electricity. Commercial buildings have a higher share of electricity (43%) and a lower share of natural gas (50%). Half of the total energy consumed in the entire building stock is used for space heating, 15% is used for water heating, and 10% each for plug loads and lighting.

Figure 8. Total building energy consumption by fuel and sector, 2016.

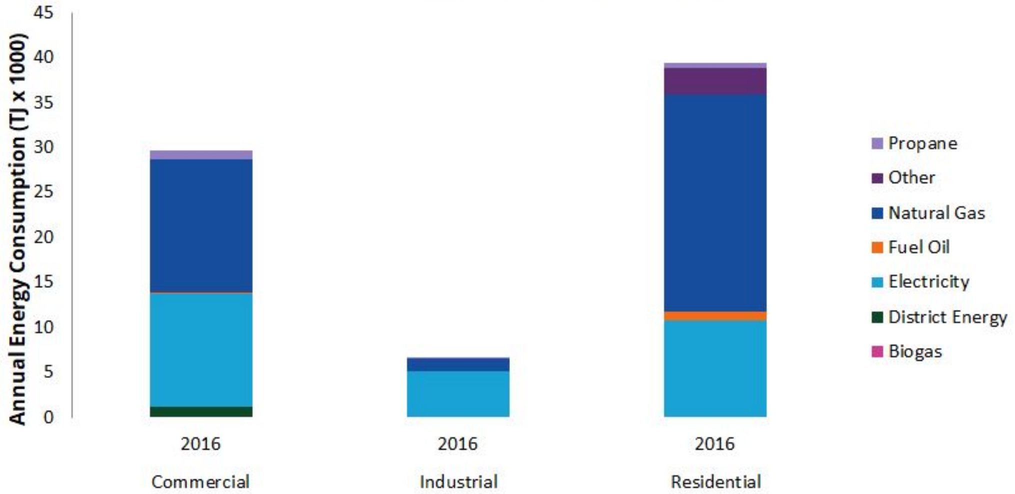
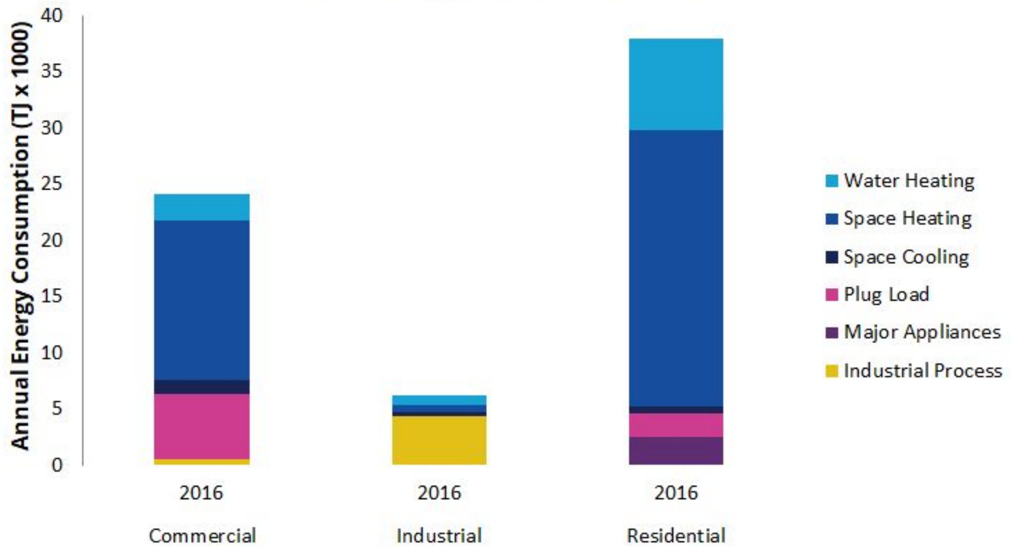


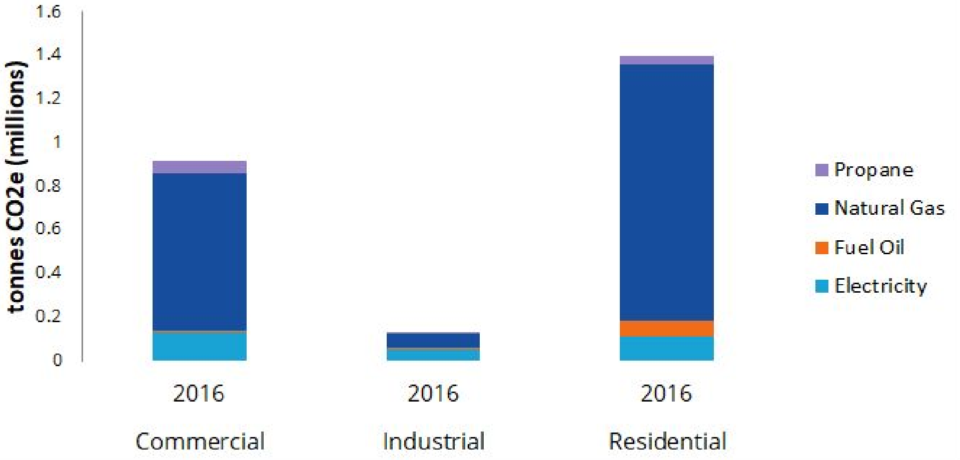
Figure 9. Total building energy consumption by end-use and sector, 2016.



Greenhouse Gas Emissions

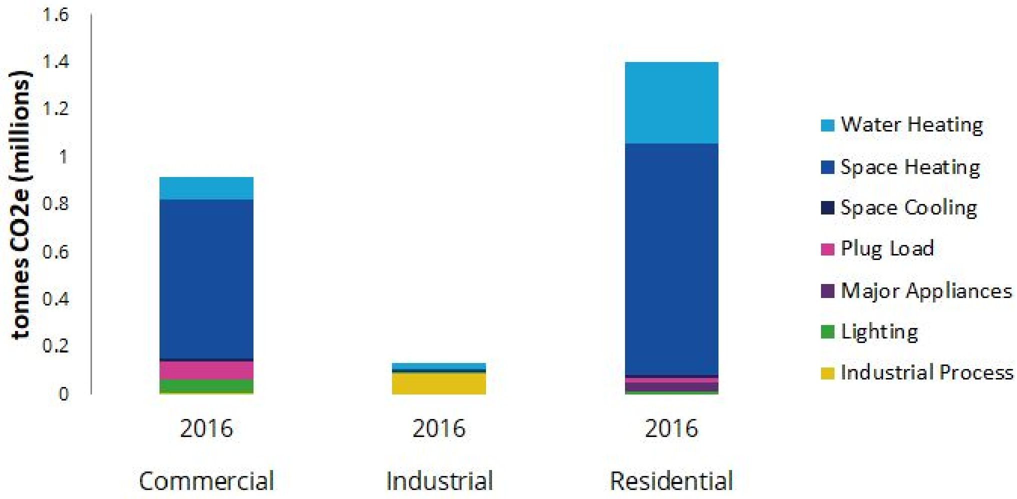
Energy consumption in buildings in Ottawa resulted in 2.4 million tCO2e in 2016, of which approximately 0.920 million tCO2e were from commercial buildings, 0.133 million tCO2e were from industrial buildings, and the remaining 1.40 million tCO2e were from residential buildings. 81% of the total GHG emissions resulted from the combustion of natural gas. In only commercial buildings, it was lower, at 78%.

Figure 10. Total building GHG emissions by fuel and sector, 2016.



Space heating and water heating accounted for 87% of the total GHG emissions, as a result of reliance on natural gas for heating. Emissions from heating are less in commercial buildings, at 83% of total.

Figure 11. Total building GHG emissions by end-use and sector, 2016.

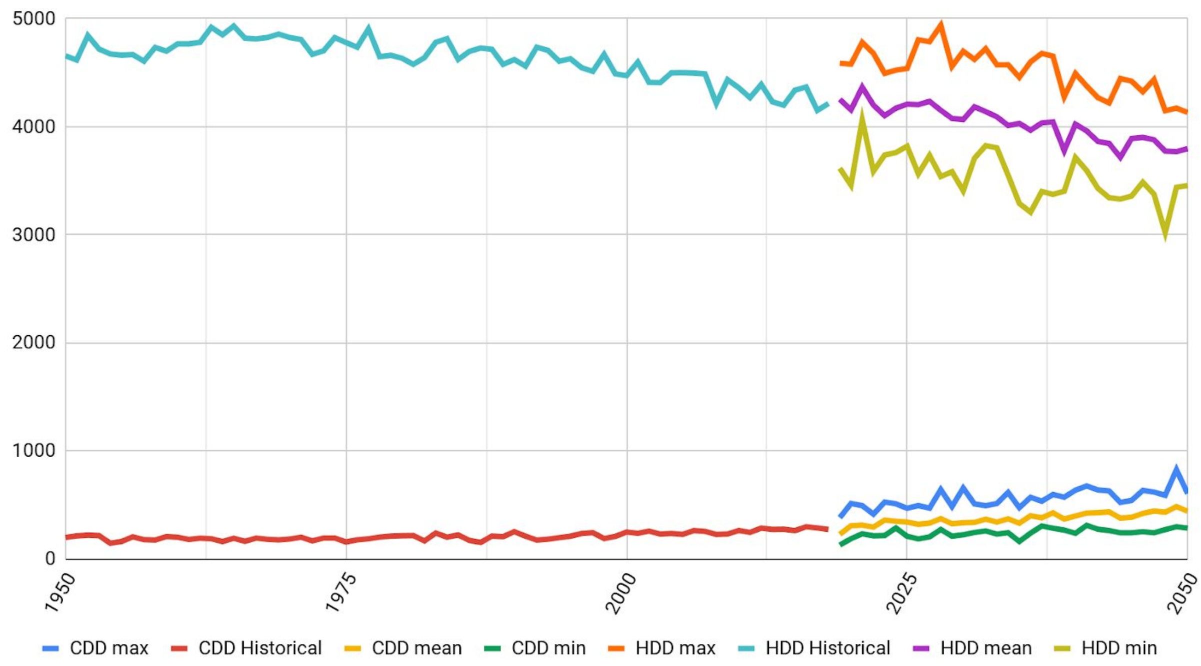


The Effect of Climate

One confounding factor influencing energy consumption and emissions is the weather, or, more specifically, the number of heating and cooling degree days (HDD and CDD, respectively). Relatively warmer years will result in greater energy consumption for air conditioning while relatively cooler years will result in greater energy consumption for heating. A heating degree day is the number of degrees that a day's average temperature is below 18°C, indicative of the amount of energy needed to heat buildings to operating temperatures in that day. For example, a day with an average temperature of 4°C has a Heating Degree Day value of 14. Similarly, a cooling degree day provides a measure of energy needed to cool buildings, noted by the number of degrees that a day's average temperature is above 18°C.

In Ottawa, heating degree days are projected to decline by 10% by 2050 over 2018, with cooling degree days increasing by 60% over the same period (Figure 12). Under a BAP scenario, space heating will go down while air conditioning use will increase.

Figure 12. HDD and CDD projections for the City of Ottawa.[5]



[5] Prairie Climate Centre (2018). The Climate Atlas. https://climateatlas.ca/data/city/459/hdd_2060_85

Evaluation of Current Pathway

Typical approaches to building retrofits in Canada do not achieve the level of GHG emissions reductions required for low carbon pathways. Retrofits are typically divided into sets of specific actions called energy conservation measures (ECMs). ECM implementation is prioritized on the basis of cost effectiveness, thus the lowest cost ECMs are completed first.[6] However, ECMs with greater costs are often those that are required to achieve low carbon building outcomes.

An alternative approach is a whole system retrofit or a comprehensive building upgrade, in which the building is analyzed and retrofit as a system. This approach has three key advantages:

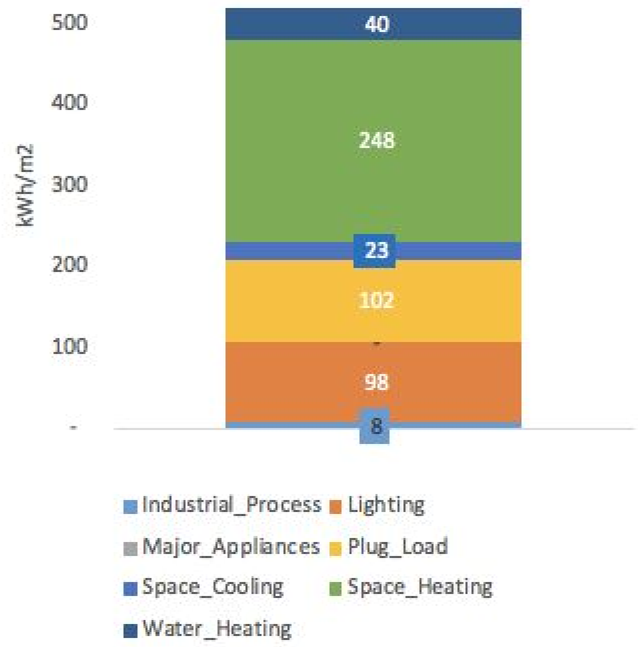
- The building is analyzed as a whole system, reducing unintended effects;
- Overall capital costs can be lower. For example, thermal upgrades can result in lower capital costs for equipment such as HVAC, whereas in a standard ECM approach, the same HVAC system may be installed, depending on when or if thermal upgrades are undertaken;
- ECMs with faster paybacks can be bundled with less cost-effective measures resulting in greater overall energy savings and GHG reductions; and
- Fuel switching—critical to GHG emissions reductions—can be incorporated as part of the systems approach.

Retrofit program with energy and GHG intensity targets

Retrofit efforts build upon recommissioning efforts by making changes to building exteriors and requiring greater changes to building materials and fixtures. There are different degrees of effort for retrofits, but they generally range from shallow, to moderate, to deep. Different actions and results are summarized in Table 2, and a more extensive description can be found in the Existing Residential Buildings Pathway. For the purposes of larger non-residential buildings, deep retrofits with an energy or emissions reduction of 50% are considered useful in meeting emission reduction targets.

[6] For a comprehensive study of ECMs, costs and GHG reductions, see: City of New York. (2016). One City: Built to Last: Transforming New York City Buildings for a Low Carbon Future. Retrieved from https://www1.nyc.gov/assets/sustainability/downloads/pdf/publications/TWGreport_04212016.pdf

Figure 13. Average energy use intensity for non-residential buildings by end-use, 2016.



Retrofit programs often target energy use reductions which result in costs savings for occupants. However, it is important to also target GHG reductions. As Ontario's electricity grid has a low emissions factor, priority should be given to actions that reduce natural gas used in thermal energy applications (i.e. heating). A focus on reducing consumption of electricity will not have much effect on emissions, so it is recommended that total emissions and not electricity or energy consumption be the focus of retrofit work in Ottawa. Table 2 summarizes varying scopes of building retrofit efforts.

Deep retrofits for larger buildings, particularly commercial or industrial, are an important strategy to help Ottawa reduce GHG emissions, highlighted by the fact that the majority of the GHG emissions are associated with space heating (Figure 14). The existing residential buildings pathway also cautions against "lock-in effect" wherein a shallow retrofit step is taken then not changed or upgraded over time. If shallow retrofits are undertaken, no additional improvements in the installed equipment can be expected over the course of its lifetime without considerable additional expense. In this way, lower levels of energy reductions can be locked in for a long period, thus neglecting opportunities for greater energy reductions.

Table 2. Comparison of retrofit depths.[7]

Retrofit Criteria	Shallow Retrofit	Moderate Retrofit	Deep Retrofit
Typical energy conservation measures	• Lighting • Smart controls • HVAC motors and fans -Caulking and sealing • Optimization	• Boiler, furnace, or AHU replacement • Steam to hot/low-temp water • Heat pumps • Drain/waste heat recovery • Heat recovery ventilation Roof/cavity insulation	• Window replacement • Wall and foundation reinsulating • Shading • Envelope replacement • Conversion to renewable district energy
Energy savings range	10-20%	30-50%	40-80%
Typical payback period and costs	1-3 year payback Commercial: <$21.5/m² MURB: <$2,000/unit	3-6 year payback Commercial: $21.5-$54/m² MURB: $2,000-$6,000/unit	6+ year payback Commercial: $215-$540/m² MURB: $10,000-$60,000/unit
Advantages	• Short payback • Cost-effective • Incentivized by current program and policy structure	• Attractive balance of energy savings and payback • Can be performed with minimal disruption to tenants	• Holistic approach • Optimizes components • Large and lasting energy and emissions reductions • Reduces the demand for externally sourced energy and local dollars leaving the community
Disadvantages	• Small energy savings • Weakens business case for deeper retrofits in the future • Missed synergies between building components • Does the least to address occupant comfort and operational issues	• Higher energy reductions difficult to achieve without envelope upgrade • May result in oversized mechanical systems compared with a deep envelope retrofit	• Complex • Longer payback period • Potential of a disruption to tenants/owners in some cases

Payback periods for building retrofits can vary greatly depending on levels of expertise, the retrofit path chosen, and the depth of the retrofit. Economic dimensions such as incentives offered or carbon pricing can greatly speed up payback periods, and the lack of of these items can make payback periods lengthy and thereby less attractive to undertake.

[7] Frappé-Sénéclauze, T., Heerema, D., Tam Wu, K. (2017). Deep emissions reduction in the existing building stock. The Pembina Institute.

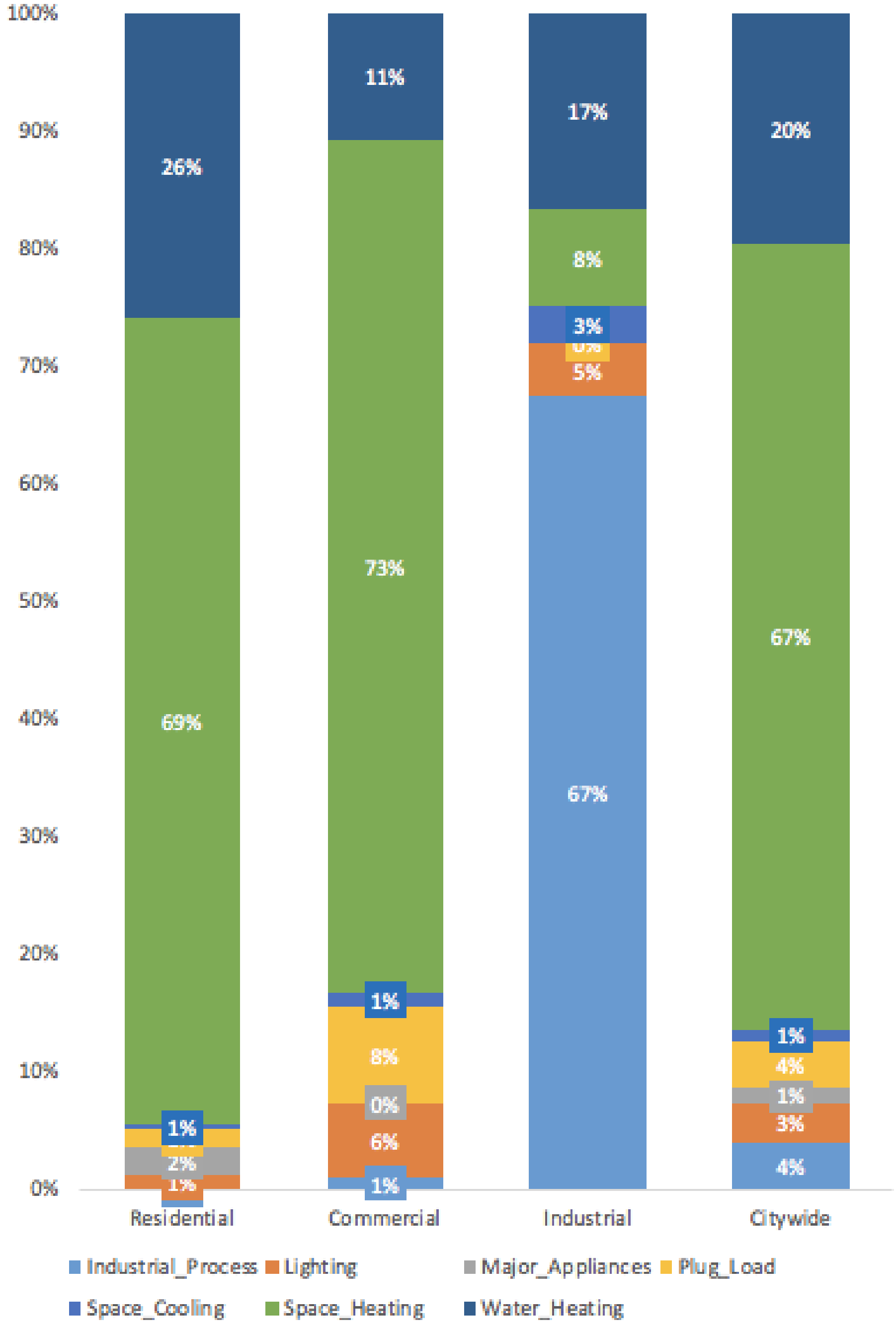
Case studies on large building retrofits by The Toronto Atmospheric Fund (TAF) show that reasonable paybacks (4-6 years) can be achieved on older and less efficient buildings in Ontario. The TAF helped to finance and provide grants for a portion of these retrofit programs.

Table 3: Retrofit case studies and payback periods.

Project Description	Retrofits	Energy, Utility, and water savings	Payback Period
45-year old multi-family building in Burlington, Ontario[8] 210 units over 18 storeys	• Boiler replacement • Toilet replacement • Chiller replacement	• 20% natural Gas reduction • 29% water reduction • 50% electricity demand reduction • 300 tonnes GHG reduction	4.4 Years
20-year old social housing apartment building, Toronto Ontario[9] 13-storeys high with with 125 1-3 bedroom units	• Boiler replacement • Make-up air/HVAC upgrade • Lighting system upgrade to LED • Toilet, shower, aerator replacements	• 11% electricity reduction • 31% natural gas reduction • 33% water reduction • 166 tonnes GHG reduction	6.2 Years
30-year old social housing building in Toronto Ontario[10] 8-storey building combined with 4-storey section, 102 1-3 bedroom units	• Programmable electric baseboard heating system installed • Boiler upgrade • Make-up air/HVAC upgrade • Centralized control for building systems added • Domestic cold water booster pump system installed • Lighting system retrofit to LED • Toilet, Showerheads, and Aerators replacement • Exterior door and lobby air conditioner replacement	• 22% Electricity reduction • 29% Natural gas reduction • 47% Water reduction • 82 tonnes GHG reduction	4 Years

[8] "15 Kensington Road." 2011. Case Study. Towerwise. Toronto, ON: Toronto Atmospheric Fund. http://taf.ca/wp-content/uploads/2018/02/TAF_TowerWise_Case_Study_Kensington_Road_2011-01-21.pdf.
[9] Finn, Derrick. 2016. "Development of Three Multi-Unit Residential Building Energy Efficiency Retrofit Case Studies." Case Study. Housing Research Report. Ottawa, ON: CMHC. ftp://ftp.cmhc-schl.gc.ca/chic-ccdh/Research_Reports-Rapports_de_recherche/2017/RR_Three_Multi_Unit_Retrofit_Case_Studies_Jun2.pdf.
[10] Ibid

Figure 14. GHG emissions by building type and end-use, 2016, City of Ottawa.



Section 2: Growth Projections for Large Existing Buildings

Projected Pathway Assessment

The projected pathway assessment is modelled as the aggressive scenario, representing the low-carbon pathway. The actions and assumptions based on this pathway paper are presented in Table 4.

Table 4. Integrated Low Carbon Pathway Actions and Parameters.

Action	Conservative scenario	Moderate scenario	Aggressive scenario
Retrofits for commercial, and office buildings	1% of the existing building stock is retrofitted to a performance level in compliance with the current building code.	Assume 40% of current building stock over 35 years old takes on deep retrofit and reduces energy (electricity and natural gas) use 50% by 2030. After 2030, assume that 1% of non-residential buildings experience major renovations each year towards 2050.	Assume 95% of the current building stock is retrofitted by 2050, achieving an average of 50% energy savings.
Fuel Switching[11]	5% of non-residential floor space uses heat pumps	13% of non-residential floor space uses heat pumps	21% of non-residential floor space uses heat pumps
Fuel Switching: District Energy	16% of existing commercial buildings; 16% of apartments; 3% of residential buildings: 14% of the system low carbon	40% of existing commercial buildings; 40% of apartments; 8% of residential buildings: 40% of the system low carbon	80% of existing commercial buildings; 80% of apartments; 15% of residential buildings; 70% of the system low carbon
Municipal Buildings	10% of existing municipal buildings are retrofitted to net-zero emissions by 2050.	50% of existing municipal buildings are retrofitted to net-zero emissions by 2050.	100% of existing municipal buildings are retrofitted to net-zero emissions by 2050.
Recommissioning of commercial buildings on an ongoing basis*	None	Recommission 50% of buildings over 18,580 m2, and 20% of buildings over 2,323 m2 every ten years. Assume 5% reduction of energy use and thermal demand of natural gas usage per building.	Recommission all buildings over 18,580 m2, and 40% of buildings over 2,323 m2 every ten years. Assume 10% reduction of energy use and natural gas usage per building.

*The recommissioning action responds to overall building degradation, where energy performance weakens over time and is brought back to baseline through the recommissioning process, thus resulting in neutral emissions.

Methodology

[11] Heat pumps are addressed in more detail in a separate pathway paper.

The modelling methodology for all of the building pathways (existing residential / non-residential and new residential / non-residential) is similar. A summary is shown below, and more information can be found in the Data, Methods, and Assumptions (DMA) manual. The CityInSight model simulates the impact of future building code standards that will affect residential and non-residential buildings in the municipality by applying target Energy Use Intensity (EUI) and thermal energy demand intensity (TEDI) values for each vintage of buildings. These target values are expressed as a percent improvement from the previous time period. CityInSight adjusts various energy use parameters such as thermal transmittance, output energy intensity, and equipment efficiencies until the modelled EUI and TEDI values meet the target. The steps involved in developing a projection are as follows:

1. Place existing buildings in space in the base year, disaggregated by geographic zone, year building and building type;
2. Simulate additions to and removals from the building stock over time, as required by the population and employment projections;
3. Derive energy use in buildings according to the thermal envelope profile, energy-using stocks (appliances, equipment);
4. Disaggregate energy use by end-use and fuel type as well as building categories;
5. Calibrate projected energy use with observed energy consumption as provided by the energy utilities;
6. Apply energy use intensity targets incrementally to the existing building stock, targeting specific criteria such as age, size, use and location of buildings; and
7. Analyze the cost of the retrofits that achieve the energy use intensity targets.

Constraints

The following are examples of the challenges that are confronted in undertaking large scale, deep energy retrofits for large buildings.

Making a business case: When energy costs are low and large businesses or building owners can still create profit per square metre of building despite poor building performance, then it can be difficult to build a business case to retrofit a building. Further, a lack of policy from all levels of government accompanied by incentives does not signal the need for change in business practice, nor create different competitive advantages to acquire new customers into energy efficient buildings.

Logistical Challenges: Large buildings may present different challenges than retrofitting personal homes. The buildings being larger may have multiple processes that need to be running on 24-hour timelines, with multiple employees or services. Shutting a system down for a longer term may require back up services or better scheduling to time a deep energy retrofit.

No current carbon pricing: The cost of avoiding carbon pricing can incentivize Ottawa residents to take on the actions in this pathway willingly but is not present currently. Ottawa can only advocate for a carbon tax; however, the Federal Government has mandated a carbon tax by 2019 for all provinces who do not have an equivalent carbon tax in place.

Net metering: Ontario has a net-metering policy in place where renewable on-site energy is sold back to utility company. This incentive is limited as businesses or building owners have not been able to sell to customers directly or capture and distribute energy credits when they have multiple buildings in their inventory.[12]

Behavioural: One of the major energy users in buildings in end-user loads, so how people interact with their buildings. If building occupants add additional loads to buildings with space heaters, air conditioning, fans, appliances, then the energy use for buildings will increase. This may not be significant when a deep energy retrofit is completed and done to maximize occupant comfort.

Ability to scale: Without a consistent funding pool, there is an inability to create a stable industry that operates at a scale needed to make retrofits less costly. In Ontario and Canada there has been little consistency for the industry and the ability to scale has therefore been limited.

Social inclusion: Many efforts to make buildings or the urban environment more sustainable with less energy use and carbon emissions may not reach people of different incomes or backgrounds. Large and expensive technologies or building overhauls may be too expensive for lower income earners. Further, in the case of older affordable housing stock that is not run by a non-profit or housing society, a lengthy retrofit can temporarily evict families, or increase prices to a non-affordable level.

[12] Gloss, Adlar. 2017. "Net-Metering in Ontario: Current Issues and Challenges." Cekap: Community Energy Knowledge. July 20, 2017. http://www.cekap.ca/blog/net-metering-in-ontario-current-issues-and-challenges.

Uptake Projections

Conservative Scenario

Figure 15. Floor area retrofit for existing non-residential buildings under the conservative scenario (m2).

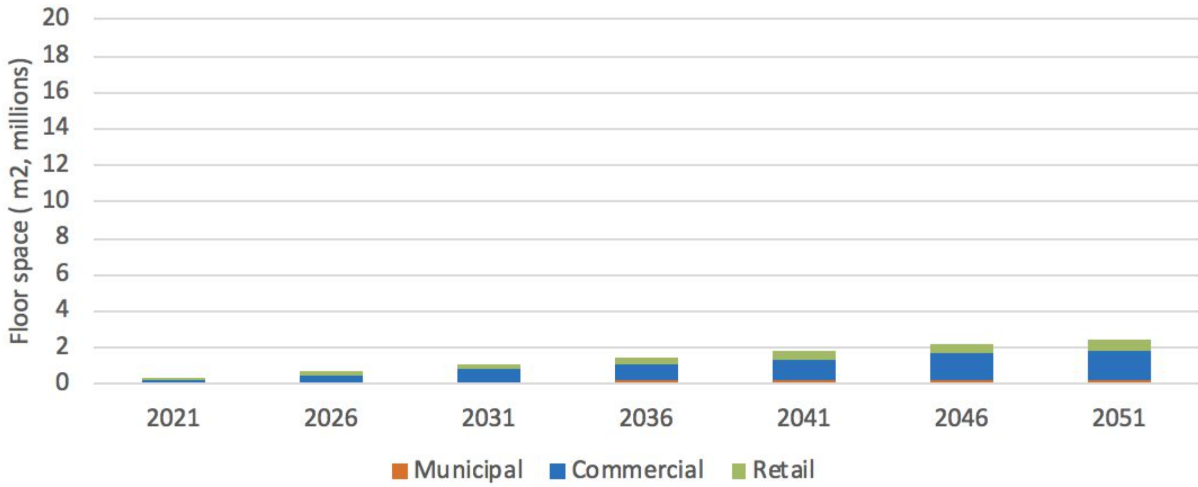


Table 5: Energy and GHG emissions results of the conservative existing non-residential buildings pathway.

Action		Cumulative emissions reductions 2018-2050 (kt CO2eq)	Emissions reductions 2050 (kt CO2eq)	Cumulative energy reductions 2018-2050 (TJ)	Energy reductions 2050 (TJ)
Retrofits for commercial and office buildings	1% of the building stock is retrofit each year in compliance with the current building code	1,136	93	30,588	2,612
Municipal Building Retrofits	50% of existing municipal buildings are retrofit to net zero emissions by 2050	417	33	6,816	500
Heat Pumps	5% of commercial floor space	512	29.19	8,204.78	432.91
District Energy	16% of existing commercial buildings; 16% of apartments; 3% of residential buildings: 14% of the system low carbon	2,006	87.03	4,049.88	175.77
Building Recommissioning	No Action	N/A	N/A	N/A	N/A

Moderate Scenario

Figure 16. Floor area retrofit for existing non-residential buildings under the moderate scenario (m2).

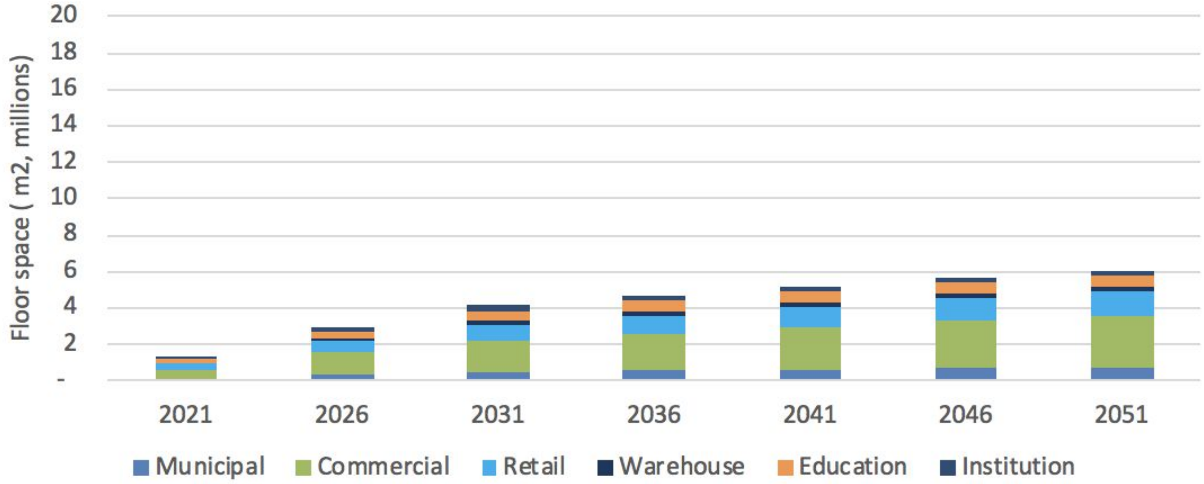


Table 6: Energy and GHG emissions results of the moderate existing non-residential buildings pathway.

Action		Cumulative emissions reductions 2018-2050 (kt CO2eq)	Emissions reductions 2050 (kt CO2eq)	Cumulative energy reductions 2018-2050 (TJ)	Energy reductions 2050 (TJ)
Retrofits for non-residential buildings	40% of the building stock over 35 years old retrofit for electricity and natural gas savings of 50% by 2030; after 2030, 1% of non-residential undertake deep retrofits each year	2,526	131	61,308	3,312
Municipal Building Retrofits	100% of existing municipal buildings are retrofit to net zero emissions by 2050	2,896	259	54,908	4,921
Heat Pumps	13% of commercial floor space	1,450	83.88	20,554.68	1,168.28
District Energy	40% of existing commercial buildings; 40% of apartments; 8% of residential buildings: 40% of the system low carbon	4,922	220.23	10,301.15	476.11
Building Recommissioning	Recommission 50% of buildings over 200,000 ft2 and 20% of buildings over 25,000 ft2 every ten years. Average savings 5% of energy.	1,860	130	42,204	3,051

Aggressive Scenario

Figure 17. Floor area retrofit for existing non-residential under the aggressive scenario (m2).

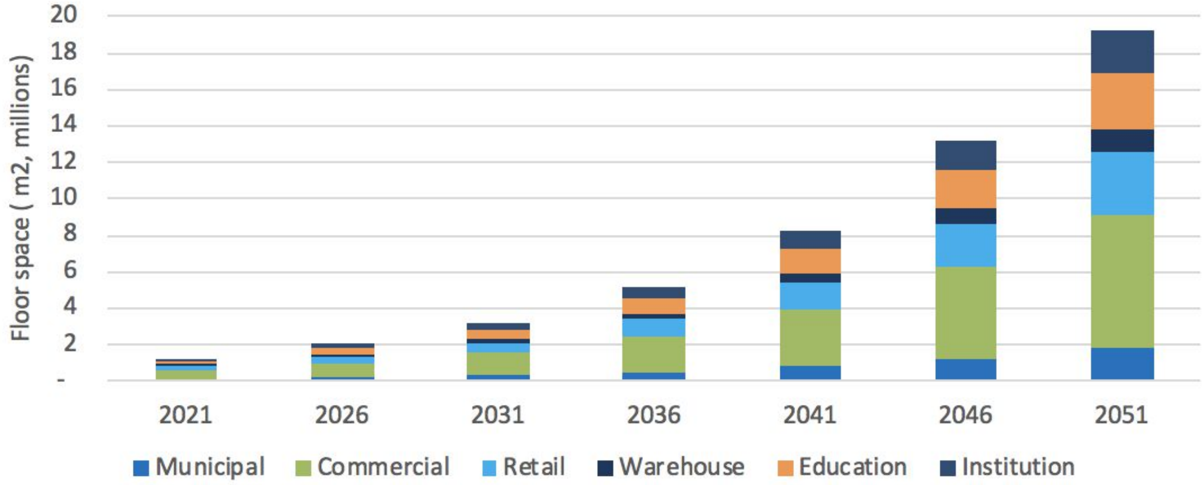


Table 7: Energy and GHG emissions results of the aggressive existing non-residential buildings pathway.

Action		Cumulative emissions reductions 2018-2050 (kt CO2eq)	Emissions reductions 2050 (kt CO2eq)	Cumulative energy reductions 2018-2050 (TJ)	Energy reductions 2050 (TJ)
Retrofits for non-residential buildings	95% of the existing building stock is retrofit by 2050 with average savings of 50%	2,935	252	71,390	6,184
Municipal Building Retrofits	100% of existing municipal buildings are retrofit to net zero emissions by 2040	4,867	277	94,278	5,643
Heat Pumps	21% of commercial floor space	2,388	139	32,905	1,904
District Energy	80% of existing commercial buildings; 80% of apartments; 15% of residential buildings; 70% of the system low carbon	10,077	454	20,547	961
Recommissioning	Recommission all buildings over 200,000 ft2 and 40% of buildings over 25,000 ft2 every ten years. Average savings 10% of energy.	3,907	255	86,334	5,854

Opportunities to Advance the Pathway

Benchmarking

A comprehensive picture is necessary to know which buildings to retrofit. Energy benchmarking is a key strategy to systematically track building energy use over time. In addition to serving a strategic purpose for targeting building segments or geographies for retrofits, energy benchmarking also provides tenants or owners with information on building selection or investment decisions. Due to lack of systematic benchmarking, the CaGBC's Roadmap to Retrofits report was unable to classify one third of building assets due to incomplete data.[13]

New York City is an early adopter and innovator in creating regulations for benchmarking, and targeting large buildings (over 4,645m^2).[14] The rationale for this decision was to mimic behaviour of nutrition labels or vehicles where consumers are more likely to choose healthier foods or more efficient vehicles; potential tenants of buildings would choose more efficient buildings.[15] Research indicated that availability of data that indicates energy consumption can urge the real estate market to keep their buildings as efficient as benchmark rates.[16]

Ontario has also adopted new legislation (Regulation 20/17) under the Green Energy Act (2009) where large buildings (4,645m^2 or greater) are required to report their energy use. Utility companies such as Hydro One will be providing aggregated use data to building owners to facilitate reporting. Benchmarking will be phased in as summarized in Table 8.

Table 8. Ontario benchmarking requirements.[17]

Deadline for Reporting to Ministry of Energy	Commercial & Industrial Buildings Gross Floor Area	Multi-Unit Residential Buildings (MURBs) Gross Floor Area
July 1, 2018 (usage for 2017 calendar year)	250,000 sq. ft. and larger	Not required to report in first year
July 1, 2019 (usage for 2018 calendar year)	100,000 sq. ft. and larger	100,000 sq. ft. and larger
July 1, 2020 (usage for 2019 calendar year)	50,000 sq. ft. and larger	50,000 sq. ft. and larger

[13] Canada Green Building Council (2017). A Roadmap for Retrofits in Canada: Charting a Path Forward for Large Buildings. Toronto.
[14] Kontokosta, C. (2012). Predicting Building Energy Efficiency Using New York City Benchmarking Data. *New York University*, 2012, 12.
[15] Ibid.
[16] Ibid.
[17] "Energy Reporting and Benchmarking." 2018. Hydro One. 2018. https://www.hydroone.com/business-services/energy-reporting-and-benchmarking-for-large-buildings.

Recommissioning

Commissioning is a corrective audit process undertaken prior to the initial occupancy of a building to ensure a building's components are functioning as intended. This includes heating and ventilation systems, appliances, and control systems. Commissioning is more extensively performed for large commercial, residential and institutional buildings due to the complexity of systems and their intended uses. Commissioning is not as extensive for smaller residential buildings which generally have more simple systems. Commissioning is a necessary step for larger non-residential buildings to ensure they are ready for initial occupancy. The process can result in better efficiency in space heating, cooling, and heating of water systems which are the most common energy users and sources of emissions within a building. However, it should be noted that the commissioning process can vary widely and greatly affect the performance of the building for years to come.

In the context of existing buildings, recommissioning is done some time (typically years) after the building has been initially occupied in order to increase efficiency, or re-tune existing systems. Examples of common deficiencies that recommissioning can fix include duct leakage, HVAC systems running when the building is unoccupied, HVAC being unbalanced, lighting systems running all day, valves leaking, improper refrigerant or appliance charge.[18] Continual recommissioning is recommended to ensure the most efficient building performance. Costs vary by the size of the building and the potential upgrades highlighted in the process, however, previous studies have shown the cost to be \$3.25 / m^2 with a payback period of 1-3 years.[19] Estimates place energy efficiency improvements to be 10-20% from recommissioning.[20]

Reaching Net Zero or Passive House Standards

Net Zero buildings have zero net energy consumption; the total energy used by the building annually is approximately the same as energy produced by the building. Passive House certification is currently the most established high-performance standard for building efficiency, with requirements for energy demand, airtightness, and thermal comfort. Net Zero builds on Passive House levels of performance by ensuring that what energy consumption that remains is provided by renewable energy.

Retrofit programs are gaining popularity in Canada due to decreasing costs, simplicity of construction, and reduced time for completion. However, Canada has not reached a scale where programs are easily available across the country, but one emerging exception may be the Energiesprong program developed in the Netherlands. The EnergieSprong program provides a turn-key retrofit service to existing buildings to convert them to Net Zero or Net Zero ready when renewable energy becomes available.[21] Energiesprong retrofits can be completed in 10 days and have been successful in updating social housing without requiring upfront capital from tenants.[22] As the process has evolved for Energiesprong, costs have decreased by 60% in three years.[23] The

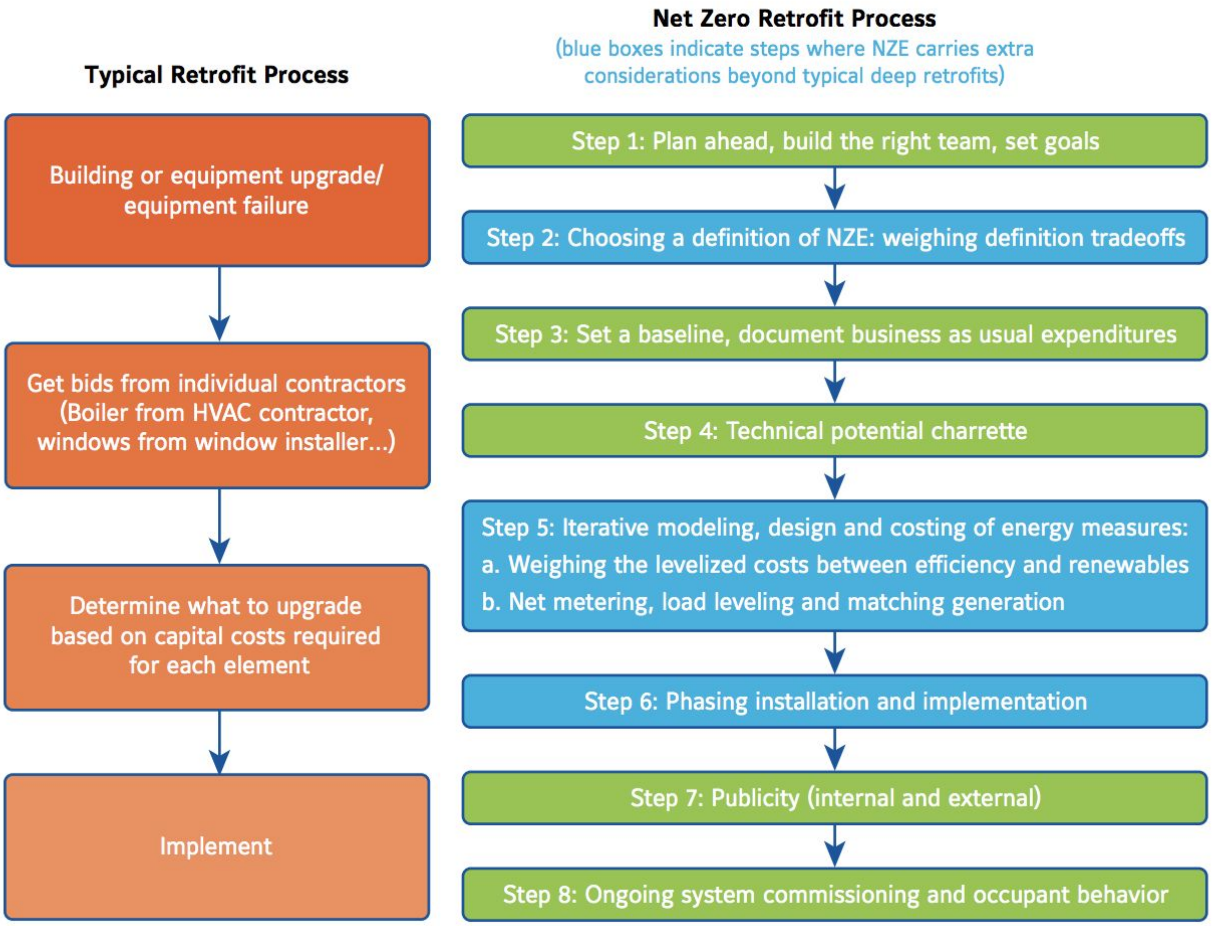
[18] "A Guide to Building Commissioning." Pacific Northwest National Laboratory, September 25, 2011. https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-21003.pdf.
[19] State and Local Energy Efficiency Action Network. (2013). Energy Audits and Retro-Commissioning: State and Local Policy Design Guide and Sample Policy Language. Prepared by A. Schulte, ICF International.
[20] Frappe-Seneclauze, T., Heerema D., Wu, K. 2017. Deep emissions reduction in the existing building stock. The Pembina Institute.
[21] Sustainable Buildings Canada. (2016). Energiesprong Summary Report. Retrieved from: https://sbcanada.org/wp-content/uploads/2017/09/Energiesprong-Summary-Report.pdf
[22] "How-to-Guide: Net-Zero Retrofit Technical and Cost Benchmark Studies." Rocky Mountain Institute, n.d. https://www.rmi.org/rmi_techno_economic_study_how_to_guide/.
[23] Ibid.

EnergieSprong model is quick and efficient by using prefabricated facades and building envelopes, efficient heating and cooling system, and insulated roofs fitted with solar PV.

New York State Energy Research and Development Authority (NYSERDA) has also announced a program called RetrofitNY based on EnergieSprong with the objective of creating a volume market for net-zero retrofits with larger buildings. Finally, Natural Resources Canada is currently working on a similar project titled Prefabricated Exterior Energy Retrofits (PEER) in the Ottawa area, and may be more applicable to the Canadian context as it factors in colder weather patterns nationally.

Irrespective of the technologies applied, achieving a retrofit with the level of ambition of net zero requires a different type of process than a conventional retrofit, with a more intensive design program, and with greater upfront costs (Figure 18).

Figure 18. Comparison of the convention versus net zero approach to retrofits.[24]



In order to expedite the design process, deep energy/net zero retrofit pathways can be developed for specific building archetypes that are relevant to the City of Ottawa. These pathways provide a basis from which more detailed design can be completed.

[24] Carmichael, C. (2018). Reinventing existing buildings: Eight steps to net zero energy. Rocky Mountain Institute.

Fuel Switching

Non-residential buildings can reduce their carbon emissions by switching boilers and heating systems to renewable energy, high-efficiency electric heating systems such as ground or air source heat pumps, or to district energy systems that uses low GHG energy inputs. Ottawa currently operates 5 district energy plants, producing 1.1 million GJ of energy annually[25,26] and some of these systems are intended to become net zero GHG emissions in the near future. District energy provides a different option to reduce dependency on natural gas, and to increase the size of low or zero carbon solutions with the potential for economies of scale.

Currently, fuel switching is disincentivized by the low cost of natural gas in Ontario. This presents a critical barrier for widespread uptake of fuel switching and the electrification of heat. Ground-source heat pumps, which Ottawa has more experience with, may have a better business case especially when combined with any potential carbon pricing measures that may be mandated by the Federal Government.

Fuel switching becomes most viable in the context of retrofits which reduce the demand for space heating, enabling the introduction of smaller equipment with reduced capital and operating costs relative to the business as usual case. The financial case is further strengthened if this process can occur at the end of life of major components in the building.

In order to achieve the target of net zero, electrification is unlikely to be sufficient, as the electricity is not 100% clean in Ontario. As a result, the building will need to provide renewable energy using solar PV or purchase renewable electricity from other sources. Balancing the costs of incremental renewable energy versus the incremental savings from energy efficiency measures is an important design question for the retrofit.

Funding & Financing Retrofits

Creating a business case for private building owners to recommission their buildings or do deep energy retrofits can be challenging. The CaGBC recommends sending consistent messages to the retrofit and recommissioning industry by ensuring that grant programs or incentives stay in place over the long term.[27] With these programs, the industry can develop, gain expertise, and be able to make efficiencies with their practices or procurement chains. However, a variety of financing methods may become available from the Province, Federal Government, or utility companies to help reduce energy and emissions from existing buildings.

The large upfront costs of deep energy retrofits are a barrier to organizations, stratas, or building residents who may have to pay to refurbish a building envelope, add high-performance windows, or overhaul an HVAC system. In response, The Rocky Mountain Institute (RMI) advocates for an integrated design approach where the whole building is considered and passive strategies that make better use of existing environmental features are prioritized, such as maximizing solar gain.[28] RMI also advocates for retrofit strategies that may have faster payback periods to begin with, using those gains to tackle more expensive items that will reach a 50% reduction in energy use.[29] The

[25] "Ottawa: Steam to Hotwater Conversion." Ever-Green Energy, 2018. http://www.ever-greenenergy.com/project/ottawa/.
[26] As modelled by CityInSight.
[27] Canada Green Building Council (2017). A Roadmap for Retrofits in Canada: Charting a Path Forward for Large Buildings. Toronto. Retrieved from: www.cagbc.org/cagbcdocs/advocacy/CaGBC_Roadmap_for_Retrofits_in_Canada_2017_EN_web.pdf.
[28] "Deep Retrofit Tools and Resources - Rocky Mountain Institute." Accessed September 9, 2018. https://rmi.org/our-work/buildings/deep-retrofit-tools-resources/.
[29] Ibid.

CaGBC recommends deep retrofits at a time when a building may need to renew their envelope, replace major equipment, when there is new ownership, or if the building is attempting to gain green building certification.[30]

Local Improvement Charges

Local Improvement Charges (LIC) are an important tool for encouraging uptake of energy efficiency upgrades. This financing method will securitize a loan against a building asset rather than an individual owner. Essentially, building owners receive a loan from municipalities, which is repaid through the local taxes, called a local improvement charge. This financing structure is often referred to as Property Assessed Clean Energy (PACE) in the United States. Ontario Regulation 586/06 Local Improvement Charge allows municipalities to undertake works that provide local benefits and recover the costs from benefitting properties.[31] Regulation 322/12 allows such projects to be used for a wider range of uses, including home retrofits.

On-bill Financing

On-bill financing programs for retrofits have a similar repayment schedule as LIC structures, except repayment occurs through monthly utility bills. On-bill financing ties retrofit activity to actual energy and cost reductions. In theory, on-bill financing aims to reach bill neutrality, where monthly costs are equal to the savings achieved through retrofits and there are little incurred costs to customers; in practice, bill neutrality is far from guaranteed.[32] Loans are transferable if the unit is sold. Utilities need to provide upfront capital for project administration and initial loan funding. Large buildings may offer a different advantage than small buildings where a building is used as a security and has more value. The larger collateral can be used to target a deep retrofit strategy which can reduce operating costs at a higher rate.

Third-party financing

Both on-bill financing and local improvement charges present an alternative to loans from a traditional lending institution. In some cases, third-party financing can be advantageous, especially if an institution can provide low interest and long-term loans or bundle energy efficiency measures within a mortgage. Third party loans are seen as a lower risk to utilities and local governments, both of which are institutions that are not traditionally designed to provide loans.

Large commercial buildings may be able to use other revenue sources to secure larger loans from a lending institution and target a deep retrofit strategy if it is proven to reduce operating costs significantly. The same advantage could be offered to a large condominium building which can use strata fees.

[30] Canada Green Building Council (2017). A Roadmap for Retrofits in Canada: Charting a Path Forward for Large Buildings. Toronto. Retrieved from: www.cagbc.org/cagbcdocs/advocacy/CaGBC_Roadmap_for_Retrofits_in_Canada_2017_EN_web.pdf
[31] Government of Ontario. O. Reg. 586/06: Local improvement charges. Retrieved from: https://www.ontario.ca/laws/regulation/060586
[32] Bardhan, A., Jafee, D., Kroll, C., Wallace, N. (2014). Energy efficiency retrofits for US Housing: Removing the bottlenecks. Regional Science and Urban Economics, 47, 45-60.

Ways to Encourage the Pathway

To move forward with reducing energy use and emissions from large existing buildings, the Ottawa community may want to consider the following actions:

- The City and its partners can help promote the new requirement of Ontario to benchmark buildings that are 4,645 m^2 or greater. As suggested in the benchmarking strategy of this pathway, there is a lack of data available to consistently measure performance of like buildings within Canada or Ottawa. Benchmarking can stop this trend and also encourage building owners to retrofit without incentive. The city can possibly start this shift by assisting in the benchmarking buildings that are 18,580 m^2 or greater and are 35 years or older.

- Encourage retrofits with modular facades. To encourage programs such as EnergieSprong which provide rapid retrofits that are cost efficient, the city can promote pilot projects the Federal Government is undertaking with the PEER program and expand the breadth of the program. Without direct financial incentives, the City can further modular facade retrofits by making the permitting process simple and straightforward.

- Incentivize deep retrofits by offering tax waivers, reduced fees, or permitting times. One way to help create a business case to conduct a deep retrofit is by offering reduced permitting fees to business owners, which can act as incentives for building owners who are contemplating renovations for other purposes. The City can also consider tax waivers for extra floor space added, such as mezzanines in large offices or industrial buildings, to further stimulate the retrofits.

- Prioritize financing options. As discussed in the "Financing and funding retrofits" section, the city and its partners have a small number of options to help finance retrofits. Local improvement charges (LICs) can be used to secure loans building improvements against the building asset, and not the owner to reduce financial risk. Further, The Ottawa community currently has the "Ottawa Sustainability Fund." This fund can prioritize the recommissioning or retrofitting of large buildings, starting with buildings greater than 18, 580 m^2, and are 35 years or older. This program could be further developed as a revolving loan fund for large buildings similar to Better Buildings Partnership in Toronto.[33]

- Target deep retrofits for organizations with multiple buildings. Organizations that have multiple buildings in their inventory such as universities, government, or military should be targeted to do campus-wide retrofits. The CaGBC suggests that greater efficiencies can be found with this approach, such as waste heat recycling and other forms of district energy.[34]

[33] For more information, see: https://www.toronto.ca/business-economy/business-operation-growth/green-your-business/better-buildings-partnership/

[34] IIESO. (2017). An examination of the opportunity for residential heat pumps in Ontario. Prepared for Ministry of Energy.

Appendix 1: Mapping of non-residential buildings from MPAC classifications to high level categories

bldgType	Municipal	Commercial	Retail	Warehouse	Education	Institution
college_university					100%	
school					100%	
retirement_or_nursing_home						100%
special_care_home						100%
hospital						100%
municipal_building	100%					
fire_station						100%
penal_institution						100%
police_station						100%
military_base_or_camp						100%
transit_terminal_or_station						100%
airport						100%
hotel_motel_inn						100%
greenhouse						
greenspace						100%
recreation						100%
community_centre						100%
golf_course						100%
museums_art_gallery						100%
retail			100%			
vehicle_and_heavy_equiptment_service			100%			
warehouse_retail				100%		
restaurant			100%			
commercial_retail		50%	50%			
commercial		100%				
commercial_residential		100%				
retail_residential			100%			
warehouse_commercial		50%		50%		
warehouse				100%		
religious_institution						100%
energy_utility						100%

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Pathway Study on Existing Residential Buildings in Ottawa

Presented to:
The City of Ottawa
110 Laurier Ave W
Ottawa, ON K1P 1J1

In relation to:
The City of Ottawa's Energy Evolution Strategy (Phase 2)

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January 2019

Contents

Executive Summary

Existing residential buildings contribute to greenhouse gas emissions in the City of Ottawa. This is because most residential buildings rely on natural gas for space and water heating needs, a portion of which is wasted because of inefficient building design. Due to low rate of building stock turnover, most small buildings that exist today will remain standing by 2050, which makes reducing the energy used by existing buildings important for decarbonization as well as gaining the economic and social benefits associated with deep retrofits.

Retrofits and fuel switching are the primary tool to reduce energy use and emissions reductions from the existing building stock. Retrofits upgrade building components to reduce energy use, while fuel switching replaces fossil fuel energy systems with renewable or low carbon sources of energy. Audits can provide property owners with information on building energy use, which can lead to up uptake of retrofits or fuel switching.

Uptake of energy efficiency upgrades is currently the direct responsibility of individual property owners. Municipalities and higher levels of government encourage uptake of energy efficiency upgrades by providing awareness of retrofit benefits or by providing financial incentives. Energy benchmarking and disclosure of energy data empowers property owners to undertake retrofits through real energy cost data. Currently, utilities deliver a suite of incentive programs for audits, high efficiency building components and retrofit activities. Local improvement charges (LIC) can also be used to provide upfront capital to property owners to undergo retrofits.

This chapter examines low carbon pathways for existing residential buildings in the City of Ottawa. This pathway models three scenarios: conservative, moderate, and aggressive. The conservative scenario is a Business-as-Planned outlook with a small proportion of retrofits, the moderate reflects increased retrofit penetration with moderate energy savings, while the aggressive scenario involves retrofitting nearly all of the pre-2016 building stock by 2050, including fuel switching to electricity for heating and solar PV for renewable energy generation; the latter two pathways are also addressed in the other building papers.

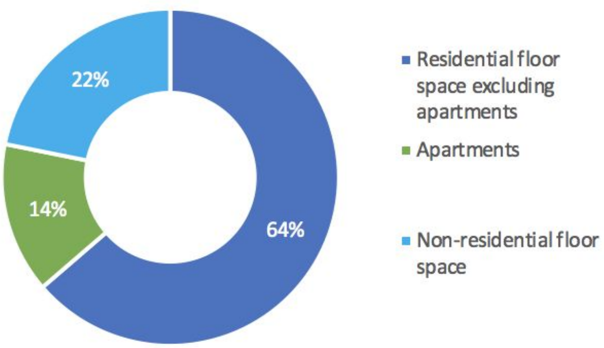
The conservative scenario reduces cumulative emissions (2018-2015) by 3.017kt CO2e. The moderate scenario sees cumulative emissions reductions of 3,356 kt CO2e. Finally, the aggressive scenarios is related to cumulative emissions reductions of 7,345 kt CO2e.

Section 1: Present Assessment of Existing Small Buildings

Pathway Description

The existing building stock accounts for approximately half of the GHG emissions in Ottawa; the residential building stock accounts for a third of the total GHG emissions. Identifying the emissions contributions of both residential and non-residential small buildings is challenging, but one approach is to segregate residential buildings that are not apartments. This approach understates the total contribution of small buildings because it doesn't include small buildings that are non-residential nor apartments that are less than five storeys. Under this approach, small buildings account for a least 64% of the total floor area of buildings in the City of Ottawa (Figure 1).

Figure 1. Floor area of small residential buildings versus other categories, 2016.



The existing small building stock is inefficient. Older buildings are often leaky, meaning energy is wasted as heat escapes beyond the building. Older appliances also have lower operational efficiency. Ottawa has a considerable portion of older residential buildings. Sixty-four percent of all residential dwellings in the City were built prior to 1990, and nearly 75% of all dwellings were built in or before the year 2000.[1]

In Ontario, new buildings are considerably more efficient. A building constructed in 2017 is approximately 35% more efficient than a building built in 1997.[2] Although new buildings are more efficient, the existing building stock will remain standing for many years to come. Estimates expect that it could take approximately 65 years to replace the existing building stock in Canada, with 66% of buildings remaining in the year 2050.[3]

Addressing GHG emissions and energy consumption of the existing residential building stock will be critical to deep emissions reductions for the City. This component is challenging because the GHG emissions are decentralized in ownership and geography. The hundreds of thousands of individual owners are typically capital constrained and do not have sophisticated energy management knowledge or tools.

Retrofits of existing buildings are effective at reducing emissions because they can minimize energy loss and reduce overall energy used for space conditioning. Conventional retrofit approaches are insufficient for a deep GHG emissions reductions pathway; whole system approaches are required. Fuel switching is also important to reduce emissions associated with fossil fuel combustion for heat. A key strategy will be integrating energy retrofits into the background cycle of renovations. Many older buildings require ongoing improvements for livability, which presents a critical opportunity for

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[1] Statistics Canada. (2017). Census Profile. 2016 Census. Statistics Canada Catalogue no. 98-316-X2016001. Ottawa.
[2] Environmental Commissioner of Ontario. (2017). Conservation: Let's Get Serious. Chapter 5: Codes and Standards.
[3] Now House. (2013). Net Zero Energy Home Retrofits. Sustainable Building/Renovating Housing Forum 2013 Kamloops Convention Centre. https://www.chbaci.ca/docs/evening_speaker_-_gauthier_kamloops.pdf

inclusion of efficiency retrofits. Of dwellings built prior to 2000 in Ottawa, 35% require minor repairs, while an additional 9% require extensive repairs for livability.[4]

Improvements to the existing residential building stock can also provide economic benefits to individuals and to local economies through reduced household spending on energy, as well as economic stimulus to the local construction sector. Reducing energy use in residential buildings can reduce demand burdens on electricity and natural gas providers, reducing the need for investments in new energy distribution infrastructure. Retrofits can also improve household living conditions, improving indoor air quality and comfort.

Pathway Boundaries

This paper describes low carbon pathways for existing residential buildings in Ottawa. Mixed-Use buildings that feature residential dwellings along with commercial or other non-residential uses are included in the non-residential building pathway papers. This pathway outlines background information related to the existing building stock and the key strategies for pathway advancement.

Section 2 of this pathway paper includes modelling method and parameters. Three uptake scenarios for existing small buildings are modelled: conservative, moderate and aggressive.

Opportunities for emissions reductions from the existing residential building stock will ultimately rely on aggressive uptake of deep whole building retrofits that include fuel switching and deployment of renewable energy and energy storage. While the whole systems approach includes fuel switching, solar PV and energy storage, these strategies are addressed in more detail in separate papers and this paper focuses on retrofits.

[4] CMHC. (2014). Dwelling condition by tenure and period of construction, Ottawa, 2011.

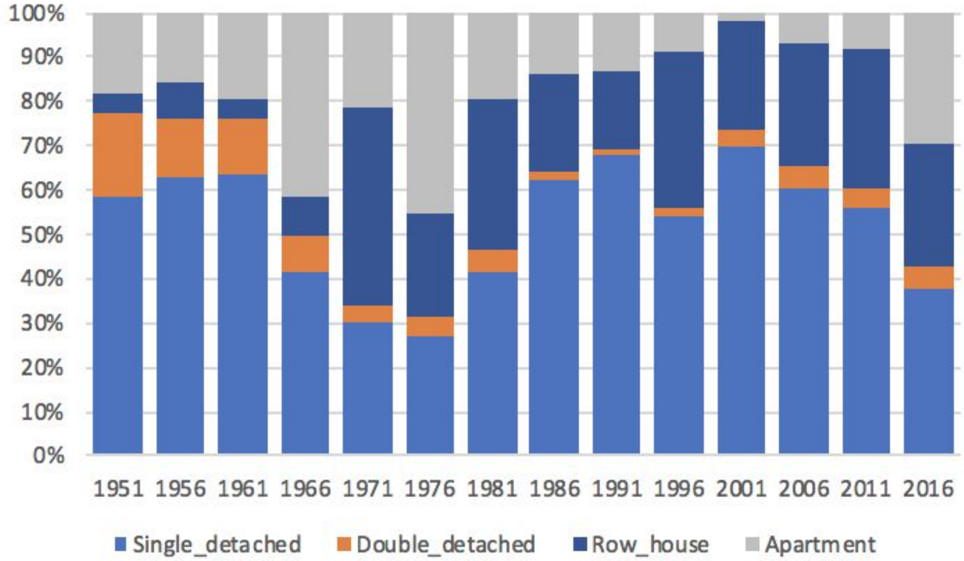
Background Information

Ottawa's Building Stock

There are approximately 104,000 units in apartment buildings in Ottawa. There are 327,000 units of of single detached homes, row houses, and duplexes. Figure 2 shows new dwellings according to the five-year increments during which they were constructed. The dwellings counted are inclusive of the cities that existed prior to amalgamation and represent the current Ottawa boundary. Note that all units constructed prior to 1951 are included in the 1951 data.

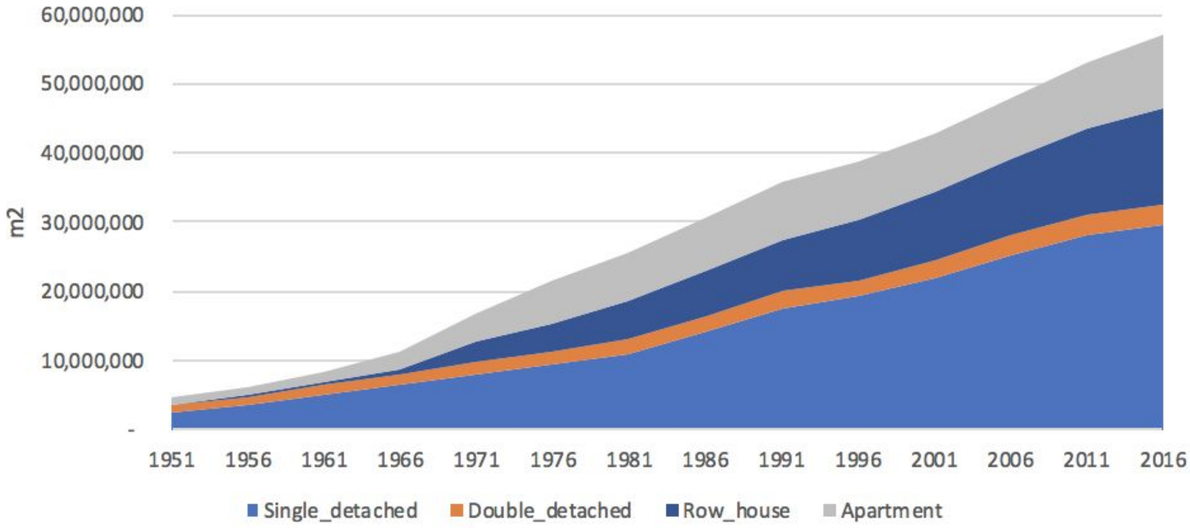
The share of different types of dwellings has gone up and down over the period, with a pronounced emphasis on small buildings from 1986 to 2011, followed by an increase in the construction of apartments over other forms in the last five years.

Figure 2. Proportion of new dwellings by type in five year increments, City of Ottawa.



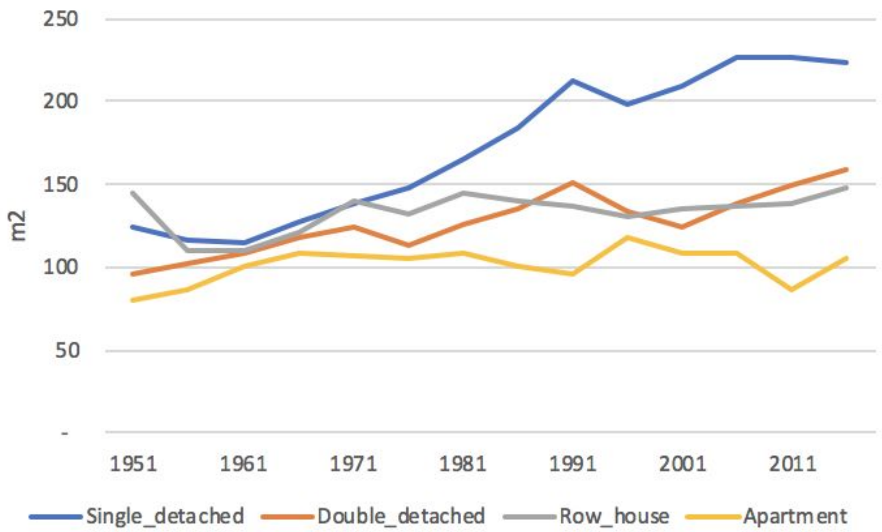
Overall, residential floor space has grown rapidly since 1951, increasing from just under 5 million m² to 60 million m² by 2016. While the overall share of apartments has gained over the period, the majority (81%) of the residential building stock in 2016 fits clearly within the small buildings category, as illustrated in Figure 3. Just over half (52%) of the dwellings were single family in 2016.

Figure 3. Cumulative floor space by dwelling type.



The size of new dwellings increases over time in all housing categories except for apartments. The trend is most pronounced in single family dwellings, whose size has increased by nearly 200%. In 1956, the average single-family home was 116 m^2; in 2016 the average house is 264 m^2.

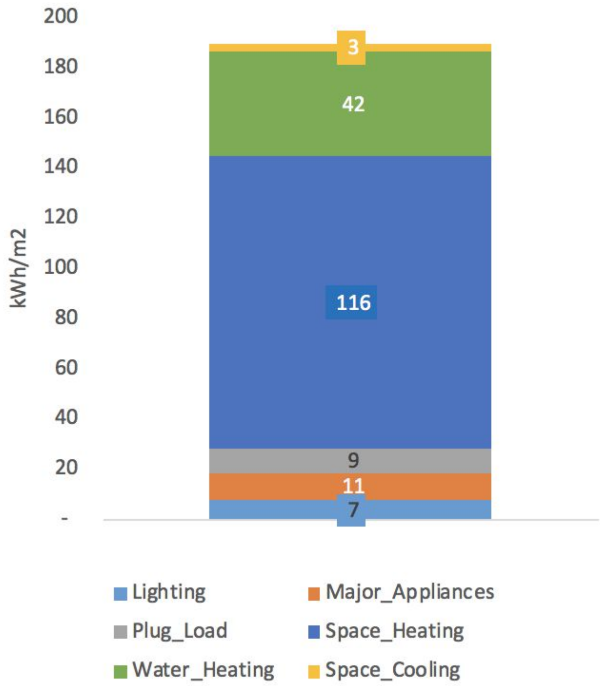
Figure 4. Average floor area by unit type.



Energy Consumption

The average residential dwelling (including apartments) in Ottawa has an energy use intensity of 190 kWh/m². Space heating represents 60% of energy use intensity, while water heating represents 22%.

Figure 5. Average energy intensity by end-use for residential dwellings in the City of Ottawa, 2016[5]

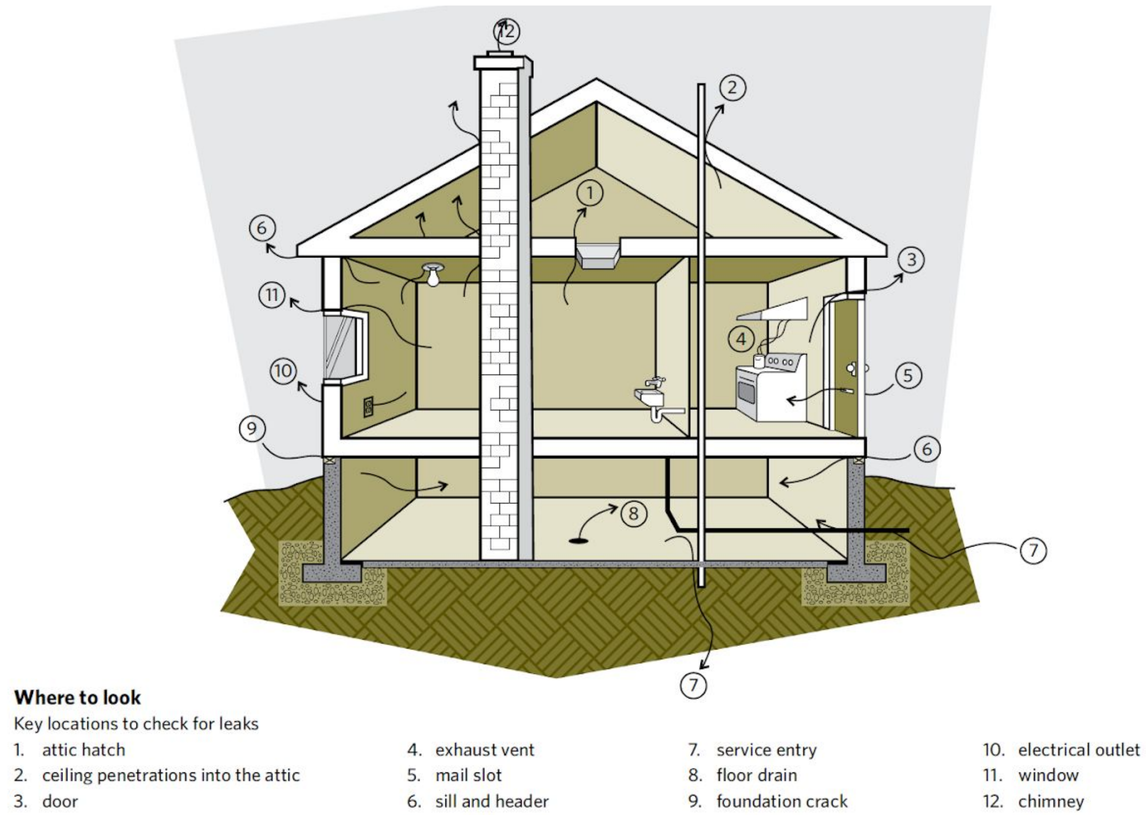


Space heating is influenced by the rate of heat loss. Buildings lose heat as it is transferred through the air, water and materials of the building, due to a temperature difference from the inside to the outside of the structure. Heat can be lost through direct contact from one object to another (conduction); through the movement of air (convection); and, through the radiation of heat from occupants to the exterior (radiation). Most heat loss occurs through convection, as air travels through the building and escapes through leakage points in the building envelope.

Air leakage can occur at multiple places in the building envelope. Walls can account for 20% of heat loss in a building, while windows and doors can be up to 25% of heat loss.[6] Common locations of air leaks are displayed in Figure 6, such as cracks near windows and in the roof. It can also occur through thermal bridging, where building components that conduct heat provide a pathway to the exterior. Thermal bridging often occurs at wall studs and balconies.

[5] This average includes apartments.
[6] Natural Resources Canada (2017). Keeping the Heat in. Retrieved from: https://www.nrcan.gc.ca/energy/efficiency/housing/home-improvements/keeping-the-heat-in/how-your-house-works/15630

Figure 6. Common air leakage points in a detached home.[7]



Air leakage is minimized in efficient buildings by ensuring there is an air barrier to block airflow through the building envelope, sealing cracks, using efficient windows and doors, and through insulation in the walls and roof. The extent of airflow movement is often referred to as the tightness of the building. The efficiency of building components is described by its R-value, referring to its resistance to thermal transmittance. Older homes were not frequently built to reduce thermal loss or have lost thermal resistance over time through a lack of maintenance or through changing building use.

Efficiency can also be integrated into structural design. Passive buildings are constructed in relation to the surrounding environments to minimize energy required to reach thermal comfort. For example, heat in the winter is maximized using south-facing windows, while shade cover from trees block solar insolation from those same windows in the summer.

Older electrical appliances, which account for just 6% of the average dwelling's energy consumption, are generally less efficient than modern appliances. Plug loads and lighting together account for 9% of total energy. More efficient lighting and plug loads decrease the waste heat produced in a dwelling and can result in increased GHG emissions if that waste heat is replaced with heat produced by natural gas.

[7] Natural Resources Canada (2017). Keeping the Heat In.

The Effect of Climate

Ottawa's climate impacts building heat loss, and the insulation required to minimize loss. Ottawa's climate is considered humid continental, relating to Koppen Dfb climate index, experiencing large seasonal temperature fluctuations, with cold winters and hot summers. This translates to high heating requirements in the winter, and greater air conditioning loads in the summer.

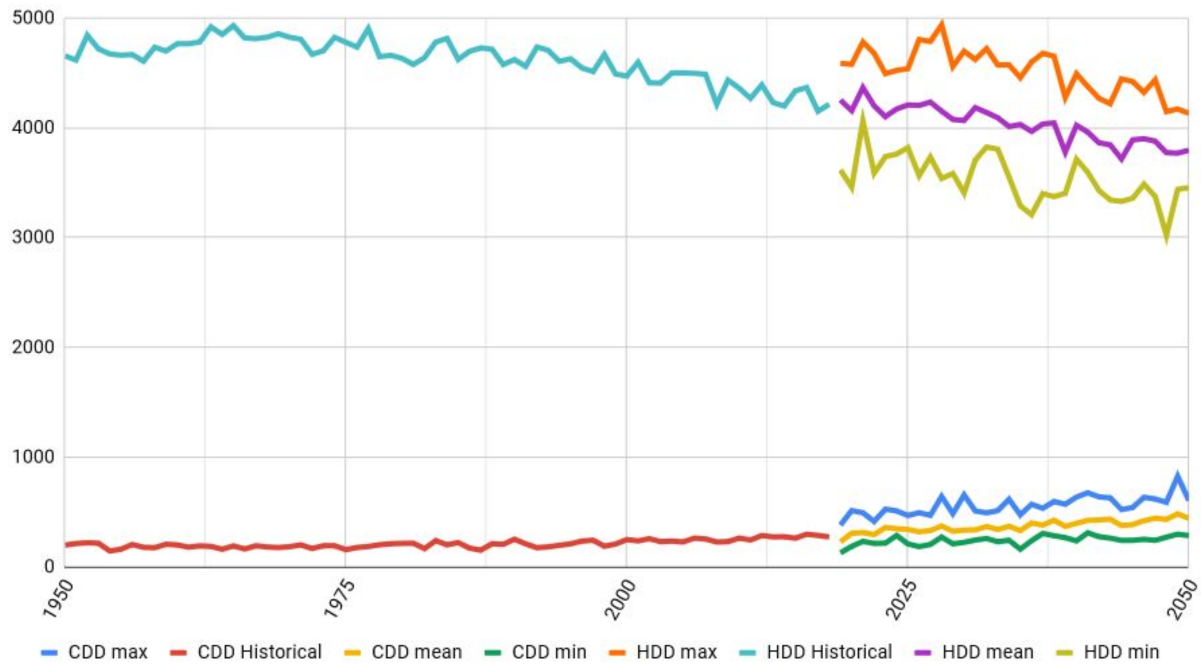
In the winter, wider temperature gradients between the interior and the exterior of a building will cause greater heat loss. In order to reach optimal thermal comfort in a leaky building, more thermal energy will be required. This generally results in higher demands for natural gas in colder temperatures causing seasonal winter peaks in gas usage. In areas outside of the gas grid, there may be increased use of heating-oil, propane or wood/pellet stoves. In an efficient building, greater insulation retains heat within the structure and minimizes peak demand for heating fuel at colder temperatures.

In the summer, air conditioning is frequently used for space cooling. There is a thermal gradient between the warm exterior of the building and the cold interior, which cause warm air to enter the building without proper insulation, ultimately requiring further space cooling demand. Building design can reduce space cooling needs through effective building design that minimizes sunlight, maximizes airflow, and by using insulation in the building exterior to keep cooler air in the building. Air conditioning contributes to critical annual peaks in electricity demand in Ontario. Because critical electrical demand peaks are often met with natural gas fired generation, high air conditioning loads in the summer can cause disproportionately higher emissions.

A heating degree day is the number of degrees that a day's average temperature is below 18°C, indicative of the amount of energy needed to heat buildings to operating temperatures in that day. For example, a day with an average temperature of 4°C will have a Heating Degree Day of 14°C. Similarly, a cooling degree day provides a measure of energy needed to cool buildings, noted by the number of degrees that a day's average temperature is above 18°C.

In Ottawa, heating degree days are projected to decline by 10% by 2050 over 2018, with cooling degree days increasing by 60% over the same period (Figure 7). Under a BAP scenario, space heating will go down, but air conditioning use is expected to increase.

Figure 7. HDD and CDD projections for the City of Ottawa.[8]



Evaluation of the Current Pathway

Energy Auditing

Energy audits are an inspection of an existing building, surveying energy use and flows in the structure. Audits often include an analysis of energy bills, inspection of building components during site visits, and some energy modelling of building components. Auditing can point to specific areas of concern with regards to energy loss within a building, describing techniques for energy and cost saving measures for property owners, often focusing on lighting, heating, cooling, ventilation and water heating.

Audits are often the first step towards building upgrades, providing initial information on building energy use. Energy audits typically cost under $1000, with actual costs varying by service provider, scope of services and the size of the building. For example, as a part of its Home Energy Conservation Program, Enbridge charges $600 for an energy audit.[9]

Energy auditing is a low-cost solution for improving existing building efficiency, as it can target simple technological and behavioural improvements to the structure and encourage building owners to perform building upgrades through real cost and energy information. Energy audits need to focus on the whole system and the steps required to achieve deep GHG emissions reductions. Natural Resources Canada has recently invested in a clean net zero pilot program in Nova Scotia to explore the design requirements to achieve net zero retrofits.[10]

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[8] Prairie Climate Centre (2018). The Climate Atlas. https://climateatlas.ca/data/city/459/hdd_2060_85
[9] Enbridge, Inc. Home energy Conservation. Retrieved from: https://enbridgesmartsavings.com/home-energy-conservation/pre-energy-audit#advisors
[10] See Clean Nova Scotia's website at: http://clean.ns.ca/clean-net-zero

Retrofits

Retrofits further expand on commissioning techniques by updating system design and building components to maximize building energy efficiency. Retrofits minimize energy loss in buildings by reducing air leakage in the building envelope, reducing heat loss through walls, installing high R-value windows and doors, using energy efficient heating systems and appliances, and installing energy management systems. Retrofit activities seek to include high efficiency components into existing buildings, to provide similar levels of comfort using less energy. Retrofit activities range in their depth: simple retrofit activities are often cheap, with little effect, while deeper but more intrusive options are expensive yet more effective at reducing emissions. A comparison of retrofits is described in Table 1.

Shallow Retrofits are aimed at simple upgrades to buildings. This includes replacing low efficiency lighting for higher efficiency LED lighting, as well as some upgrades to higher efficiency appliances, such as refrigerators and ovens. Shallow retrofits can sometimes include light weatherization, targeting caulking and sealing open gaps where heat can escape the building. It can also include installing automated thermostats to allow building owners to see energy use, energy prices and control thermostat temperatures remotely.

Shallow retrofits are often lower cost than other deeper retrofits, with average costs at less than $5,000 for a detached home, and less than $2,000 per unit in a multi-unit residential building, but do not provide the same energy savings. One estimate places energy savings at approximately 10-20% through shallow retrofits.[11]

Moderate retrofits include similar techniques as in shallow retrofits but can also target upgrades to heating systems and insulation. This includes upgrading to a greater efficiency boiler or furnace for the building or replacing with a heat pump. Medium retrofits can also include improving roofing insulation.

Moderate retrofits are more expensive per unit than shallow retrofits as more building components have been modified or upgraded. Average costs can be from $5,000-$50,000 for a detached house, and $2,000-$6,000 per unit in a MURB. Although more expensive, energy savings are estimated to be closer to the 30-50% range.

Deep building retrofits target all aspects of heat loss in a building, and often require structural upgrades to the building. Deep retrofits can include replacement of window and doors with higher R-values, re-insulation of foundation and walls, envelope replacement, and changes to home heating system. Energy savings can be higher, from 40-80%, although deep retrofits are considerably more expensive. Estimates place deep retrofits at over $100,000 for a detached home, and $10,000-$60,000 per unit in a MURB.

[11] Frappe-Seneclauze, T., Heerema D., Wu, K. (2017). Deep emissions reduction in the existing building stock. The Pembina Institute.

Table 1. Comparison of retrofit depths.[12]

	Shallow Retrofit	Moderate Retrofit	Deep Retrofit
Typical energy conservation measures	• Lighting • Smart controls • HVAC motors and fans Caulking and sealing Optimization	• Boiler, furnace, or AHU replacement • Steam to hot/low-temp water • Heat pumps • Drain/waste heat recovery • Heat recovery ventilation Roof/cavity insulation	• Window replacement • Wall and foundation reinsulating Shading • Envelope replacement • Conversion to renewable district energy
Energy savings range	10-20%	30-50%	40-80%
Typical payback period and costs	1-3-year payback MURB: <$2,000 / unit Home: <$5,000	3-6-year payback MURB: $2,000-$6,000/unit Home: $5,000-$50,000	6+ year payback MURB: $10,000-$60,000/unit Home: $100,000-$150,000
Advantages	• Short payback Cost-effective • Incentivized by current program and policy structure	• Attractive balance of energy savings and payback • Can be performed with minimal disruption to tenants	• Holistic approach optimizes components • Large and lasting energy and emissions reductions
Disadvantages	• Small energy savings Weakens business case for deeper retrofits in the future • Missed synergies between building components • GHG reductions can be small when focusing on electrical savings only	• Higher energy reductions difficult to achieve without envelope upgrade • May result in oversized mechanical systems compared with a deep envelope retrofit	• Complex • Longer payback period • Disruption to tenants/owners

[12] Frappe-Seneclauze, T., Heerema D., Wu, K. (2017). Deep emissions reduction in the existing building stock. The Pembina Institute.

Payback periods for building retrofits are a major part of building a business case for any level of retrofit. Payback periods can vary greatly depending on levels of expertise, the retrofit path chosen, and the depth level of the retrofit. Other economic dimensions such as incentives offered or carbon pricing can greatly speed up payback periods, and the lack of of these items can make payback periods lengthy and thereby less attractive to undertake.

Case studies on larger apartment building retrofits by The Toronto Atmospheric Fund (TAF) show that reasonable paybacks (4-6 years) can be achieved on older and less efficient buildings in Ontario. The TAF helped to finance and provide grants for a portion of these retrofit programs.

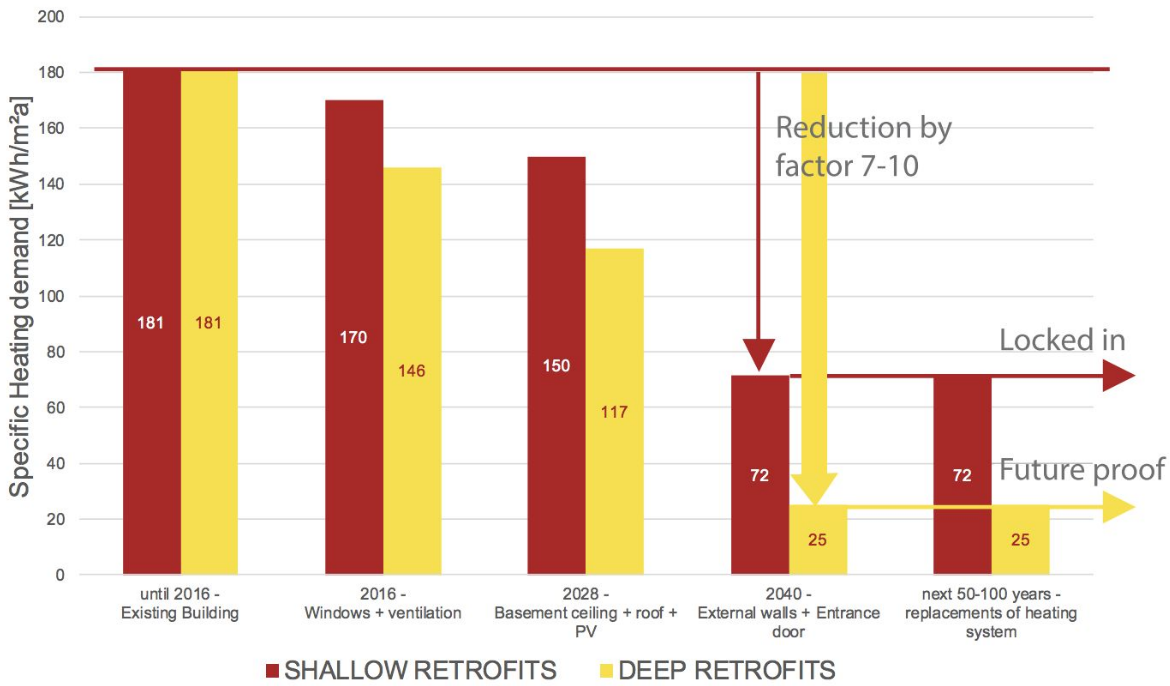
Table 3: Retrofit case studies and payback periods.

Project Description	Retrofits	Energy, Utility, and water savings	Payback Period
45-year old multi-family building in Burlington, Ontario[13] 210 units over 18 storeys	• Boiler replacement • Toilet replacement • Chiller replacement	• 20% natural Gas reduction • 29% water reduction • 50% electricity demand reduction • 300 tonnes GHG reduction	4.4 Years
20-year old social housing apartment building, Toronto Ontario[14] 13-storeys high with with 125 1-3 bedroom units	• Boiler replacement • Make-up air/HVAC upgrade • Lighting system upgrade to LED • Toilet, shower, aerator replacements	• 11% electricity reduction • 31% natural gas reduction • 33% water reduction • 166 tonnes GHG reduction	6.2 Years
30-year old social housing building in Toronto Ontario[15] 8-storey building combined with 4-storey section, 102 1-3 bedroom units	• Programmable electric baseboard heating system installed • Boiler upgrade • Make-up air/HVAC upgrade • Centralized control for building systems added • Domestic cold water booster pump system installed • Lighting system retrofit to LED • Toilet, Showerheads, and Aerators replacement • Exterior door and lobby air conditioner replacement	• 22% Electricity reduction • 29% Natural gas reduction • 47% Water reduction • 82 tonnes GHG reduction	4 Years

[13] "15 Kensington Road." 2011. Case Study. Towerwise. Toronto, ON: Toronto Atmospheric Fund. http://taf.ca/wp-content/uploads/2018/02/TAF_TowerWise_Case_Study_Kensington_Road_2011-01-21.pdf.
[14] Finn, Derrick. 2016. "Development of Three Multi-Unit Residential Building Energy Efficiency Retrofit Case Studies." Case Study. Housing Research Report. Ottawa, ON: CMHC. ftp://ftp.cmhc-schl.gc.ca/chic-ccdh/Research_Reports-Rapports_de_recherche/2017/RR_Three_Multi_Unit_Retrofit_Case_Studies_Jun2.pdf
[15] Ibid.

The lock-in impacts of retrofits should be considered. Many building components last 20 or more years, or even 40-60 years for the building shell. If shallow retrofits are undertaken, no additional improvements in the equipment installed can be expected over the course of its lifetime without considerable additional expense. In this way, lower levels of energy reductions can be locked in for a long period. In one example, a house that undergoes shallow retrofit measures has an energy demand three times as high as that with deep retrofit measures, over the buildings lifetime (Figure 8).

Figure 8. The lock-in effect of shallow retrofits.[16]



The Passive House Institute has developed Energy Retrofits with Passive House Components (EnerPHit), a certification program for existing buildings. EnerPHit is a retrofit plan that may include multiple steps using Passive House standard components such as insulation, opaque building envelope, high-R windows, which can ensure the building does not exceed a prescribed maximum heating demand.[17]

Reaching a net-zero retrofit is also possible, and generally includes rooftop solar PV, ground source heat pumps, solar thermal and highly efficient building design to reduce overall energy needs.

Reaching Passive House or net-zero performance levels in a deep retrofit is possible, but existing buildings present some difficulties. For example, Passive House standards are harder to achieve in retrofitted buildings, often because of the difficulty in retrofitting basements, the orientation of the building relative to sun exposure, and high area to volume ratios.[18] Ottawa's climate presents further challenges, as the high heating and cool requirements will require considerable airtightness.

Over time, a building's structure and operational performance degrade, especially with little maintenance and upkeep. In some instances, it may be more advantageous—both economically and from an emissions perspective—to replace an existing building. Replacement is most effective if it

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[16] Passive House Institute. (2016). Implementing deep energy step-by-step retrofits. Retrieved from https://europhit.eu/sites/europhit.eu/files/EuroPHit_brochure_final_PHI.pdf
[17] Passive House Institute. (2016). Criteria for the Passive House, EnerPHit and PHI Low Energy Building Standard. Retrieved from: https://passiv.de/downloads/03_building_criteria_en.pdf
[18] Passive House Canada. Passive House FAQs. Retrieved from: http://www.passivehousecanada.com/passive-house-faqs/

targets the worst-performing buildings. Retrofit-or-replace decisions are building-specific, and largely depend on property owner decision-making.

Retrofit Information

Industry knowledge is an important tool in effective retrofit programs uptake, as it can instill trust in homeowners and provide superior retrofit outcomes.[19] Improved energy retrofit information can encourage building owners to invest in retrofits. Despite availability of energy efficiency information—including energy models available to homeowners—it is often perceived as difficult to navigate, and potentially unreliable when taken with local policy and climate context.[20] There are multiple actors, certification schemes, contractors, and financing options to consider. Energy efficiency awareness is also an important tool to encourage local knowledge, a role that local governments and utilities take on through task forces, training offerings, local events and publicly available information.

Encouraging local one-stop-shops for retrofit services is seen as an important driver for uptake.[21] This has been encouraged in Alberta with the development of the Energy Efficiency Alberta Agency, a public facing entity that encourages retrofits and energy savings.[22] In Ontario, Peterborough Utilities and other community organizations have developed a local hub for information on energy efficiency.[23]

Retrofit Funding / Financing Programs

<u>Local Improvement Charges</u>
Local Improvement Charges (LIC) are an important tool for encouraging uptake of energy efficiency upgrades. Homeowners receive a loan from municipalities, which is repaid alongside local taxes, called a local improvement charge. This financing structure is often referred to as Property Assessed Clean Energy (PACE). *Ontario Regulation 586/06 Local Improvement Charge* allows municipalities to undertake works that provide local benefits and recover the costs from benefitting properties.[24] Regulation 322/12 allowed such projects to be used for a wider range of uses, including home retrofits. The City of Toronto and City of Guelph have both developed PACE/LIC programs.

Local improvement charges reduce the upfront costs of retrofit activities, a considerable barrier for retrofit activities. The LIC charge is also tied to the property, which can be transferred to new owners in the event of property sale, addressing the split incentive issue so that those who benefit from the investment pay for the investment. While this can be a positive benefit, it may also have the unintended consequence of discouraging the purchase of homes that have a pre-existing loan attached to the property.[25] In Canadian examples of LIC programs, interest rates are 2%-3.5% on loan repayment, which is considered low cost capital.[26] LIC programs require startup funding for loans and to cover administration costs, which can be a barrier to uptake for municipalities.[27]

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[19] Wolfe, A., Hendrick, T. (2012). Homeowner decision making and behavior relating to deep home retrofits. Oak Ridge National Laboratory.
[20] Bardhan, A., Jafee, D., Kroll, C., Wallace, N. (2014). Energy efficiency retrofits for US Housing: Removing the bottlenecks. Regional Science an urban Economics, 47, 45-60.
[21] Frappe-Seneclauze, T., Heerema D., Wu, K. (2017). Deep emissions reduction in the existing building stock. The Pembina Institute.
[22] Energy Efficiency Alberta. Retrieved from: https://www.efficiencyalberta.ca
[23] GreenUp. (2016, April 8). Green Business Program will provide One-Stop-Shopping for Energy Efficiency. Retrieved from: https://www.greenup.on.ca/green-business-program-will-provide-one-stop-shopping-energy-efficiency
[24]O. Reg. 586/06: LOCAL IMPROVEMENT CHARGES - PRIORITY LIEN STATUS. https://www.ontario.ca/laws/regulation/060586
[25] City of Ottawa. (2014). Air Quality and Climate Change Action Plan, Appendix F.
[26] City of Toronto. Home energy Loan Program. Retrieved from: https://www.toronto.ca/services-payments/water-environment/environmental-grants-incentives-2/home-energy-loan-program-help
[27] City of Ottawa. (2014). Air Quality and Climate Change Action Plan, Appendix F.

On-bill Financing

On-bill financing programs for retrofits have a similar repayment schedule as LIC structures, except repayment occurs through monthly utility bills. On-bill financing ties retrofit activity to actual energy and cost reductions. In theory, on-bill financing aims to reach bill neutrality, where monthly costs are equal to the savings achieved through retrofits and there are little incurred costs to customers; in practice, bill neutrality is far from guaranteed.[28] Loans are transferable if the unit is sold. On-bill financing can better target rental units because the retrofit costs can be passed to the tenant through the utility bill if renters directly pay the utility, which is not always the case. Utilities need to provide upfront capital for project administration and initial loan funding.

There has been multiple successful on-bill financing for retrofit programs in Canada. Manitoba Hydro has provided $317M in loan support to 75,000 customers. A similar program has been used by Nova Scotia Power. Some jurisdictions have not found the same success, and have transitioned to third-party financing, including SaskPower and the City of Vancouver (provided through BC Hydro).[29]

Third-party financing

Both on-bill financing and local improvement charges present an alternative to loans from a traditional lending institution. In some cases, third-party financing can be advantageous, especially if an institution can provide low interest and long-term loans or bundle energy efficiency measures within a mortgage.[30] Third party loans are seen as a lower risk to utilities and local governments, both of which are institutions that are not traditionally designed to provide loans. Unfortunately, third-party lending may screen out applicants that are perceived unable to repay loans, which may overlap with properties that may benefit the most from a retrofit program. Furthermore, the disconnect between energy savings and loan costs may make it difficult for home owners to see the value and immediate savings.

Third-party financing program examples include VanCity Credit Union's Home Energy Loan, which provides a prime+1% loan to be repaid over 15 years.[31] The program is associated with BC Hydro's Home Energy Rebate Offer, presenting an interesting hybrid between commercial and utility-led lending. An example of a program currently available in Ottawa is Desjardins' Energy Efficiency Loan for businesses.[32]

Incentive Programs

Incentives are also frequently used to encourage efficiency upgrades. Incentives provide building owners non-repayable sums of money (directly or as a rebate) to purchase efficient appliances and products or to perform energy audits or recommissioning.

For the most part, the Government of Ontario has provided upfront capital to fund incentives through SaveOnEnergy, the IESO's energy conservation initiatives. Local utilities are responsible for administering IESO funding at a local scale. Table 2 describes available funding incentives in Ottawa. Many of the incentives targeted to businesses can be applied to both small and large buildings.

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[28] Bardhan, A., Jafee, D., Kroll, C., Wallace, N. (2014). Energy efficiency retrofits for US Housing: Removing the bottlenecks. Regional Science and Urban Economics, 47, 45-60.
[29] Natural Resources Canada. (2016). Financing Energy Efficiency Retrofits in the Built Environment. Energy and Mines Ministers' Conference.
[30] Ibid.
[31] VanCity. Home Energy Loan. Retrieved from: https://www.vancity.com/Loans/TypesOfLoans/HomeEnergyLoan
[32] Desjardins. Energy Efficiency Loan. Retrieved from: https://www.desjardins.com/ca/business/financing-credit/long-term-financing/energy-efficiency-loan/index.jsp

Table 2. Available incentives in the province for existing small buildings.

Program Name	Target	Provider	Description
Affordability Fund	Residential	Government of Ontario	Free installations of energy saving devices for low-income households.
Home Assistance Program	Residential	IESO, utilities and GreenSaver	Free energy assessment and upgrades to low-income households and tenants.
Home Winter Proofing Program	Residential	Enbridge, Inc	Attic insulation, programmable thermostat and draft proofing provided to customers under a specified income level or on federal assistance programs.
Home Energy Conservation Program	Residential	Enbridge, Inc with Union Gas	Up to $5,000 in rebates for efficiency upgrades including heat pumps, lighting and ventilation. Requires an energy audit.
Heating and Cooling Incentive Program	Residential	IESO via SaveonEnergy	Up to $850 for furnace and air conditioning upgrades; up to $4000 for installation of a heat pump.
Business Refrigeration Incentive	Business	IESO via SaveonEnergy	Up to $2,500 for refrigeration incentives.
Small Business Lighting Incentive Program	Business	IESO via SaveOnEnergy	Up to $2,000 for efficient lighting upgrades.
Retrofit program	Business	IESO via SaveOnEnergy	Range of funding options for retrofit activities.
Ontario Energy Audit Funding	Business	IESO via SaveOnEnergy	50% of the cost of an energy audit.
Existing Building Commissioning	Business	IESO via SaveOnEnergy	Funding for chilled water systems. Generally geared towards larger buildings, but could be applied to smaller buildings.
CMHC Green Home	Residential	CMHC	Rebate of up to 25% of CMHC mortgage for homeowners who intend to retrofit new home.

Incentives are often targeted to low-income households, including the Affordability Fund and the Home Assistance Program. These programs work directly to target energy poverty, with a focus on reducing energy bills for low income households.

Retrofit incentive programs increase uptake of efficiency measures. For example, In British Columbia, the Federal ecoENERGY Retrofit Program combined with the LiveSmart BC residential incentive program reach 1% of BC homes per year, with average emissions reductions of 26% per unit.[33] In Ontario, IESO programs corresponded to energy reductions of 2,810 GWh from 2015-2016.[34] Table 3 demonstrates participation from IESO SaveOnEnergy programming in 2016.

[33] Frappe-Seneclauze, T., Heerema D., Wu, K. (2017). Deep emissions reduction in the existing building stock. The Pembina Institute.
[34] IESO. (2016). Conservation Results Report.

Table 3. IESO Save on Energy program participation relevant to existing small buildings and energy savings in 2016.

	Energy Savings (GWh)	Program Costs ($M)	Incentive Costs ($M)	Participation
Residential Sector				
Coupons	428	10	31	17,053,287 products
Heating and Cooling Incentive	76	5	33	136,617 HVAC measures
Home Assistance	8	3	7	5,066 homes
peaksaver PLUS	150 MW DR	3	6	320,158 devices
Business Sector				
Audit Funding	3	2	1	213 projects
Retrofit	567	38	102	11,190 projects
Small Business Lighting	11	3	3	2,421 projects
Existing Building Commissioning	0	1	0	0 projects
Process and System Upgrades	12	5	17	5 projects
Energy Managers	13	1	3	69 projects

While program uptake shows positive momentum, current programs have not yet reached a scale that can meaningfully contribute to emissions reductions in the existing small buildings sector. The 76 GWh of energy savings through the Heating and Cooling Incentive, displayed in Table 3, corresponds to 0.23 PJ of energy savings. In comparison, the residential sector in Ontario used 281 PJ of energy for space heating in 2015.[35]

Some see the wide range of incentive programs as a potential barrier. Although considerable funding is provided, it is spread across various jurisdictions and targets different end uses, which can lead to piecemeal uptake of retrofits.[36]

[35] Office of Energy Efficiency. (2016). Table 2: Secondary Energy Use and GHG Emissions by End use. http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=CP&sector=res&juris=on&rn=2&page=0

[36] Sustainable Buildings Canada. (2016). Energiesprong Summary Report. Retrieved from: https://sbcanada.org/wp-content/uploads/2017/09/Energiesprong-Summary-Report.pdf

Aggregated Retrofit Programming

Scaling retrofits provides an opportunity to reach economies of scale by targeting multiple similar buildings in one retrofit.

Retrofit aggregation programs that follow the Energiesprong model are increasingly being pursued in Canada. The program was originally developed in the Netherlands and aggregates sufficient demand for retrofits to create a market demand for contractors, which can be quickly deployed using prefabricated components.

Natural Resources Canada is currently developing its Prefabricated Exterior Energy Retrofit (PEER) program. The goal of the program is to develop prefabricated building components for the residential building exteriors that can be easily installed on similar buildings. This often includes exterior cladding, switching the HVAC and other mechanical components, as well as the addition of rooftop solar. Prefabricated components reduce the cost and complexity of retrofits and can improve aesthetics.[37] Because the retrofits are externally applied, there is limited disruption to residents.

The PEER program is currently working to advance commercialization and examine costs of building components and program administration. Building associations, advocacy groups and housing associations have also showed interest in the program, including Sustainable Buildings Canada, which is spearheading the initiative in Canadian cities, including Ottawa.[38]

According to analysis by Sustainable Buildings Canada, aggregated retrofits could reduce total energy use by 50% using wall applications, with further energy reductions possible through switching HVAC systems.[39] Despite the potential benefits, aggregated retrofits are still cost prohibitive, with costs reaching approximately $144,000 per unit.[40] However, it is expected that costs will decrease as program uptake continues.

Aggregated retrofit models using pre-fabricated components are also currently targeting social and low-income housing, reducing energy spending and improving living conditions for residents.[41] Such programs work directly to tackle housing inequality and reduce energy poverty.

Retrofit requirements

In the United States, energy efficiency upgrades have been mandated through local government ordinances. For example, Boulder, Colorado's SmartRegs Ordinance requires that all rental properties meet a specified level of energy efficiency by the year 2019.[42] Although not geared to efficiency, upgrades to at-risk residential properties for seismic upgrades has been mandated in the City of Los Angeles and other cities in California. Mandatory programming can be politically risky but can influence uptake of efficiency upgrades. In Ontario, municipalities cannot pass by-laws that counteract or exceed the Ontario Building Code. However, the province is considering provisions for energy efficiency upgrades during renovations in the Ontario Building Code.[43] A key lever for encouraging retrofits in Ottawa would be through tiered building requirements similar to Toronto's Green Standard or BC's Step Code. Buildings that undergo renovations could be subject to mandatory requirements for energy efficiency and sustainable building design.

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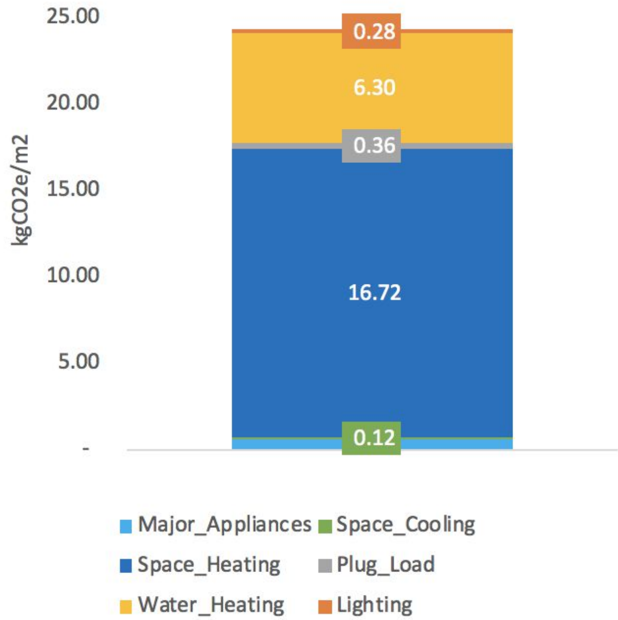
[37] Natural Resources Canada (2017). PEER Prefabricated Exterior Energy Retrofit.
[38] Ibid.
[39] Ibid.
[40] Ibid.
[41] The Pembina Institute. (2017). Affordable Housing Renewal: Retrofits at Scale.
[42] City of Boulder (2018). SmartRegs requires all licensed rental housing to meet a basic energy efficiency standard by Dec. 31, 2018. Retrieved from: https://bouldercolorado.gov/plan-develop/smartregs
[43] Government of Ontario (2017). Potential changes to Ontario's Building Code. http://cleanairpartnership.org/cac/wp-content/uploads/2017/09/MMA-Proposed-Building-Code-Energy-Efficiency-Requirements-for-Renovations.pdf

Fuel Switching

Deeper retrofits often target fuel switching to avoid energy use produced from emitting fuels such as natural gas, which is a critical component for emissions reductions in Ottawa. Propane and heating-oil are also emitting fuels in Ottawa but to a lesser extent. Natural gas is predominately used for space and water heating, which account for 94% of the GHG emissions from residential dwellings in Ottawa, as illustrated in Figure 9.

Figure 9. Average dwelling unit GHG intensity, by end use, 2016.[44]



A whole system retrofit aims to reduce the need for space and water heating through conservation measures aligned with the EnerPHit standard, but also to switch away from fossil fuel-based sources of energy. A typical pathway is to electrify heating using heat pumps, either ground source or air source to maximize the efficiency.

Policy Options for Existing Residential Buildings

Policy options are typically focused on increasing awareness and offer funding to encourage building owners to pursue energy efficiency upgrades. Such policies typically include incentives for low-flow toilets, renewable energy systems, heat pumps, building envelope upgrades, light bulb modernization, appliance upgrades, window upgrades, energy assessments, etc.

Energy Benchmarking

Energy Benchmarking refers to systematically tracking building energy use over time. This allows tracking energy reduction progress and enables comparisons between similar buildings. Greater awareness of a building's energy use, especially in relation to other buildings, can encourage property owners to take on energy efficiency and conservation work.

Generally, energy benchmarking programs are geared to large commercial, institutional or industrial buildings, although energy benchmarking principles can be applied to small residential buildings as well. Disclosure of energy use at the time of property sale is the primary benchmarking tool for

[44] Note that emissions from major appliances are hidden behind space cooling.

smaller buildings.[45] Energy disclosure provides incentive for buyers to purchase energy efficient homes or buildings by explicitly revealing operational costs of low efficiency systems. This can increase the market value of energy efficient homes, with one study estimating that energy disclosure of efficient buildings can increase the sale price by 3%.[46]

Energy benchmarking and disclosure programs can also improve the data available on energy use. Required disclosure of energy data can be analyzed in relation to retrofit activities, providing greater accuracy for property owners on the potential outcomes of retrofit activities.

Disclosure programs can include a required home energy rating system, disclosure of utility bills and disclosure of results from an energy audit.[47] Multiple cities in the United States have energy disclosure programs for residential buildings.[48] In Austin, Texas, the Energy Conservation Audit and Disclosure Ordinance requires that residential buildings older than ten years are audited with information disclosed prior to home sale, with non-compliance subject to a fine.[49] The City of Toronto and the City of Vancouver have energy benchmarking programs for large buildings, but there are no energy benchmarking programs for small buildings yet in Canada.

Announced under the Climate Change Action Plan, a residential energy disclosure program was considered in Ontario. Ontario's Home Energy Rating and Disclosure Program intended to make energy audit information mandatory during home sale and would provide funding for individuals to perform energy audits. The program has since been postponed.

Under Ontario's 2017 Long Term Energy Plan, a Green Button Program Regulation was moved forward. The proposed program would require utilities to provide customers with access to their individual energy use data by 2020.[50] Hydro Ottawa already provides Home Energy Reports, detailing monthly use summaries, a comparison of homes in the neighbourhood and tips to reduce energy.[51]

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[45] Frappe-Seneclauze, T., Heerema D., Wu, K. (2017). Deep emissions reduction in the existing building stock. The Pembina Institute.
[46] Naima Canada. (2017, November 2). Home Energy Rating and disclosure Guide. Retrieved from: http://www.naimacanada.ca/home-energy-rating-disclosure-guide
[47] ACEE. (2014). Residential Energy use disclosure: a guide for policymakers. https://aceee.org/files/pdf/toolkit/residential-energy-use-disclosure.pdf
[48] Ibid.
[49]Austin Energy. energy Conservation Audit and disclosure Ordinance. Retrieved from: https://austinenergy.com/ae/energy-efficiency/ecad-ordinance/energy-conservation-audit-and-disclosure-ordinance
[50] Loewen, E. (2018, May 27). introducing the Green Button: Empowering consumers through energy data. The Atmospheric Fund. http://taf.ca/introducing-green-button-empowering-consumers-energy-data
[51] Hydro Ottawa. Home Energy Reports. Retrieved from: https://hydroottawa.com/save-energy/monitor-consumption/home-energy-reports

Section 2: Growth Projections for Existing Residential Buildings

The following assumptions are applied to the existing building stock in three different scenarios, representing conservation, moderate and aggressive pathway uptake.

Table 4. Low carbon pathway action parameters.

Action	Conservative scenario	Moderate scenario	Aggressive scenario
Retrofit older homes (pre-1980).	1% of the existing building stock is voluntarily retrofitted to a performance level in compliance with the current building code.	Achieve thermal savings of 40%; electrical savings of 25%: scale up rate of retrofits exponentially between 2020 and 2050 to 68% of the dwellings by 2050.	Achieve thermal savings of 60%; electrical savings of 50%: scale up rate of retrofits exponentially between 2020 and 2050 to 98% of the dwellings by 2050.
Retrofit newer homes (post 1980).	1% of the building stock is retrofit each year in compliance with the current building code.	Achieve thermal savings of 30%; electrical savings of 20%: scale up rate of retrofits exponentially between 2020 and 2050 to 68% of the dwellings by 2050.	Achieve thermal savings of 50%; electrical savings of 40%: scale up rate of retrofits exponentially between 2020 and 2050 to 98% of the dwellings by 2050.
Retrofits for small commercial and office buildings	1% of the existing building stock is voluntarily retrofitted to a performance level in compliance with the current building code.	Achieve thermal savings of 30%; electrical savings of 20%: scale up rate of retrofits exponentially between 2020 and 2050 to 68% of the dwellings by 2050.	Achieve thermal savings of 50%; electrical savings of 40%: scale up rate of retrofits exponentially between 2020 and 2050 to 98% of the dwellings by 2050.
Fuel Switching	10% of buildings switch from natural gas, heating-oil, and propane to air source heat pumps by 2050; 2% of buildings switch to ground source heat pumps by 2050.	30% of buildings switch from natural gas, heating-oil, and propane to air source heat pumps by 2050; 10% of buildings switch to ground source heat pumps by 2050.	60% of buildings switch from natural gas, heating-oil, and propane to air source heat pumps by 2050; 30% of buildings switch to ground source heat pumps by 2050.

Methodology

The methodology for all of the building pathways (large existing, small existing, new large, new small) follows a similar modelling methodology. A summary is shown is below.

Energy and GHG emissions are derived from a series of connected stock and flow models, evolving on the basis of current and future geographic and technology decisions/assumptions. The model accounts for physical flows such as energy use as determined by stocks such as buildings and heating equipment.

CityInSight incorporates and adapts concepts from the system dynamics approach to complex systems analysis. For any given year within its time horizon, CityInSight traces the flows and transformations of energy from sources through energy carriers such as gasoline, electricity, and hydrogen to end uses such as personal vehicle use and space heating to energy costs and to GHG emissions. An energy balance is achieved by accounting for efficiencies, conservation rates, and trade and losses at each stage in the journey from source to end use.

Residential buildings are allocated to a CityInSight zone based on its parcel location. Each building is classified by archetype, using a detailed set of 30+ building archetypes capturing footprint, height and type (single, double, row, high rise apartment, low rise apartment), in addition to year of construction. This enables a "box" model of buildings and the estimation of surface area. With this "box" model methodology, CityInSight models residential buildings as rectangular boxes with fixed aspect ratios without individual components such as doors, windows, crawl spaces, or foundations. CityInSight applies an average thermal envelope performance (thermal transmittance or U-value) to the building surface area and degree-days to calculate space conditioning energy demand independent of any particular space heating or cooling technology and fuel.

The number of dwelling units drives stock levels of key energy service technologies such as heating systems, air conditioners and water heaters. These stocks are modelled with a stock-turnover approach capturing equipment age, retirements, and additions - exposing opportunities for efficiency gains and fuel switching, but also showing the limits to the rate of new technology adoption and the effects of lock in. The energy service stocks are allocated to the energy service demand.

Residential building archetypes are also characterized by number of contained dwelling units, allowing the model to capture the energy effects of shared walls but also the urban form and transportation implications of population density.

The model multiplies the residential building surface area by an estimated thermal transmittance (heat flow per unit surface area per degree day) and the number of degree days to derive the energy transferred out of the building during winter months and into the building during summer months. The energy transferred through the building envelope, the solar gain through the building windows, and the casual heat gains from equipment inside the building constitute the space conditioning load to be provided by the heat systems and the air conditioning. The initial thermal transmittance estimate is a provincial average by dwelling type from the Canadian Energy System Simulator (CanESS), a model of the Canadian energy system.

Starting values for output energy intensities and equipment efficiencies for other residential and non-residential end uses are also provincial averages from CanESS. All parameter estimates are further adjusted during the calibration process.

Using assumptions for thermal envelope performance for each building type, the model calculates total energy demand for all buildings, independent of any particular space heating or cooling technology and fuel. Space conditioning demand is allocated to different fuel types by specified fuel shares. Efficiency by fuel type is applied to derive input energy use for space conditioning.

Total buildings energy demand, derived from the buildings box model, is calibrated against observed utility data for electricity and natural gas, provided by utilities. In the calibration process, fuel shares are adjusted to meet the ratio of electricity to natural gas energy use in a given sector. The thermal transmittance for residential building space conditioning and output energy use intensities for non-residential buildings and non-space conditioning residential end uses are then adjusted until the model estimate of electricity and natural gas use matches the observed data.

Steps in developing the scenarios for existing small buildings are as follows:

1. Place existing buildings in space in the base year, disaggregated by geographic zone, year building and building type.
2. Simulate additions to and removals from the building stock over time, as required by the population and employment projections.
3. Derive energy use in buildings according to the thermal envelope profile, energy-using stocks (appliances, equipment).
4. Disaggregate energy use by end-use and fuel type as well as building categories.
5. Calibrate projected energy use with observed energy consumption as provided by the energy utilities.
6. Apply energy use intensity targets incrementally to the existing building stock, targeting specific criteria such as age, size, use and location of buildings to represent retrofits.
7. Analyse the cost of the retrofits that achieve the energy use intensity targets.

Constraints

Heritage building status presents a minor barrier to retrofit upgrades. Under the Ontario Heritage Act, the City of Ottawa has influence over the preservation of buildings of cultural, architectural and stylistic merit. There are approximately 900 properties on Ottawa's heritage register.[52] While there are no demolition restrictions on these properties, building owners must notify the City for negotiation of building demolition or upgrades. There are also concerns that retrofits can cause a loss of building character. Programs specifically geared to heritage buildings to maintain building heritage character is a possible solution, similar to the Vancouver Heritage Foundation's Heritage Energy Retrofit Grant.[53]

In order to provide retrofits at the scale that will yield energy reductions in the City, there must be a construction and retrofit industry available to do the work. Inconsistent introduction and removal of incentives provided by higher levels of government creates instability in market demand for retrofits, and therefore is seen as risky for a contracting business to pursue training in building efficiency.[54]

There is also a lack of understanding and practical examples about how to achieve deep GHG emissions reductions and energy savings through retrofits. Initial pilot projects and research is required to support the development of retrofit pathways that are aligned with the City of Ottawa's GHG reduction targets.

Uptake of retrofits is also limited in rental housing, as most funding structures do not align benefits to landlords, who are ultimately responsible for retrofit activities. For example, LIC and third-party loan structures reduce energy bill costs, but may increase property taxes. These retrofit programs are limited in rental housing, because energy bills are frequently paid by tenants, while property taxes are covered by the property owner; this provides less incentive for landlords to take up retrofit activities because benefits are ultimately experienced by tenants. On-bill financing theoretically reduces this issue as repayment is the responsibility of the utility ratepayer, however, there is still a disconnect between who is responsible for paying for retrofits. The City of Vancouver's Green Landlord Program has examined solutions to the disconnect between landlord/tenant benefits, by providing guidance and support to landlords, and leveraging potential utility incentives.[55]

There are also behavioural limitations to retrofit uptake. In the case of retrofits, despite being presented with potential cost savings, rebates and other policy encouragements, homeowners may still choose not to perform efficiency upgrades for various reasons, including upfront capital, a lack of interest or other competing priorities. Similarly, behavioural changes to everyday activities for energy conservation is also not straightforward. Policies to encourage energy efficiency are limited because of uncertainties on consumer energy use behaviour.[56] Greater availability of real-time energy data attempts to overcome behavioural barriers by providing individuals with data to make rational decisions related to energy use.

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[52] City of Ottawa. Heritage Conservation Overview. Retrieved from: https://ottawa.ca/en/city-hall/planning-and-development/heritage-conservation#overview
[53] Vancouver Heritage Foundation. Heritage Energy Retrofit Grant. Retrieved from: http://www.vancouverheritagefoundation.org/get-a-grant/heritage-energy-retrofit-grant/
[54] Frappe-Seneclauze, T., Heerema D., Wu, K. (2017). Deep emissions reduction in the existing building stock. The Pembina Institute.
[55] City of Vancouver. (2016). Building Energy Retrofit Fund: Accelerating the Implementation of the Energy Retrofit Strategy for Existing Buildings. Administrative Report RR-1c.
[56] Bardhan, A., Jafee, D., Kroll, C., Wallace, N. (2014). Energy efficiency retrofits for US Housing: Removing the bottlenecks. Regional Science and Urban Economics, 47, 45-60.

Uptake projections

The following tables detail the energy use and emissions reductions based on the actions and assumptions described in this pathway paper.

Conservative Scenario

Table 5. Energy and GHG emissions results of the conservative existing buildings pathway.

Action		Cumulative emissions reductions 2018-2050 (kt CO2eq)	Emissions reductions 2050 (kt CO2eq)	Cumulative energy reductions 2018-2050 (TJ)	Energy reductions 2050 (TJ)
Retrofit older homes (pre-1980)	1% of the building stock is retrofit each year in compliance with the current building code	1,897	112	41,983	2,540
Retrofit newer homes (post-1980)	1% of the building stock is retrofitted each year in compliance with the current building code	1,120	72	25,240	1,712

Moderate Scenario

Table 6. Energy and GHG emissions results of the moderate existing buildings pathway.

Action		Cumulative emissions reductions 2018-2050 (kt CO2eq)	Emissions reductions 2050 (kt CO2eq)	Cumulative energy reductions 2018-2050 (TJ)	Energy reductions 2050 (TJ)
Retrofit older homes (pre-1980)	Scale up rate of retrofits to 68% of all dwellings by 2050; achieve thermal savings of 40%; electrical savings of 25%	1,898	148	44266	3,442
Retrofit newer homes (post-1980)	Scale up rate of retrofits to 68% of all dwellings by 2050; achieve thermal savings of 30%; electrical savings of 20%	1,457	113	35,333	2,749

Aggressive Scenario

Table 7. Energy and GHG emissions results of the aggressive existing buildings pathway.

Action		Cumulative emissions reductions 2018-2050 (kt CO2eq)	Emissions reductions 2050 (kt CO2eq)	Cumulative energy reductions 2018-2050 (TJ)	Energy reductions 2050 (TJ)
Retrofit older homes (pre-1980)	Scale up rate of retrofits to 98% of all dwellings by 2050; achieve thermal savings of 60%; electrical savings of 50%	3,637	313	86,476	7,477
Retrofit newer homes (post-1980)	Scale up rate of retrofits to 98% of all dwellings by 2050; achieve thermal savings of 50%; electrical savings of 40%	3,708	317	91,974	7,921

Opportunities to advance this pathway

To move forward with reducing energy use and emissions from large existing buildings, the City of Ottawa and its partners may consider the following actions:

1. Undertake pilot projects on deep retrofits for small buildings in coordination with colleges, NRCan, universities and industry.
2. Develop a whole systems approach to a program for retrofits including audits, financing and implementation that can support building owners or homeowners in undertaking projects with minimal logistical considerations.
3. Develop a retrofitting strategy based on prioritizing of measures and the avoidance of lock-in
4. Ensure that non-energy related renovations oblige a property owner to undertake energy and emissions retrofits
5. Ensure retrofits integrate fuel switching to electricity and renewable energy installation.
6. Provide incentives for deep retrofits such as expedited building approvals or financial contributions in coordination with utilities.

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Pathway Study on New Non-Residential Buildings in Ottawa

Presented to:
The City of Ottawa
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Ottawa, ON K1P 1J1

In relation to:
The City of Ottawa's Energy Evolution Strategy (Phase 2)

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January 2019

Contents

Executive Summary

This pathway study examines new non-residential buildings in the City of Ottawa. The non-residential sector includes institutional, commercial, industrial, and mixed-use buildings, and the buildings typically have large floor space, requiring more complex systems for space heating and cooling, lighting, or other processes related to commercial uses. The pathway will detail strategies for newly constructed non-residential to meet emissions reduction goals in the Ottawa's Energy Evolution Strategy.Buildings have a long life cycle of 40 to 80 years or more, which locks in building energy consumption patterns for decades. Ensuring that new buildings have low operational energy use is important for reducing future emissions. Emissions from new buildings is dependent on a variety of factors. Insulation, solar insolation and other aspects of urban form influence the energy required for building operation. Occupant density can also reduce energy use per capita from buildings.

Green building standards requiring new buildings to reach specified energy targets and include other sustainable design features such as green roofs and connections to district energy systems are a key tool for influencing energy efficiency in new buildings. The impacts of urban form on building energy use can be assessed on individual buildings, with flexibility provided to individual building designers.

This pathway considers three scenarios for new large buildings: conservative, moderate and aggressive. The conservative scenario represents a business as planned outlook, moderate reflects application of a Green Standard on a delayed time frame, while the aggressive scenario considers immediate uptake of a Green Standard. Each scenario achieves a different degree of emissions reductions.

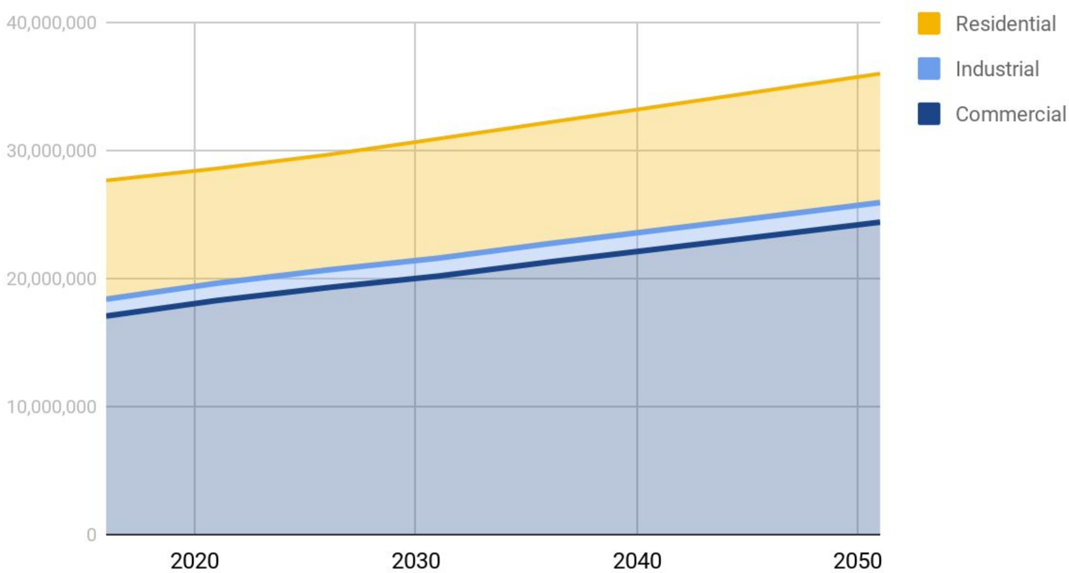
Section 1: Present Assessment of New Large Buildings

Pathway Description

Buildings lock in patterns of energy use and GHG emissions for many years due to their long life cycle. It is easier and more cost-effective to build a new zero energy building than it is to retrofit an existing building to achieve the high levels of energy performance that will enable deep GHG emissions reductions. In a context in which the entire building stock needs to be as close to net zero as possible, the more quickly new buildings can increase their performance, the lower the burden on society to undertake retrofits. Two leading jurisdictions, the City of Vancouver[1] and the City of Toronto,[2] have recently identified detailed pathways and policies to ensure new buildings achieve net zero emissions or energy. These two approaches provide the basis for a pathway for new non-residential buildings for the City of Ottawa.

Ottawa's population is set to grow by 372,877 people by 2051, accompanied by an estimated 8 million m² of new construction for residential and non-residential buildings by 2050, as illustrated in Figure 1.[3] The commercial sector is projected to lead new development through this time period.

Figure 1: Floor space of new large buildings between 2018 and 2050.



Buildings last 40 to 80 years or more. Ottawa's existing building stock will have a more significant impact on the overall trajectory of energy and GHG emissions than its new buildings over the next 32 years. Initial construction represents the most significant investment over the course of the building's life and is the primary opportunity to maximize energy efficiency through building and systems design.

[1] City of Vancouver. (2016). Zero emissions building plan. Retrieved from https://vancouver.ca/files/cov/zero-emissions-building-plan.pdf
[2] Integral Group, Morrison Hershfield, & Provident. (2017). City of Toronto Zero Emissions Buildings Framework (p. 118).
[3] Population projections provided by the city of Ottawa towards 2031, and projected using CityInSight Modelling towards 2050.

Pathway Boundaries

This pathway identifies and contextualizes low carbon pathways for new non-residential buildings inclusive of institutional, commercial, mixed-use, and industrial buildings. Table 1 identifies the primary action reviewed in this paper and its influence on emissions in new large buildings, in the Ottawa context.

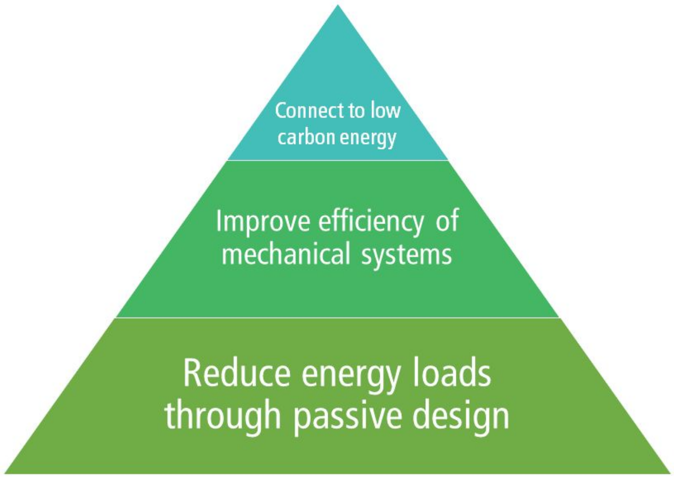
Table 1. Parameter and definition for new large buildings pathways study.

Parameter	Definition
Green Standard	Building design requirement structure that is tiered based on performance. The lowest tier is mandatory. Higher tiers are voluntary but are subject to reductions to development charges. A green standard becomes more rigorous over time.

There is increasing consensus around performance-based frameworks for new construction, which identify energy-use intensity and GHG intensity targets. This approach maintains flexibility for designers and adaptability to local contexts, whereas some certification building standards are highly prescriptive and lack a focus on energy and emissions performance. Performance-based pathways can incorporate the influences described below.

In designing for high performance, passive design strategies are essential in order to minimize costly mechanical systems and even more costly renewable energy technologies. Figure 2 illustrates the hierarchy of the design approach.

Figure 2: Hierarchy of building design principles.[4]



[4] City of Toronto. (2017). The City of Toronto zero emissions buildings framework.

Urban form refers to individual building morphology and interaction with surrounding structures. It plays a role in building energy consumption in two key ways: heat transfer and solar access.[5] At the individual building scale, building morphology refers to characteristics such as: size and shape of a building, surface to volume ratio (S:V), plan depth, building height, and façade design characteristics (glazing ratios and distribution, building orientation, and envelope performance). At the block or neighbourhood scale, urban structure refers to the arrangement and spacing of buildings, streets, and open space, which include measures such as density (floor area ratio or FAR), land coverage, and spacing between buildings.

Assessing energy and emissions at the neighbourhood scale also captures the cumulative impact of the relationships between multiple buildings (building massing, heights, arrangements and spacing), and their impact on energy consumption. The impacts of urban form on energy at the neighbourhood scale are less frequently considered and have less developed methods available for modelling in comparison with those available at the individual building scale.

Other considerations include the embodied energy of buildings related to construction and component manufacturing, as well as the impact of the location of buildings. These considerations are not included in the modelling scope.

Background Information

Building Heating and Cooling

Heating and cooling energy density are a function of the characteristics and use of the built environment. While these characteristics represent design and planning decisions, they in turn are driven by the level of economic activity, fuel prices, climate and other variables.[6] The growing focus on the relationship between the built environment and energy demand is highlighted in Chapter 8 of the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report which explicitly recognizes the extent of urbanization anticipated and the idea that urbanization can itself be a greenhouse gas emissions mitigation strategy that integrates multiple sectors.[7] The IPCC chapter specifically references the urban form characteristics of density, land-use mix, connectivity, and accessibility as drivers of energy and GHG emissions. This section narrows to consider the factors influencing energy consumption associated with heating and cooling future buildings.

Data on energy consumption in buildings is currently measured by the utilities that provide energy to these buildings and is reflected in a utility bill. This data provides a reliable and accurate basis from which to understand the energy demands of the existing building stock and to model the energy demand of the future building stock.

Energy consumption in buildings is expressed using energy intensity factors, as $GJ/m^2/yr$ or $eKWh/m^2/yr$. Figure 3 illustrates the factors that affect energy consumption in buildings; these are the factors that will influence the heating and cooling energy density.

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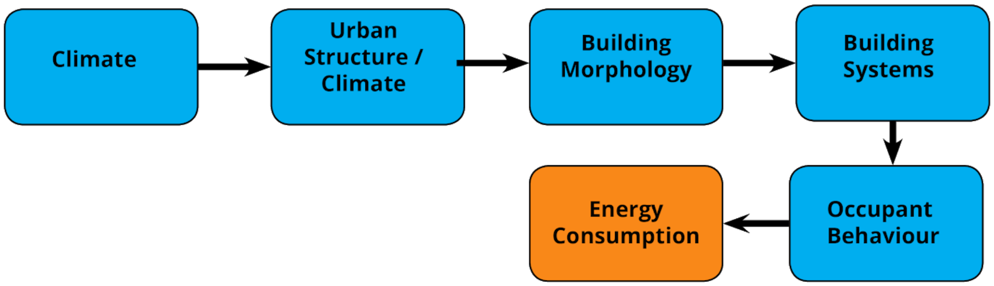
[5] Miller, N. (2013). Urban form and building energy: Quantifying relationships using a multi-scale approach. University of British Columbia, Vancouver.
[6] Creutzig, F., Baiocchi, G., Bierkandt, R., Pichler, P.-P., & Seto, K. C. (2015). Global typology of urban energy use and potentials for an urbanization mitigation wedge. *Proceedings of the National Academy of Sciences*, *112*(20), 6283–6288. https://doi.org/10.1073/pnas.1315545112
[7] Seto, K. C., Dhakal, S., Bigio, A., Blanco, H., Delgado, G. C., Dewar, D., ... others. (2014). Human settlements, infrastructure and spatial planning. Retrieved from http://pure.iiasa.ac.at/11114/

Figure 3: Factors influencing energy intensity in buildings. [8]



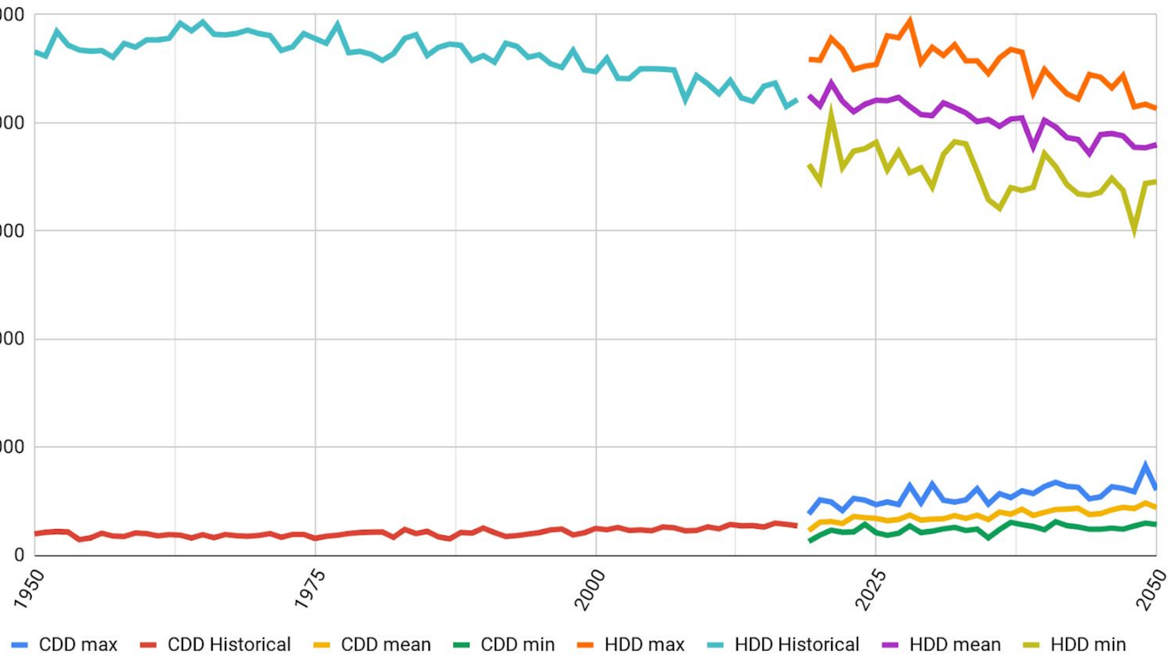
The Effect of Climate

Energy demand is climate and context specific, and any analysis of energy systems needs to consider *all* greenhouse gas emissions associated with the system. For example, buildings in warmer climates can have lower operational energy use due to the reduction in heating energy required. However, this does not necessarily imply that buildings in warmer climates use less energy overall, as warmer climates may result in increases in energy demand for mechanical cooling. The most common working fluids in mechanical cooling systems on the market today are hydrofluorocarbons (HFCs), which are greenhouse gases with a high global warming potential thousands of times more potent than carbon dioxide. The mechanical cooling load is also dependent upon building design and whether non-mechanical cooling methods, such as operable windows, are implemented. Therefore, climate has a significant impact on heating and cooling energy consumption, and the extent of this influence is determined by the way in which the built environment responds to the climate, through design, or the lack thereof.

In Ottawa, heating degree days (HDD) are projected to decline by 10% by 2050 over 2018, with cooling degree days (CDD) increasing by 60% over the same period (Figure 4). This has potential implications in heating and cooling requirements for buildings in Ottawa, with potential reductions in natural gas requirements for heating in the winter, and increasing electricity loads for cooling in the summer.

[8] Adapted from: Ratti, C., Baker, N., & Steemers, K. (2005). Energy consumption and urban texture. *Energy and Buildings*, *37*(7), 762–776; Salat, S. (2009). Energy loads, CO2 emissions and building stocks: morphologies, typologies, energy systems and behaviour. Building Research & Information, 37(5–6), 598–609; Miller, N. (2013). Urban form and building energy: Quantifying relationships using a multi-scale approach. University of British Columbia, Vancouver.

Figure 4: HDD and CDD projections for the City of Ottawa.[9]



Building Density

Density is a measure of the concentration of development (residential, commercial, industrial, etc.) per unit of land. Density is measured in a number of ways including people per hectare/acre, dwelling units per hectare/acre (for residential), and floor space ratio (FSR) or FAR. FSR and FAR are a measurement of the ratio of a building's floor area to the area of the lot on which the building is built.[10]

As density increases, total energy demand increases (i.e. the energy intensity factor is applied across a greater floor area). However, buildings typically consume less energy per capita or per area basis as density increases.[11] That is, energy intensity factors decrease as building density increases. Shared walls and floors/ceilings and shared building mechanical systems contribute to lower heating and cooling loads. Annual heating and cooling energy per square metre for apartments can be very similar to those for detached houses.[12] However, when comparing energy per person (by considering people per unit), the energy usage for apartments is significantly lower than for detached houses, as the occupancy per square meter is higher for apartments than for detached houses.

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[9] Prairie Climate Centre (2018). The Climate Atlas. Retrieved from: https://climateatlas.ca/data/city/459/hdd_2060_85

[10] Senbel, M, Church, S., Bett, E., Maghsoudi, R., & Zhang, K. (2010). The relationship between urban form & GHG emissions: A primer for decision makers. Urban Design Lab.

[11] Ratti, C., Baker, N., & Steemers, K. (2005). Energy consumption and urban texture. *Energy and Buildings*, *37*(7), 762–776. https://doi.org/10.1016/j.enbuild.2004.10.010

[12] Newton, P. W., Tucker, S. N., & Ambrose, M. D. (2000). Housing form, energy use and greenhouse gas emissions. Retrieved from http://researchbank.swinburne.edu.au/vital/access/manager/Repository/swin:8196

Compact urban form also contributes to improved health outcomes. In the past five to ten years there has been an explosion of literature on this relationship. Higher density is associated with higher levels of active transportation,[13] which in turn translates into improved health outcomes with respect to heart disease, type 2 diabetes, colon cancer, breast cancer, and mortality.[14]

Municipalities also provide services such fire as protection, policing, recreation, schools and transit, all of which are significantly impacted by the spatial distribution of buildings in a city. The City of Calgary found in an analysis of alternative growth scenarios that savings of 33% or $11 billion over 60 years could be achieved in operations and maintenance through compact growth.[15]

Building Envelopes

The building envelope (i.e. the physical separator between a conditioned indoor space and unconditioned outdoor space) and its performance have a significant impact on building energy consumption. As the majority of energy consumed in buildings is for space heating and cooling, heat transfer between interior and exterior space determines the level of energy required in a building to maintain comfortable levels of heating and cooling. Improving the thermal performance level of a dwelling can have a dramatic effect on its heating and cooling energy consumption. In general, energy use decreases as thermal performance increases. However, results also show that as envelope performance increases in certain cases, heating demand decreases while cooling demand increases.[16] This is in part due to other factors such as glazing ratio, building compactness and local shading, which are discussed further in this section.

Vertical Surface Area to Floor Area Ratio

A building's compactness refers to the surface-to-volume ratio of a building, or the ratio between total building surface area and total enclosed building volume. In general, as building density increases (and building height increases), more building volume is enclosed by building surface, resulting in a lower surface-to-volume ratio, and a more compact building. The predominant effect of compactness is reducing heat transfer, as more compact building shapes enclose more building volume with less surface area through which heat can escape. Analysis for the BC Step Code compared the energy performance of three buildings which were identical except for their shape, which was classified according to the vertical surface area to floor area ratio (VFAR). Figure 5 illustrates the VFAR for different configurations of buildings, while Figure 6 shows the impact of VFAR on energy performance for different Canadian cities. Energy performance is described by energy use intensity (EUI), a measure of energy per unit area, and by thermal energy demand intensity (TEDI), which describes thermal energy requirements for a building per unit area basis. Articulated and narrow building shapes result in a higher VFAR, which results in greater thermal energy loss through exterior walls and increases overall thermal energy demand.

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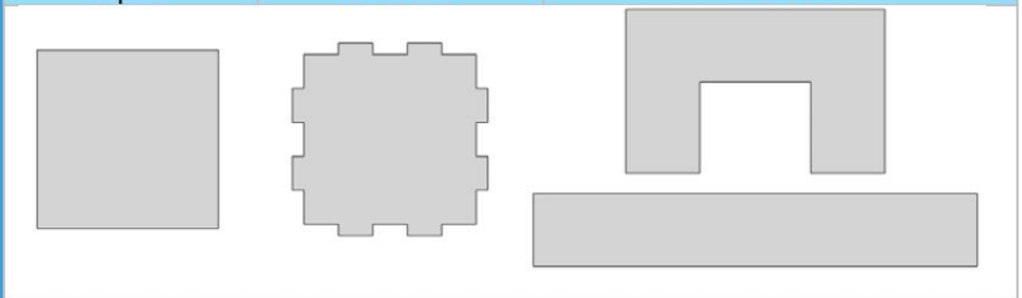
[13] Sallis, J. F., Cerin, E., Conway, T. L., Adams, M. A., Frank, L. D., Pratt, M., ... Owen, N. (2016). Physical activity in relation to urban environments in 14 cities worldwide: a cross-sectional study. The Lancet, 387(10034), 2207–2217. https://doi.org/10.1016/S0140-6736(15)01284-2

[14] Hankey, S., Marshall, J. D., & Brauer, M. (2011). Health Impacts of the Built Environment: Within-Urban Variability in Physical Inactivity, Air Pollution, and Ischemic Heart Disease Mortality. Environmental Health Perspectives, 120(2), 247–253. https://doi.org/10.1289/ehp.1103806

[15] IBI Group. (2009). The implications of alternative growth patterns on infrastructure costs. City of Calgary.

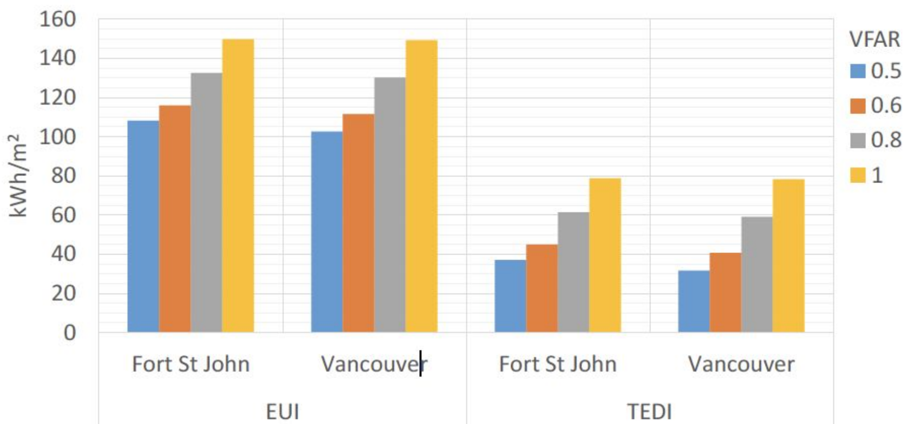
[16] Miller, N. (2013). Urban form and building energy: Quantifying relationships using a multi-scale approach. University of British Columbia, Vancouver.

Figure 5: Example of the influence of building shape on VFAR.[17]



Floor Plate Size	Building Shapes		
	Square	Articulated	Narrow
$600m^2$	0.49 VFAR	0.59 VFAR	0.7 VFAR
$400m^2$	0.6 VFAR	0.72 VFAR	0.86 VFAR

Figure 6: Example of the influence of the VFAR on EUI.[18]



Glazing Ratio

Glazing ratio is the ratio between total glazing area and total building area. Heat loss through glazed surfaces is higher than typical wall assemblies, and as such is a significant factor in overall envelope performance and building energy demand. In general, higher glazing ratios result in higher heating and cooling demand, counteracting much of the benefit of efficient surface-to-volume ratios. During cold weather, heating demand increases with increased glazing due to loss of heat through the less thermally resistive glazing components of the building envelope. However, increased glazing allows for passive solar heating opportunities, where heating demand is decreased as passive zones (areas adjacent to glazing) experience heat gain from sunlight. The loss of heat, however, generally outweighs passive heating effects during cold weather. In contrast, cooling demand primarily increases with increased glazing due to the increase in solar gains during warm weather. Buildings with excessive glazing ratios and untreated façades (symptomatic of high-rise buildings) make them particularly vulnerable to overheating during the summer and to heat losses during the winter.

[17] Integral Group. (2017). Energy step code: 2017 metrics research. BC Housing.
[18] Ibid.

Building Orientation

A building's orientation, and the distribution of glazing, relative to the sun's position, also impacts a building's opportunities for passive heating. For space heating, glazing oriented to the east and south (for buildings in the northern hemisphere) provides the most useful gains. In comparison, western orientations provide solar gains late in the day when temperatures are at a maximum and buildings are already heated.[19]

Solar access is influenced primarily by building spacing and arrangements, which are dependent upon a number of urban pattern elements such as street widths, parcel size, building setbacks, building heights, and the distribution of open spaces. A measure of building spacing and arrangement is the urban horizon angle (UHA). The UHA is the average angle of elevation of surrounding buildings from the centre of a given façade and is affected by the height of and distance between structures. The UHA accounts for building shading and significantly affect solar access; particularly in the winter when the sun is lower in the sky.[20]

While any findings are context and climate specific, one analysis indicated that the UHA can affect heating energy demand by as much as 30%, cooling demand by 20%, and lighting demand by 150%, with the greatest impacts occurring for south-facing façades.[21] In general, higher-density development provides the benefit of reduced heating demand through more compact building shapes and more efficient use of floor area (e.g. smaller residential units). However, several key urban form factors tied to increased density also work against heating demand benefits, such as high glazing ratios, high-rise buildings with lower envelope performance requirements, and increased shading effects due to high UHAs. An analysis completed by SSG for Waterfront Toronto found that by reorienting the buildings in a neighbourhood, energy savings of nearly 20% could be achieved through additional solar gain, if the buildings were designed to be able to capture the solar energy.[22]

Focus on Thermal Energy Needs

The operational energy consumed in buildings is predominantly used in space heating and cooling, and in running appliances, including domestic hot water and lighting. Energy consumption changes for different building uses or activities. In general, residential dwellings are dominated by space heating, while commercial buildings have significantly larger requirements for space cooling and lighting. Commercial buildings also consume more energy per square metre than both residential and industrial buildings.[23]

Different building-use activities require different types of heating and cooling systems and equipment, lighting and hot water systems, with large variations in capacity and efficiency. In general, as systems and equipment efficiency decreases, energy demand increases. Also, buildings containing different activities do not use energy at the same rate and at the same time of day. In general, commercial and industrial uses consume more energy during working hours, whereas residential energy consumption peaks in the morning and evening, before and after regular working hours, respectively.

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[19] Baker, N., & Steemers, K. (2000). Energy and environment in architecture: A technical design guide. E & FN Spon.
[20] Ratti, C., Baker, N., & Steemers, K. (2005). Energy consumption and urban texture. *Energy and Buildings*, *37*(7), 762–776. https://doi.org/10.1016/j.enbuild.2004.10.010
[21] Steemers, K. (2003). Energy and the city: density, buildings and transport. Energy and Buildings, 35(1), 3–14. https://doi.org/10.1016/S0378-7788(02)00075-0
[22] SSG. (2016). Waterfront Toronto Villiers Island precinct plan climate positive assessment report.
[23] Doherty, M., Nakanishi, H., Bai, X., Meyers, J., & others. (2009). Relationships between form, morphology, density and energy in urban environments. GEA Background Paper. Retrieved from http://www.academia.edu/download/32180219/GEA_Energy_Density_Working_Paper_031009.pdf

Heat Island Effect

Many urban areas are subject to the urban heat island (UHI) effect. Increased densities are generally accompanied by increases in built materials and paved areas and decreases in natural land cover (e.g. vegetation and bare soil). These conditions exacerbate UHI, resulting in higher temperatures in denser city centres, which can lead to increased cooling demand.[24] Vegetation can play a significant role in regulating the urban microclimate through solar absorption and the cooling effects provided by shade and evapotranspiration. Interestingly, UHI effects may also reduce heating requirements in the winter.[25] In Ottawa, this can potentially equate to reduced heating requirements. Vegetation may therefore have more relevance to stormwater, noise and aesthetics over emissions reductions related to heat.

Occupant Behaviour

Occupant behaviour affects building energy use directly and indirectly through various activities including opening/closing windows, turning on/off or dimming lights, turning on/off equipment and electronics, turning on/off heating, ventilation and air-conditioning (HVAC) systems, and setting indoor thermal, acoustic and visual comfort criteria.[26] There are certain occupant characteristics and economic factors that can lead to increases in energy demand, such as increasing household income (related to larger residential homes and increasing area per person), uptake of more electronic and consumer goods due to declining prices, and, where applicable, low energy prices.[27]

Occupant behaviour is one of the most significant sources of uncertainty in the prediction of building energy use by simulation programs due to the complexity and inherent uncertainty of occupant behaviour. The effect can vary energy consumption by a factor of two between buildings, even among buildings with comparatively similar functions.[28] While some authors theorize that occupants could be more likely to adopt energy efficient behaviour if they live or work in an energy efficient building and are aware of its efficiency measures, others suggest that if occupants are aware that the building they occupy is very well insulated, they might feel less incentivized to monitor their heating consumption.[29]

Embodied Energy

In addition to the energy and GHG emissions that result from the operation of a building, there are also GHG emissions and energy use that occur as a result from building construction, known as embodied energy. Embodied energy can be further divided into three categories, namely, material manufacturing (including raw material acquisition, transportation and manufacturing), transportation to site and on-site construction. As building density increases and more square footage is constructed, more building materials are used, and the total embodied energy increases.

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[24] Doherty, M., Nakanishi, H., Bai, X., Meyers, J., & others. (2009). Relationships between form, morphology, density and energy in urban environments. GEA Background Paper. Retrieved from http://www.academia.edu/download/32180219/GEA_Energy_Density_Working_Paper_031009.pdf

[25] Sharlach, M. 92018). Cold wave reveals potential benefits of urban heat islands. Princeton University. Retrieved from: https://engineering.princeton.edu/news/2018/07/23/cold-wave-reveals-potential-benefits-urban-heat-islands

[26] Hong, T. (2014). Occupant behavior: impact on energy use of private offices. In ASim 2012-1st Asia conference of International Building Performance Simulation Association., Shanghai, China, 11/25/12-11/27/12. Retrieved from https://escholarship.org/uc/item/6jp5w8kn.pdf

[27] Gray, R., & Gleeson, B. (2007). Energy demands of urban living: what role for planning. In *Proceedings of 3rd National Conference on the State of Australian Cities*. Retrieved from http://soac.fbe.unsw.edu.au/2007/SOAC/energydemandsofurbanliving.pdf

[28] Ratti, C., Raydan, D., & Steemers, K. (2003). Building form and environmental performance: archetypes, analysis and an arid climate. Energy and Buildings, 35(1), 49–59.

[29] Salat, S. (2009). Energy loads, CO2 emissions and building stocks: morphologies, typologies, energy systems and behaviour. *Building Research & Information*, *37*(5–6), 598–609. https://doi.org/10.1080/09613210903162126

As building density increases, area per person tends to decrease, and embodied energy of built area decreases per capita.[30] It could similarly be argued that construction of a denser built environment could result in lower transportation and on-site construction energy per capita, as time and materials are focused at a centralized site over a shorter period of time, in comparison to decentralized low-density construction.

Building lifetime or durability is also important to consider. Initial embodied energy accounts for only the beginning of a building's life. The longer the building stands, the higher the benefit of that embodied energy over time. Over a 40 year life span, embodied energy can represent up to 15% of a buildings energy, while operational energy is closer to 75%.[31] At this time, embodied energy is beyond the modelling scope. As operational energy use declines with increasing deployment of net zero buildings, embodied energy will become an increasingly important contributor to emissions. Embodied energy is being increasingly considered in building policy, described in Table 2.

Table 2: Embodied energy and emissions policies in Canada.[32]

Policy	Requirement
Vancouver green buildings policy for rezoning	Developers seeking a rezoning application need to comply with one of two stringent sustainability requirements. One option includes requirement for whole-building embodied emissions reporting.
LEED™	The most recent version of the influential LEED Building Design and Construction (v4) green building rating system includes whole building LCA-optimization as a strategy for the first time. This includes meeting a 10% reduction in embodied emissions from a project-specific baseline.
Zero carbon building standard	The Canada Green Building Council (CaGBC)'s new zero carbon building standard includes a requirement to report embodied emissions.
Public Services & Procurement Canada	PSPC requires whole-building LCA for its new building projects, however it is unclear whether this requirement is typically followed.
Quebec's Wood Charter	Quebec requires a comparative analysis of GHG emissions for structural materials in provincially-funded new building projects.

Building Element Combinations

While increasing compactness and building density generally reduces heat loss, increasing these characteristics does not guarantee overall building energy reductions. The trend for increased glazing as building density increases can counteract some of the thermal performance benefits of more efficient surface-to-volume ratios and shared walls and floors, increasing energy demand. Minimizing heat losses during the winter requires minimization of the surface-to-volume ratio; but this implies a reduction of the building envelope exposed to the outside environment, thus reducing the availability of daylight and sunlight and increasing energy consumption for artificial lighting and mechanical ventilation.[33]

[30] Stupka, R., & Kennedy, C. (2010). Impact of neighborhood density on building energy demand and potential supply via the urban metabolism. ACEE Summer Study on Energy Efficiency in Buildings, 239–252.bb
[31] Carpenter, S. (2010). How important is embodied energy? Building Magazine. Retrieved from: https://www.building.ca/features/how-important-is-embodied-energy
[32] Embodied carbon in construction: Policy primer for Ontario. (2017).
[33] Ratti, C., Raydan, D., & Steemers, K. (2003). Building form and environmental performance: archetypes, analysis and an arid climate. Energy and Buildings, 35(1), 49–59.

The relationships between compactness, building density and building energy are further complicated by differences between residential and commercial uses. For residential buildings, increasing building density from detached housing to apartments can reduce heating energy demand. However, such density increases typically require increased building depth, increased building height or reduced building spacing that limit access to passive heating and daylighting. In certain contexts, low-density residential design with high surface-to-volume ratios maximized for passive solar heating may provide greater opportunities than density for reduced energy demand. For commercial buildings, increasing the building depth of offices reduces the availability of natural ventilation and daylight, resulting in an anticipated increase in mechanical ventilation and artificial lighting. However, heat losses are likely to decrease as the surface-to-volume ratio decreases with increasing plan depths.

Arguments for and against density, balancing the need to reduce heat loss with the need for solar access (resulting in passive heating) are complex and affected not only by factors of building design and use, but also local context. At the block or neighbourhood scale, building energy consumption is influenced primarily by the shading of adjacent buildings, which limits solar access. This substantially reduces opportunities for passive solar heating and natural daylight, increasing overall heating and lighting demand. These same shading effects, however, also reduce overall cooling demand.

New Policy Measures

The introduction of new policy measures to increase the energy efficiency of new buildings as well as the adoption of voluntary standards such as Passive House will likely result in significantly lower energy density. Europe has been a leader in low energy building policies, through its Energy Performance of Buildings Directive, which requires member state countries have policies that require nearly zero energy buildings by 2020.[34]

Table 3: Requirements and standards driving towards net zero.[35]

Building Standard	Approach	Targets or requirements
Denmark BR10 Building Regulations 10	Mandatory	"Nearly Zero" required in Building Class 2020. Residential 20 kWh/m2/yr Non-Residential 25 kWh/m²/yr
Germany EnEV2009 Energy Savings Ordinance	Mandatory	By 2020 buildings should be operating without fossil fuel. 20% reduction in heat demand levels by 2020. 80% reduction of primary energy demand of buildings by 2050.
Norway TEK10	Mandatory	PassivHaus minimum requirement in 2015 Building Code. Zero-Energy Buildings by 2020.
France RT2012 Thermal Regulations	Mandatory	2020 all new buildings to be energy-positive.
England & Wales Part L Conservation of Fuel, UK	Mandatory	Residential buildings are net zero energy by 2016.
Seattle Target Performance Path - Seattle Energy Code	Mandatory	Total building energy use intensity of 40-65 kWh/m²/yr
Vancouver Building Bylaw	Mandatory	All new buildings zero emissions by 2030.
California Title 24 Part 6	Mandatory	All new homes and apartments required to be net zero by 2020.
Architecture 2030	Voluntary	Zero-Energy and Zero-Emissions Buildings by 2030.
Minergie	Voluntary (Switzerland and Europe)	Public/office/schools- 40 kWh/m²/yr (thermal) (requirements for other building types)
PassivHaus	Voluntary (Worldwide); Mandatory (Hanover)	120 kWh/m²/yr (total) and 15 kWh/m²/yr (thermal)

[34] Vandevyvere, H., & Stremke, S. (2012). Urban Planning for a Renewable Energy Future: Methodological Challenges and Opportunities from a Design Perspective. Sustainability, 4(12), 1309–1328. https://doi.org/10.3390/su4061309
[35] Integral Group. (n.d.). Global best practices in energy efficiency policy, 110.

Evaluation of the Current Pathway

Low emissions buildings are becoming more prevalent. Canada Green Building Council recently awarded an office building in the ByWard market Canada's first zero carbon building certification.[36] The City of Ottawa has shown leadership through its Green Buildings Policy, with 23 municipally-owned LEED certified buildings. There are no large buildings in Ottawa that are certified Passive House.

A critical tool in advancing low-carbon building policies for large buildings is through financial incentives for developers. A Green Standard consolidates building requirements with financial incentives for sustainable elements through a reduction in development charges.

The City of Toronto has invested considerable work in the development of the Toronto Green Standard with the objective of providing a transparent, incentive-based framework for increasing the energy performance of buildings towards net zero energy and emissions. Application of a Green Standard in Ottawa could be relevant because both Ottawa and Toronto have similar GHG reduction targets, both of which have a considerable portion of emissions resulting from buildings energy use. Both cities have relatively similar humid continental climates, and each face growth pressures for large buildings to encourage urban density. Application of an existing program tailored to Ottawa's specific context could be an important tool for the City.

All new planning applications, including zoning bylaw amendments, site plan approvals and draft plans of subdivision are required to meet Tier 1 of the Toronto Green Standard, while Tier 2 is voluntary. Those projects which achieve Tier 2 are eligible for a partial refund of development charges as an incentive to support early action and innovation.

The Green Standard includes a set of targets for the five most common building archetypes that achieve a near-zero emissions level of performance by the year 2030. While most buildings codes are prescriptive in describing specific components or assemblies, the Green Standard establishes intensities for energy performance, thermal demand and GHG emissions. Energy targets are performance based, which can provide greater flexibility to building designers,[37] and mitigate elements of energy loss in a building, based on the context of the individual building.

Figure 7: Stepwise introduction of the tiers to illustrate increasing mandatory performance.

2018	2022	2026	2030
V3 Tier 1	--	--	--
V3 Tier 2	V4 Tier 1	--	--
V3 Tier 3	V4 Tier 2	V5 Tier 1	--
V3 Tier 4	V4 Tier 3	V5 Tier 2	V6 Tier 1

Off-site renewable energy procurement
= Zero Emission Buildings

[36] Building. (June 13, 2018). CaGBC give Ottawa project 'Zero Carbon Building - Performance' Certification. Retrieved from: https://www.building.ca/cagbc-gives-ottawa-project-zero-carbon-building-performance-certification/
[37] NRCan. Canada's national energy code. Retrieved from: https://www.nrcan.gc.ca/energy/efficiency/buildings/20675

Figure 8: TGS targets for high rise multi-unit residential buildings.

Tier	New TGS Targets			Overall % Change in Construction Costs
	EUI (kWh/m2)	TEDI (kWh/m2)	GHGI (kgCO2e/m2)	
SB-10	225	80	28	N/A
TGS v2 T1	190	77	26	1%
TGS v2 T2	170	70	20	4%
T1	170	70	20	4%
T2	135	50	15	5%
T3	100	30	10	7%
T4	75	15	5	6%

In addition to the performance standards, TGS also has a series of mandatory requirements, including air tightness testing to validate energy modelling, building commissioning submetering, energy benchmarking and reporting and a climate resilience checklist. An optional requirement is to provide 5% of the total energy using on-site renewable energy sources, where renewable energy is defined as photovoltaics, solar thermal systems, biogas, wind or geoexchange.

A financial analysis of the impact of TGS found that the construction costs increased by between 1% and 7% as a result of the performance requirements of TGS. When lifecycle costs were considered, the investments resulted in a positive present value of savings.[38]

[38] City of Toronto. (2017). Zero Emissions Building Framework.

Section 2: Growth Projections for New Non-Residential Buildings

Implementing a green standard in Ottawa represents a viable path for emissions reductions in new non-residential buildings. A green standard is a blanket policy tool that uses performance based compliance targets. Therefore, the influences on building energy use, as described above, are not explicitly modelled in this pathway because performance based pathways provide flexibility in the development of individual buildings.

The parameters below represent three pathways for emissions reduction in new large buildings. Three scenarios have been modelled: conservative, moderate and aggressive uptake of actions. The scenarios are described in Table 4.

Table 4. Low carbon pathway actions and parameters.

Action	Conservative	Moderate	Aggressive
New commercial	Building energy intensity levels held constant (2016)	Implement a Green Standard, delayed by five years in relation to Toronto's timeline	Implement a Green Standard in alignment with Toronto's timeline

Methodology

Energy modelling undertaken for this study is based on the following approaches and assumptions:

1. Identifying future population projections: future population by zone for 2023 and 2031 was provided by the City. Linear extrapolation was used to estimate population to 2050.
2. Assigning the population to dwellings, some of which will be apartments: Using MPAC data, population is assigned to dwellings based on historical people per dwelling ratios, which are carried forward. This calculation determines the number of projected dwellings.
3. Assigning the population to employment types: the working age population is allocated to employment sectors according to the historical mix of employment types. Existing employment projections informed the allocation of population to employment sectors.
4. Translating the employment into buildings: the ratio of jobs per floor area for each sector was calculated based on the calibrated year.
5. Reflecting trends of declining office space per employee and an increased mix of apartments: the 2016 ratio for employees per year and people per household were adjusted according to historical or projected trends. The mix of dwelling types can also be adjusted, either to align with the mix in the zone where they will be allocated or according to trends or projections.
6. Specifying the location of the buildings, as determined by current land-use plans: new buildings to accommodate population and employment projections were allocated to zones according to the Official Plan.
7. Setting EUI targets for new buildings based on TGS, according to the time period that each Tier of TGS will become mandatory. The energy performance (energy use intensity) targets were applied to buildings as they are added to the building stock.
8. Adjusting the building design and end uses to meet the energy performance targets: the performance of equipment and thermal envelope for new construction will be adjusted to achieve the energy performance targets.

9. Adjusting the energy system of the buildings: those buildings which are located in areas with sufficient energy density will be connected to district energy. Geothermal or heat pumps will be incorporated to the remaining buildings. Finally, solar PV will be added to the roofs of new construction according to a predetermined schedule.

Constraints

The primary legal constraint is that municipalities cannot directly require energy performance in buildings beyond the building code in Ontario. In BC, municipalities can select to apply different levels of a stretch code as a way to drive performance, but this option is not yet available in Ontario. This means that Ottawa cannot require new builds to meet a certain level of energy performance. The City of Toronto uses the planning approvals process, site control and rezoning agreements between city and developers as the mechanism to require increased energy performance.

Municipalities in Ontario have the same legislative authority to require sustainable performance measures found in the TGS under section 41 of the Planning Act. These powers can only be implemented if both the Official Plan and a Site Plan Control Bylaw contain relevant provisions. Ottawa has not yet included provisions in its Official Plan to enable such agreements and must therefore include provisions for sustainable design elements in the Official Plan prior to developing a Green Standard.

While designers can specify the thermal performance of buildings, it is more challenging to definitively influence the behaviour of building occupants. Various strategies have been proposed to address behavioural occupants including energy ambassadors, real time energy monitors and sophisticated building control systems. The energy performance of equipment is regulated federally and is not within the City's sphere of influence.

Expertise and capacity are likely barriers; few architects and engineers are experienced in net zero energy and emissions design, although this is changing due to requirements in Vancouver and Ontario and the rest of the world.

Buildings are already being constructed to net zero energy and emissions in Canada and elsewhere, so there are no technological or design limits to achieving this level of performance. However, net zero buildings are new, and are still associated with higher costs than conventional buildings. While net zero energy and emissions projects are likely to have a positive net present value over their lifetime, in most cases the entity that constructs the building is not the entity that will receive the operational savings. Incremental investments must therefore be justified based on the ability of the building to attract increased rents or supported by incentives and other financing strategies. The TGS is supported by an incentive program that helps address the incremental costs. Another strategy is to use a Property Assessed Clean Energy program to provide the incremental upfront capital and apply future payments to the building occupants commensurate with the energy savings. Recent Ontario legislation allowed program structures through local improvement charges.

Uptake projections

The results of each of the three uptake scenarios is presented in Table 5, as evaluated against the Business as Planned (BAP) scenario. Note that the conservative projection, which holds energy consumption constant, results in an increase in GHG emissions and energy consumption in comparison to the BAP scenario. In the BAP scenario, new buildings experience a 10% improvement in energy efficiency every year as a result of enhanced building codes.

Table 5: Results of the uptake projections.

Scenario	Parameter	Cumulative emissions reductions 2018-2050 (kt CO2eq)	Emissions reductions 2050 (kt CO2eq)	Cumulative energy reductions 2018-2050 (TJ)	Energy reductions 2050 (TJ)
Conservative	Building energy intensity levels held constant (2016)	-1,554 (emissions gain)	-107 (emissions gain)	-39,330 (energy use gain)	-2,813 (energy use gain)
Moderate	Implement a Green Standard, delayed by five years in relation to Toronto's timeline	190	11	2,423	274
Aggressive	Implement a Green Standard in accordance with Toronto's timeline	1,834	74	43,503	1,890

Ways to advance this pathway

To move forward with reducing energy use and emissions from large existing buildings, the City of Ottawa may consider the following actions:

1. In order to implement a Green Standard under current municipal and provincial regulatory environment, Ottawa will need to amend its Official Plan to include sustainable provisions under site plan control, subdivision and other planning processes.
2. Financing tied to the building asset could be used to offset capital costs of new efficient buildings, although it is more likely it will be used instead for existing building retrofits.
3. The City has made strides in the energy efficiency of its own building inventory, through the passing of its Green Buildings Policy that informs the sustainability of municipal buildings and through its programs under the Building Engineering and Energy Management section. Multiple city buildings are LEED certified. The City could require even further stringent new building policies, such as a requirement for new municipally owned buildings to be Zero Carbon or Passive House certified.
4. On large development proposals with multiple buildings, encourage designs that maximize passive solar gain, maximize potential for on-site renewable energy, or reach higher targets for building performance such as Zero Carbon or Passive House.
5. Finally, provide awareness on the benefits of zero emission buildings. The community could develop a clearinghouse of information on green buildings and provide awareness through information campaigns and through its ongoing relationships with the building and construction industry. There could also be training and workshops for zero emissions building construction principles. Building benchmarking programs, while more applicable to existing buildings, can highlight the costs of energy loss in inefficient buildings. This can indirectly incentivize the construction of zero emission buildings.

Pathway Study on New Residential Buildings in Ottawa

Presented to:
The City of Ottawa
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Ottawa, ON K1P 1J1

In relation to:
The City of Ottawa’s Energy Evolution Strategy (Phase 2)

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January 2019

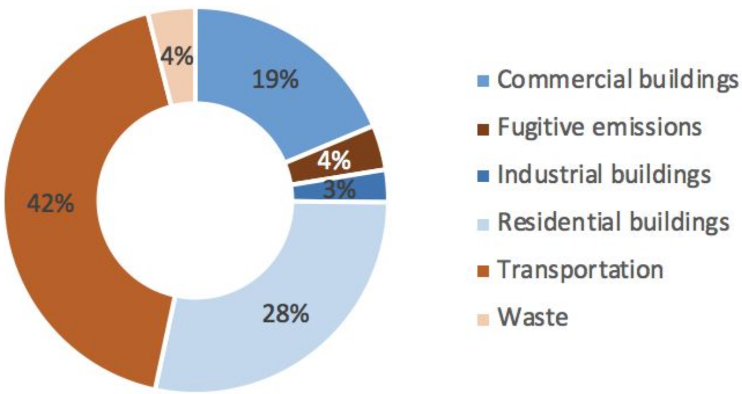
Contents

Executive Summary

This pathway profiles new residential buildings in the City of Ottawa and details relevant strategies to reduce their energy use and emissions in order to meet the goals and objectives of the City's Energy Evolution Strategy. As Ottawa grows, there will be a continued demand for new homes and buildings. New growth can take the form of new single detached housing that may be built outside of the greenbelt area, or intensification of existing areas within the greenbelt with increased rowhouses or low-rise buildings. Whether it is greenfield or infill development, the analysis undertaken in this Pathway Study indicates/suggests that achieving the City's long-term GHG reduction target will require efforts to improve the energy performance of new small buildings built in Ottawa.

Put into context, buildings represent the largest source of community GHG emissions, generating approximately 2.4 million tonnes of CO2e emissions annually and accounting for roughly 50% of the city's total emissions in 2016 (see Figure 1). Without significant intervention, it is anticipated that emissions from the building stock will continue to grow in a linear fashion, with residential buildings leading emissions growth due to the large proportion of floor space that they occupy within the city.

Figure 1. Emissions by sector, Ottawa 2016.



Using detailed data on Ottawa's current (2016) built form and energy consumption patterns, this Pathway Study models future energy scenarios associated with new small buildings based on four general approaches or input parameters: energy efficiency improvements, uptake or adoption of net-zero requirements, variations in the anticipated mix of housing form, and variations in the size of future dwellings. The boundaries specifically discuss strategies for a low-carbon pathway that will include zoning practices for a diversity of housing types, decreasing house size, the implementation of green standards for new builds including passive house, and the use of low carbon and renewable energy.

The pathway boundaries inform modelling procedures in three scenarios: conservative, moderate, and aggressive. The conservative scenario parallels a Business-as-Planned outlook, the moderate reflects a slow pathway to net zero new construction, and the aggressive scenario expedites the introduction of net zero residential buildings.

Section 1: Present Assessment of Residential Buildings

Pathway Description

In 2016, buildings accounted for 50 percent of Ottawa's total community-wide greenhouse gas (GHG) emissions.[1] Space and water heating are the largest end uses of energy, which are primarily provided through natural gas combustion in the Ottawa region—a significant source of greenhouse gas emissions. More rural areas may use propane or heating-oil for heating purposes. Electricity is also used in Ottawa buildings for heating and plug loads, but the GHG emissions intensity of electricity is low in Ontario. Electricity use for heating has historically been costly, but the Fair Hydro Plan (2017) is an action to lower the associated costs.

Most buildings are constructed following minimum efficiency requirements set out by the Ontario Building Code. While ongoing updates to the Ontario Building Code have improved building energy performance over the past decades, homes built to Code still contribute sustantially to Ottawa's emissions production.

This pathway explores technological, construction, and policy options available to improve the energy performance of new residential buildings in Ottawa. Buildings constructed today lock in future energy consumption and patterns of GHG emissions. The City estimates that there will be an additional 113,000 homes built between 2011 and 2031.[2] The initial construction of a building represents a critical moment in a building's life for maximizing energy performance. Every new home constructed to net zero emissions is one fewer building that will need a complex and disruptive future retrofit to achieve deep emissions reductions.

This pathway assesses the mainstreaming of net zero building principles into current design and construction practice for residential buildings, including passive design, inclusion of renewable energy generation on site, minimizing building size and encouraging more efficient residential building types.

Pathway Boundaries

The analysis and energy modelling undertaken for this Pathway Study categorizes strategies for achieving energy reductions and transitions in new small buildings into four broad boundaries or input parameters. These boundaries are:

1. Energy performance
2. Net zero homes
3. Dwelling mix
4. Dwelling size

These strategies are examined in relation to the current pathways for building development, including an overview of building energy systems, relevant policy, followed by potential tools for uptake such as incentives and awareness.

This paper will focus most heavily on new residential buildings. Low density single-detached neighbourhoods are very common in Ottawa and strategies to make them more energy efficient and to reduce their respective emissions are a key component to achieving the City's 2050 emissions reduction target. Larger non-residential buildings with institutional, commercial, or industrial uses are examined in the non-residential building pathway papers.

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[1] City of Ottawa. (2014). Air Quality and Climate Change Action Summary. Appendix A GHG inventory Summary.
[2] City of Ottawa. Official Plan. Section 2: Strategic Directions.

Background Information

Building Type and Location

Different forms of low-rise residential buildings have different energy requirements (Table 1). The weighted average of household energy use in Ottawa was 104 GJ in 2016. Generally, detached housing has greater energy requirements than non-detached because it is exposed on all sides, and has higher surface area to volume ratios, which increases energy loss.[3] Detached homes also tend to be larger than non-detached, requiring more energy for space heating. Shared walls and stacked units reduce heat loss in a building.

Table 1. Average annual energy use per household in Ontario in 2015, by building type.[4]

Building Type	Description	Average annual energy use per household (GJ/yr)
Single Detached	Free-standing structure	122.6
Semi-detached	Two homes sharing a wall	102.2
Duplex	Two homes sharing a ceiling/floor	89.9
Row	>2 homes joined side-by-side	84.2
Low-rise multi-unit residential building (MURB)	Multiple homes arranged besides and above one another	53.7

Emissions from new residential buildings can be reduced by changing the building type mix. This includes encouraging higher residential density and mixed-use neighbourhoods to accommodate the growing population. The acceptance of home downsizing is generally becoming more common, but social barriers to living in smaller dwellings still exist.[5]

In addition to greater housing density, encouraging heterogenous neighbourhoods can also reduce emissions associated with new residential buildings. Mixed-use neighbourhoods combine various land uses to form 'complete' communities. These neighbourhoods are generally dense in population per hectare and support a range of services and amenities. Increased accessibility to services can make dense neighbourhoods more attractive, which can motivate a switch away from less dense, energy-intensive suburban lifestyles. In addition to reducing energy demand, mixed-use neighbourhoods also reduce vehicle kilometres traveled, as services can be accessed by active transportation. If a vehicle is required, the distances to services are short. Heterogeneous building mixes concentrate people closer to municipal service infrastructure as well, reducing the demand on, and costs of, services such as road maintenance and utility infrastructure.[6]

Achieving Low Carbon Homes Through Building Design Certification Standards

Current best practices in new building emissions reduction focus on net-zero energy and energy/carbon positive design. Net-zero energy homes produce as much energy as they use, including energy used for space heating, hot water, ventilation, air conditioning, appliances, lighting, and all other household electrical consumption. The emergence of electric vehicles and their charging requirements may require an increase in on-site energy produced to meet the net-zero threshold. Energy and carbon positive homes produce more energy than they consume and reduce

[3] City of Vancouver. 2016. Zero Emissions Building Plan.
[4] Statistics Canada. Statistics Canada. Table 25-10-0061-01 Household energy consumption, by type of dwelling, Canada and provinces. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2510006101
[5] Huebner, G., Shipworth, D. (2017). All about size? – The potential of downsizing in reducing energy demand. Applied Energy, 186, 226-233.
[6] Murphy, R., Boyd, K., Jaccard, M. (2016). Evaluation of actions and policies to reduce urban GHG emissions using multiple criteria: a contribution towards energy efficiency in British Columbia's Built Environment. Simon Fraser University.

their GHG emissions beyond zero, typically by exporting renewable energy produced on site. In its most recent climate action plan, the Ontario Government identified net zero energy homes as a target for the 2030 building code. The federal government has committed to a "net-zero energy ready" model building code for 2030 through the Pan Canadian Framework.[7]

The most effective approach to achieving net zero is to maximize energy efficiency in order to limit energy demand. Passive solar building design is considered a best practice in this respect, as passive thermal gain can provide most or all of a home's heating needs, as well as much of the lighting required during the day. Heating requirements are minimized through the sun-orientation of the building, as well as glazing choice, shading design, enhanced airtightness, reduced thermal bridging, extensive use of thermal insulation, well designed ventilation design with heat recovery, and high R-value windows and doors.[8] Passive solar design can achieve heating and cooling energy reductions of up to 90%, with an average of 50% total energy savings.[9] Passive House is one example of a green building standard that is performance-based certification (meaning that certification reflects actual post construction performance that meet a set standard) and exemplifies this design approach.

Table 2. Passive House Canada Standards.[10]

Criteria	Yearly performance standard
Heating	Space heating demand maximum of 15 kWh/m2 OR Heating Load Max of 10 W/m2 (also applies to space cooling)
Airtightness	50 Pa max results in 0.6 ACH
Energy Demand	Total primary energy demand maximum of 120 kWh/m2

The Passive House standard has typically been applied to detached residences, as their size and simple shape, as well as the relative ease of sourcing high efficiency building components for them, enables ease of energy modelling and building design. In recent years, Passive House certification has also been applied to low-rise multi-unit residential buildings, office buildings, and high-rises.

Building to a Passive House standard currently costs more than conventional building due to the added cost of high performance building components and soft costs incurred from greater design efforts. Passive House Canada estimates that the incremental cost of building to Passive Standard is approximately 10% over building a conventional structure, with an annual reduction in heating and cooling energy consumption of 80-90%.[11] Gaining Passive House certification costs $3,000-$5,000, in addition to the 10% building costs.[12] In one Ottawa example, a Passive House single detached home was built for $337,130, with annual energy savings of 30,685 kwh/yr. over a similar-sized home built to the Ontario Building Code.[13] Another Ottawa example estimates a payback period of 15-30 years, with annual savings of $1,000, with an upfront additional cost of $15,000-$30,000.[14] Payback periods of building to Passive House is dependent on a variety of factors over the building's life, including building components used and energy costs over time, and are therefore case specific.

[7] Natural Resources Canada (2017). Build Smart: Canada's Building Strategy. Retrieved from: https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/emmc/pdf/Building_Smart_en.pdf
[8] Passive House Institute. Passive House Requirements. Retrieved from: https://passiv.de/en/02_informations/02_passive-house-requirements/02_passive-house-requirements.htm
[9] Passive House. A Developer's Guide to Passive House Buildings. Retrieved from: http://www.passivehousecanada.com/downloads/PHC-developers-guide.pdf
[10] Passive House Canada. Building Certification. Retrieved from: http://www.passivehousecanada.com/passive-house-building-certification
[11] Passive House Canada. Frequently Asked Questions.
[12] Passive House Canada. Building Certification. Retrieved from: http://www.passivehousecanada.com/passive-house-building-certification
[13] https://ekobuilt.com/ekobuilts-services/ottawa-passive-house/cost-analysis-for-building-an-eko-passive-house
[14] Local Impact Design. The Business Case for Passive House. Retrieved from: http://localimpactdesign.ca/wp-content/uploads/2016/04/The-Business-Case-for-Passive-House.pdf?189db0

The incremental cost of a net zero home can vary considerably. A recent study from the Rocky Mountain Institute (RMI) found incremental costs ranging from US$2,000 to US$6,000, in part because of additional efforts to drive down energy consumption in order to reduce the requirements for solar PV systems.[15] While not required for Passive House certification, inclusion of on-site renewable energy generation helps buildings achieve net-zero energy and emission levels. Roof-top solar PV or solar thermal systems combined with air or ground source heat pumps are common strategies to achieve net-zero standards.

Near-zero buildings are becoming more feasible as more buildings are built to Passive House certifications; greater local building expertise is developed; common issues are resolved, and components become more widely available. In the Ottawa region, Passive House certified buildings are becoming more common, with seven currently certified.[16] In order to successfully achieve significant GHG emissions reductions, the portion of new builds that are built to Passive House, or similar standards, needs to be scaled up.

Other voluntary standards and efficiency labelling programs also encourage awareness of efficient building design. In addition to Passive House Certification other standards and labelling schemes include:

- *EnerGuide:* This is the Government of Canada's official labelling program to display energy efficiency of appliances, vehicles and homes. Previously, EnerGuide rating used a rating scale of 0-100, where 100 is full energy efficiency, and 0 is complete energy loss. EnerGuide is now transitioning to demonstrate total energy use in GJ/year. Energuide labels are displayed on consumer products to show average energy use and associated energy costs, compared to the relative efficiency of other products in its class. If a property owner is purchasing new appliances as a part of a retrofit, EnerGuide can encourage energy efficient purchasing decisions.

- *Energy Star*: Developed by the US EPA, Energy Star is a marking system that labels energy efficient appliances, homes and vehicles. Energy Star Canada works in concert with EnerGuide.

- *R-2000:* Natural Resources Canada's internally developed standard for highly efficient home building, encouraging efficiency best practices in construction. Buildings must be built by R-2000 certified contractors to achieve this certification.

- *LEED:* Leadership in Energy and Environmental Design (LEED) is a rating system to describe positive environmental attributes. LEED is a pioneering program which continues to help transition the design and construction industry to advance low carbon, energy efficient buildings. LEED uses a point system, where various building attributes such as energy systems, efficiency features, building location, and efficient water devices are allocated points.

- Canada Green Building Council (CaGBC) Zero Carbon Building Program: Launched in 2017, the CaGBC developed a system to make carbon emissions as the driver for better building performance. This practice will advance the goals of the LEED program which will target energy reductions and not necessarily carbon emissions. The key components of this system include offsetting GHG emissions by building operations, increasing efficiency and driving down thermal energy demand, the use of on-site renewable energy, and building materials that are low-carbon.[17]

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[15] Peterson, A., Gartman, M., & Corvidae, J. (2018). The economics of zero energy homes. Rocky Mountain Institute.
[16] Passive House Canada. Project Maps. Retrieved from: http://www.passivehousecanada.com/projects/?keyword=Ottawa&province=Province&building_type=BuildingType&search=_Search
[17] "Zero Carbon Building Standard." 2017. Canada: Canada Green Building Council. https://www.cagbc.org/cagbcdocs/zerocarbon/CaGBC_Zero_Carbon_Building_Standard_EN.pdf

District energy connection

Phase 1 of the Energy Transition Strategy featured a pathway on District Energy and its use can have energy and emissions impacts on new residential buildings. If there is sufficient housing density, implementing a district energy connection can present and opportunity to provide new residential buildings access to low carbon heat sources. For example, Drake Landing Solar Community in Alberta represents a best-practice model for solar thermal storage district energy systems in new developments. This system connects 52 single detached homes to an underground solar thermal energy storage battery, storing most of the thermal energy during the summer for use in winter months. The system provides 90% of the total thermal energy used in the subdivision.[18]

While connection to a district energy system for new houses represents one option for low carbon thermal systems, other low carbon, energy efficient housing approaches may be superior, such as passive design and distributed energy resources. Vancouver now requires new buildings to design and implement low-carbon energy systems, which do not necessarily use district energy systems, providing greater flexibility to developers. The experience of the City of Vancouver has been that district energy systems are only as useful as buildings are energy inefficient.

The use of District Energy may apply in contexts where Ottawa is considering new mixed-use districts or subdivisions with a variety of housing density meeting the needs for a variety of stakeholders and residents.

'District-Energy Ready' guidelines in new subdivisions ensure that a building can easily connect to a district energy system in the future, should such connections become available. District energy ready features include:[19]

- The ability to supply thermal energy from the ground level, including adequate space for an energy transfer station;
- Easement between the mechanical room and the property line for thermal piping;
- Two-way pipes placed in the building to carry the thermal energy from the district energy network to the potential location of the energy transfer station;
- A low temperature hydronic heating system that is compatible with a district energy system; and
- Thermal energy metering capabilities.

[18] Drake Landing Solar Community. About DLSC. Retrieved from: https://www.dlsc.ca/about.htm
[19] City of Toronto. (2016). Guidelines for District Energy Ready Buildings.

Current Pathway Assessment

The make-up of residential buildings in Ottawa is dominated by detached single housing, which represents the largest portion of floor area in new development applications to the City. In 2017, single detached units represented 51% of all area of new development applications.[20] However, the total number of detached units constructed in Ottawa has declined since 2001. There were 3,497 single detached units completed in 2001, whereas single detached completions were 1,745 units in 2017.[21] The portion of single units in relation to another low rise residential is displayed in Figure 2 and Figure 3.

Figure 2. Residential completions by building type in Ottawa from 2001-2017.[22]

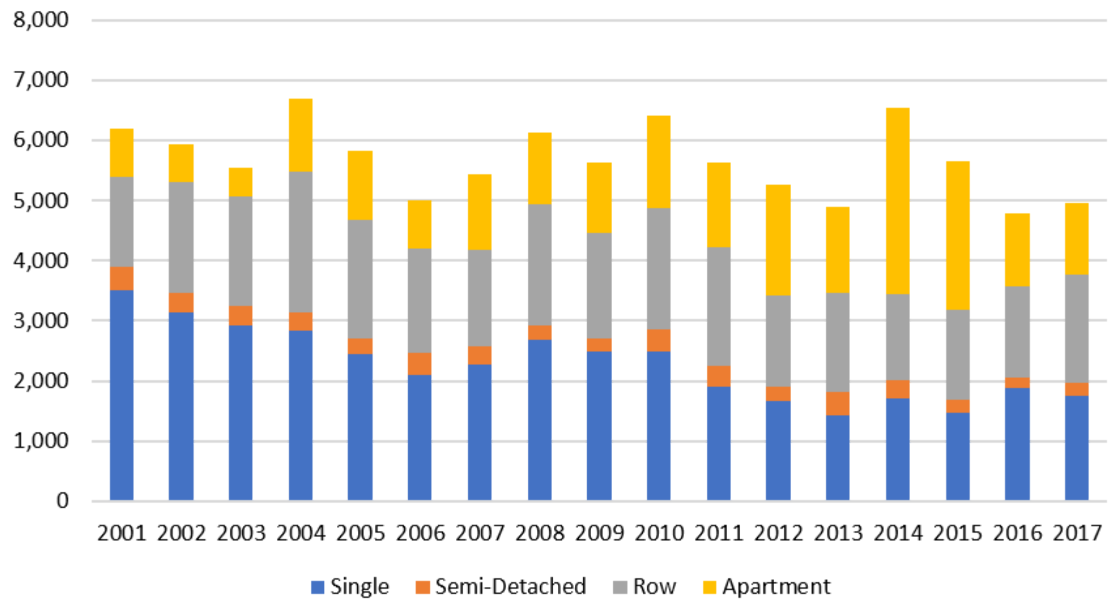
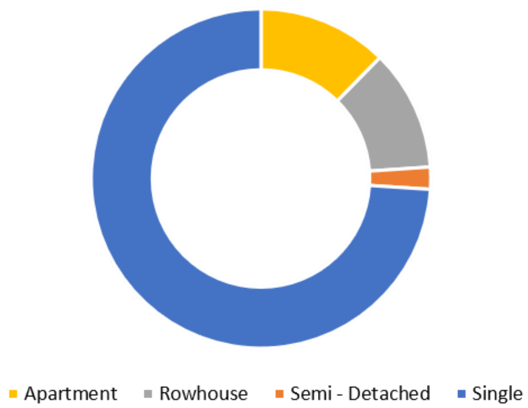


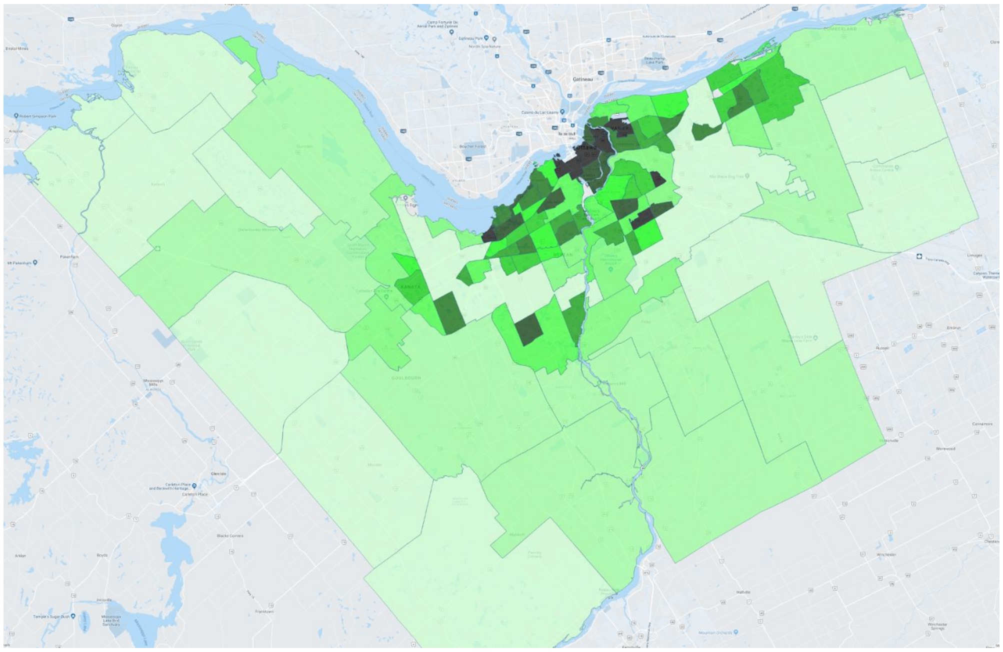
Figure 3. Floor area (m2) of approved residential permits in Ottawa in 2017.[23]



[20] City of Ottawa. (2018). Issues Permit Statistics for the Period of 2017-Jan-01 to 2017-Dec-31.
[21] CMHC. 2018. Housing Starts and Completion Survey. Retrieved from: https://www03.cmhc-schl.gc.ca/hmip-pimh/en#Profile/3506008/4/Ottawa%20(CV)%20(Ontario)
[22] Ibid.
[23] City of Ottawa. (2018). Issues Permit Statistics for the Period of 2017-Jan-01 to 2017-Dec-31.

Large rural areas and predominantly single-family housing residential neighbourhoods make Ottawa's population density low compared to other Canadian cities.[24] There is higher population density in Ottawa's downtown neighbourhoods; both Lowertown and Centretown have a population density above 7000 persons/km2.[25] Residential density in Ottawa is depicted in Figure 4.

Figure 4. Population density by neighbourhood (persons/km2). Darker green represents higher density.[26]



Ottawa's population is expected to grow over the coming decades. Population and housing change estimates from the Official Plan are included in Table 3.

Table 3. Population and housing estimates.[27]

Area	Totals by 2021		Totals by 2031	
	population	homes	population	homes
Inside Greenbelt	562,000	258,000	591,000	278,000
Outside Greenbelt, urban	367,000	140,000	432,000	168,000
Rural	102,000	38,000	113,000	43,000
Total	1,031,000	436,000	1,136,000	489,000

[24] Statistics Canada. Population and Dwelling Counts, Highlight Tables, 2016 Census.
[25] Ottawa Neighbourhood Study. Retrieved from: https://www.neighbourhoodstudy.ca/maps-2
[26] Ibid.
[27] City of Ottawa. Official Plan. Section 2: Strategic Directions.

The location of new dwellings is important because greenfield or suburban development is associated with greater energy consumption due to the buildings form and size as well as increased vehicular transportation (see Transportation Pathway). Intensification, in contrast is associated with smaller dwellings that have lower energy consumption because of shared walls. Residential intensification and mixed-use neighbourhood development in urban areas are objectives in the Official Plan. The City is planning to accommodate approximately 90% of new population growth within its urban boundaries, with a focus on mixed-use and transit-oriented sites.[28]

Based on the Official Plan, most growth from 2021-2031 will be in the areas outside the Greenbelt, which are further away from the city centre. Furthermore, greenfield development still occurs in Ottawa, where new development - predominantly single detached housing - occurs in previously undeveloped areas. While this largely occurs in rural areas and neighbourhoods peripheral to the city, it further contributes to urban sprawl, and establishes long term development of neighbourhoods that feature detached and less-dense housing forms.

The primary mechanism for urban intensification available to the City is zoning by-laws. The City can allow rezoning to encourage or require denser building types, and meet goals to ensure that commercial and institutional land uses are also nearby. Establishing land for duplexes, townhomes and multi-unit residential buildings, and reducing zoning for single detached housing can encourage higher population density in residential neighbourhoods. One strategy, which may or may not be applicable to Ottawa, is the application of a differentiated development levy to incentivize intensification over greenfield projects.[29]

Municipal Influence on Building Design

The Ontario Building Code (OBC) governs technical and administrative requirements for building development and construction in the province. The Code includes requirements to encourage fire prevention, hazard reduction and energy efficiency in buildings. OBC is updated every five to seven years, with each cycle bringing improvements in building design and efficiency. The next Code update is slated for 2019. OBC incorporates national model codes, such as the Model National Energy Code for Buildings, and considers input through a consultation process.

OBC has both prescriptive and performance compliance pathways. Prescriptive compliance includes specific design criteria to guide builders, such as minimum requirements for insulation and passage of heat (RSI-values). In contrast, performance-based compliance relies on actual building performance. In the OBC, this currently relates to a reference building against which the buildings' modelled energy use is compared. Although not yet a part of the OBC, absolute energy targets are considered to be more effective in evaluating energy use and greenhouse gas emissions because it provides a value for total energy use intensity. Natural Resources Canada's EnerGuide program is moving away from its relative energy rating scale towards a total energy use value (GJ/year). Because of this shift, the Building Code is no longer associated with an EnerGuide rating.

As of 2017, two supplementary energy efficiency standards came into effect in the Ontario Building Code. SB-10 includes efficiency requirements for Part 9 commercial and Part 3 buildings. SB-12 is a supplementary standard for houses that includes both prescriptive and performance-based compliance paths. Prescriptive requirements include using drain water heat recovery and heat recovery ventilators, as well as various requirements for windows, insulation and other components to have a minimum RSI-value. Compliance through performance requires builders to meet various performance metrics for airtightness, wall-window ratios and others.[30] SB-12 also allows an alternative compliance through achieving Energy Star or R-2000 certification.

[28] Ibid.
[29] Stikeman Elliott (2016). City of Calgary passes new off-site levies bylaw. Retrieved from: https://www.stikeman.com/en-ca/kh/real-estate-municipal/city-of-calgary-passes-new-off-site-levies-bylaw
[30] Ministry of Municipal Affairs. (2016). MMA Supplementary Standard SB-12 Energy Efficiency for Housing. Retrieved from: http://www.mah.gov.on.ca/AssetFactory.aspx?did=15947

The province recently completed consultations for the next phase of energy efficiency improvements, for implementation in the 2019 OBC, with some measures to be implemented in 2022. Possible requirements in the Building Code include mandatory airtightness testing before occupancy and improved envelope performance, ultimately resulting in 60% improvements in energy efficiency over a home built in 2005.[31] Implementation of Phase 2 components is now under the decision of the new provincial government.

Although OBC is provincially designated, it is the responsibility of municipalities to enforce the Building Code. Municipalities can control the administration of the building code through municipal by-laws. Municipalities do not have the jurisdiction to enforce any building requirements other than the OBC. In practice, this means that the City of Ottawa cannot mandate better-than-code efficiency requirements for buildings.

Municipalities in Ontario can not Site Plan Control to influence features on the interior of a building, and as such, cannot influence heating system components and design. Single-unit dwellings are exempt from Site Plan Controls, which further limits the influence the City has on single detached units.[32]In Ottawa, the City has designated the entire area within territorial limits as within Site Plan Control Area, where the city can require developers to provide elements or facilities as a condition for approval, so long as such conditions are required in the City's Official Plan. Conditions put forward by the City can only relate to the exterior of the building, including parking, driveways, walkways, trees, fences, and other exterior features. This mechanism can be used to encourage sustainable design features, including orienting buildings for passive solar, measures to reduce urban heat island effects, permeable paving surfaces, and other features.[33]

There are also provisions within the Planning Act that allow municipalities to impose conditions on rezoning applications. However, because such conditional zoning is not currently referenced within Ottawa's Official Plan, this opportunity would require a change to the Official Plan.[34]

[31] Ministry of Municipal Affairs. (2017). Potential changes to Ontario's Building Code: Summer and Fall 2017 Consultation. Retrieved from: http://www.mah.gov.on.ca/AssetFactory.aspx?did=19606
[32] Ibid.
[33] City of Ottawa. (2013). 2012 Green Buildings Promotion Program.
[34] Ibid.

GHG and Energy Intensity Targets

GHG and energy intensity targets can encourage emissions reductions in new residential buildings. Absolute performance targets can better describe how buildings contribute to local GHG emissions. GHG and energy intensity targets are related to building performance rather than prescriptive building requirements, which provide flexibility for builders and designers. Compliance with performance targets requires modelling building energy use, which can cause discrepancy between modelled and actual energy and GHG intensity of a given building.

GHG and energy use intensity targets can gradually 'step', to require greater reductions in overall GHG and energy use in the building stock. Vancouver and Toronto use GHG and energy targets that step up until the year 2030. Both cities use three metrics for GHG and energy use intensity limits, described in Table 4.

Table 4. Common performance-based yearly targets for buildings.

Metric (yearly)	Description
GHG Intensity (GHGI, kg CO2e/m2)	Total amount of energy supplied to the building by type, multiplied by the energy's carbon intensity, divided by the building area in m2.
Thermal Energy Demand (TEDI, kWh/m2)	The annual heating energy demand for space conditioning and conditioning of ventilation air
Total Energy Use Intensity (TEUI, kWh/m2)	Total amount of externally provided thermal energy to a building per unit of floor area.

Vancouver Zero Emissions Building Plan

Vancouver uses rezoning applications to require increasingly stringent energy and GHG targets. The City has established a timeline for reductions in GHGI and TEDI metrics for new buildings, for major building types. Vancouver's Green Building Policy for Rezoning currently requires buildings to meet Passive House requirements or GHGI, TEDI and TEUI targets. These same targets are then included in Vancouver's Building Bylaw five years later. In doing so, builders and developers that apply for rezoning push forward innovation in efficient design, help establish local demand for efficient products and become the 'first-movers' in efficient buildings to make it more feasible for widespread uptake years later. Low-rise multi-unit residential building GHG and TEDI targets are displayed in Table 5.

Table 5. Vancouver's time-stepped GHG and TEDI requirements for Low-rise MURBS.[35]

Current Bylaw		Current Rezoning		2016 Bylaw Updates		2016 Rezoning Update		2020 Rezoning Update		2025 Bylaw Requirement	
GHGI	TEDI	GHGI	TEDI	GHGI	TEDI	GHGI	TEDI	GHGI	TEDI	GHGI	TEDI
12.5	50	10.5	42	5.5	35	5	25	4.5	15	0	15

Detached homes are also subject to a GHG and energy use intensity limit (Table 6). However, there is no rezoning policy in place for detached homes in Vancouver, and these buildings are therefore not included within the 'step' framework.

Table 6. Vancouver's time stepped GHG and TEDI limits for detached homes.[36]

2007 Baseline		Current Bylaw		2020 bylaw		2025 Bylaw	
GHGI	TEDI	GHGI	TEDI	GHGI	TEDI	GHGI	TEDI
23	113	12	84	7	55	0	30

[35] City of Vancouver. (2016). Zero Emissions Building Plan.
[36] Ibid.

Toronto Green Standard

The City of Toronto also uses a stepped energy efficiency performance tool to transition new building construction to be near-zero emission by 2030. The Toronto Green Standard is a tiered set of measures for building performance, that includes both performance target and prescriptive requirements for common building types:

- *Performance Targets*: total energy use, thermal energy demand and GHG intensity targets for each tier.
- *Prescriptive*: renewable energy generation, district energy connection, air tightness testing, building commissioning, submetering, building labelling, disclosure requirements for each tier.

Tier 1 is mandatory for all new planning applications, including zoning bylaw amendments, site plan approvals and subdivision plans, which does not typically include small buildings. Tiers 2, 3 and 4 have increasingly stringent efficiency and sustainability elements but are voluntary. Higher tiers are incentivized through reduced development charges for developers. Voluntary steps are intended to drive innovation, establish local supply chains and develop ideal outcomes for buildings. Over time, the voluntary tiers step-up: Tiers 2, 3 and 4 will eventually become mandatory through Green Standard updates. For example, Tier 2 of TGS version 2 is now Tier 1 of version 3. The schedule for TGS updates is displayed in Figure 5. The stepped format prepares the building industry for future mandatory requirements.

Figure 5. TGS stepped schedule.[37]

2018	2022	2026	2030
V3 Tier 1	--	--	--
V3 Tier 2	V4 Tier 1	--	--
V3 Tier 3	V4 Tier 2	V5 Tier 1	--
V3 Tier 4	V4 Tier 3	V5 Tier 2	V6 Tier 1

Off-site renewable energy procurement = Zero Emission Buildings

Version 3 of the TGS was required in May 2018. Figure 6 displays the GHG and energy intensity targets set out for low-rise residential buildings with more than five units. The City also intends to provide support to developers that aim to build in the upper tiers through awareness, energy modelling resources, and financial support.

[37] City of Toronto. (2018). Toronto Green Standard v3.

Figure 6. TGS targets for low-rise MURBs.[38]

Tier	New TGS Targets			Overall % Change in Construction Costs*
	EUI (kWh/m²)	TEDI (kWh/m²)	GHGI (kgCO2e/m²)	
TGS v2 T1 (SB 10 2017)	198	97	28	N/A
TGS v2 T2	165	65	20	0.4%
TGS v3 T1	165	65	20	0.5%
TGS v3 T2	130	40	15	2.1%
TGS v3 T3	100	25	10	5.1%
TGS v3 T4	70	15	5	4.9%

Although Toronto and Vancouver provide a compelling model, Ottawa has less jurisdictional power than either of these two cities.

Both Vancouver and Toronto programs capture low-rise MURBs, but target larger buildings more effectively. In Vancouver and Toronto there are fewer policy levers applied to detached homes. Furthermore, Ontario municipalities are not provided the same jurisdiction under Ontario's Planning Act. The exemption of detached housing is a critical gap that needs to be addressed in Ontario's programming to allow Ottawa to make a more meaningful impact in this sector.

A Green Standard could also include a requirement for connections to district energy systems. Toronto's Green Standard includes provisions for district energy connection at Tier 2 for large MURBs.

Financial incentives

Ultimately, the primary barrier for high efficiency buildings is the increased upfront costs, which will need to be addressed if high efficiency buildings are to reach wide scale deployment.

The Independent Electricity System Operator (IESO) provides funding for new builds that are efficient, through the SaveOnEnergy High Performance New Construction Program.[39] Enbridge also offers its Savings by Design Program, which provides design support and funding incentives for efficient building components.[40] While these programs are a positive start, their impact so far is miniscule. The New Construction Program reached 130 homes for overall energy savings of 2 GWh in 2016.[41]

A key factor in driving forward the Toronto Green Standard is the reduced Development Charges for developers. Because financial incentives are built into to the upper tiers of the Green Standard, financial incentives are widely available to developers and under the terms of the City. Other financial incentives that were considered by the City of Toronto are a 'feebate' structure for under-performing buildings, financial support for building modelling and financial support for information and training.[42] In the development of a Green Standard for Ottawa, reduced Development Charges are considered a core component of program design, as well as additional financial supports for encouraging industry capacity.

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[38] Ibid.
[39] https://saveonenergy.ca/en/For-Business-and-Industry/Programs-and-incentives/High-Performance-New-Construction
[40] http://residential.savingsbydesign.ca/incentives.php
[41] IESO. (2017). 2016 Conservation Results Report.
[42] City of Toronto. (2017). Zero Emissions Building Framework.

Section 2: Growth Projections for New Residential Buildings

The following assumptions are applied to the residential building stock in three different scenarios, representing conservation, moderate and aggressive pathway uptake.

Table 7. Low carbon pathway action parameters.

Action	Conservative scenario	Moderate scenario	Aggressive scenario
Improve energy performance of new construction	Apply a 5% increase in energy performance every ten years to reflect revisions to the building code.	Scale up the performance of residential buildings so that 100% of new buildings achieve Passive House levels of performance by 2050.	Scale up the performance of residential buildings so that 100% of new buildings achieve Passive House levels of performance by 2030.
Net zero homes	Increase the percent of new construction which is net zero energy from 0% in 2030 to 50% in 2050.	Increase the percent of new construction which is net zero energy from 50% by 2030 and 100% by 2050.	Increase the percent of new construction which is net zero energy buildings to 100% by 2030.
Dwelling mix	Maintain existing shares of dwellings types consistent with 2016.	Decrease the share of single-family homes to 10% by 2050.	Decrease the share of single-family homes to 10% by 2030.
Dwelling size	Maintain 2016 sizes of dwellings.	Decrease the average dwelling size by 10% by 2050.	Decrease the average dwelling size by 16% by 2050.

Methodology

The modelling approach for new residential buildings is as follows:

1. Identifying future population projections: Future population projections will be generated out until 2050, in alignment with the City of Ottawa's projections.
2. Assigning the population to dwellings, some of which will be apartments: Population will be assigned to dwellings based on historical people per dwelling ratios, which are carried forward into the future. This calculation will determine the number of dwellings that will be projected.
3. Assigning the population to employment types: The working age population will be allocated to employment sectors according to the historical mix of employment types. If an employment projection is available, the mix of allocations to sectors will align with this projection.
4. Translating the employment into buildings: The ratio of jobs per floor area for each sector will be calculated based on the calibrated year.
5. Reflecting trends of declining office space per employee and an increased mix of dwelling types: The 2016 ratio for employees per year and people per household will be adjusted according to historical or projected trends. The mix of dwelling types can also be adjusted, either to align with the mix in the zone where they will be allocated or according to trends or projections.

6. Specifying the location of the buildings, as determined by current land-use plans: The new buildings that result from the population and employment projections allocated to zones according to the Official Plan policies or another projection in five-year increments.
7. Setting targets for new buildings that achieve net zero energy.
8. Adjusting the building design and end uses to meet the energy performance targets. The performance of equipment and thermal envelope for new construction will be adjusted to achieve the energy performance targets.
9. Adjust the energy system of the buildings: Those buildings which are located in areas with sufficient energy density will be connected to district energy. Geothermal or heat pumps will be incorporated to the remaining buildings. Finally, solar PV will be added to the roofs of new construction according to a predetermined schedule.

Constraints

From a technological perspective, high efficiency building design has been shown to be feasible in multiple examples in the Ottawa region and there are notable technological and logistical barriers. Attachment to district energy is physically constrained in many locations, based on proximity to existing systems, and most district energy systems are not yet zero emissions. Ongoing developments in supply chain and process design will be important to lower upfront costs for Passive House standard or net-zero buildings. For MURBs, financial incentives for Green Standard will be important to incentivize higher efficiency projects. A final strategy is to use local improvement charges or a Property Assessed Clean Energy (PACE) program to distribute the upfront costs over the lifetime of the building in alignment with avoided energy costs.

There are some limitations to urban intensification that need to be mitigated to effectively pursue urban intensification. This includes local opposition, which can significantly slow development on a case-by-case basis. Local opposition makes low-rise multi-unit residential an attractive option in relation to high-rise MURBs. Development charges by unit can also disincentivize higher density building projects.[43]

The primary constraint to influencing a low carbon pathway for new residential buildings is that Ottawa does not have legal jurisdiction to require better-than-code efficiency standards. Although Ottawa can rely on mechanisms relating to Site Control and conditions on new planning applications for larger buildings or larger development projects, an ability to require better than code outcomes could help maximize efficient building design in a timely manner. There is uncertainty as to how future updates to the Building Code will be rolled out, decisions which rest with the Provincial Government. Furthermore, the City has limited control over detached single unit homes making Passive House standards difficult to reach. Site Plan Control and other rezoning controls can influence low-rise MURBs and new subdivisions, but not individual small detached units.

Finally, industry capacity is also an important barrier to large scale uptake of high efficiency design in new residential buildings.[44] Home construction is generally performed by smaller companies, which adds a layer of complexity in the transfer of information on building practices required to achieve high efficiency as they may have limited capacity to learn and employ new construction techniques. Certification and standards provide a strong foundation for industry awareness and uptake of principles of efficient design by providing certainty in the direction of the industry. LEED certification still remains one of the most important industry certifications, as it is widely known and recognized. Similarly, Natural Resources Canada's R-2000 standard also seeks to increase industry standards by requiring that contractors be R-2000 certified to build. The City of Ottawa currently uses certification

[43] Graham, K. (n.d.). How can the development permit system be used to achieve residential intensification outcomes in the suburbs?
[44] Wolfe, A., Hendrick, T. (2012). Homeowner decision making and behavior relating to deep home retrofits. Oak Ridge National Laboratory.

schemes to encourage new efficient building construction. Under the 2012 Green Building Promotion Program, Ottawa has taken multiple steps to increase capacity for efficient buildings, including LEED training and revision of permits. Certification schemes provide indirect support to encouraging near-zero buildings but are not a standalone solution.

Uptake projections

The following tables detail the energy use and emissions reductions based on the actions and assumptions described in this pathway paper.

Conservative

Figure 7. Number of new dwellings that meet Passive House standard in five year increments in the conservative scenario.

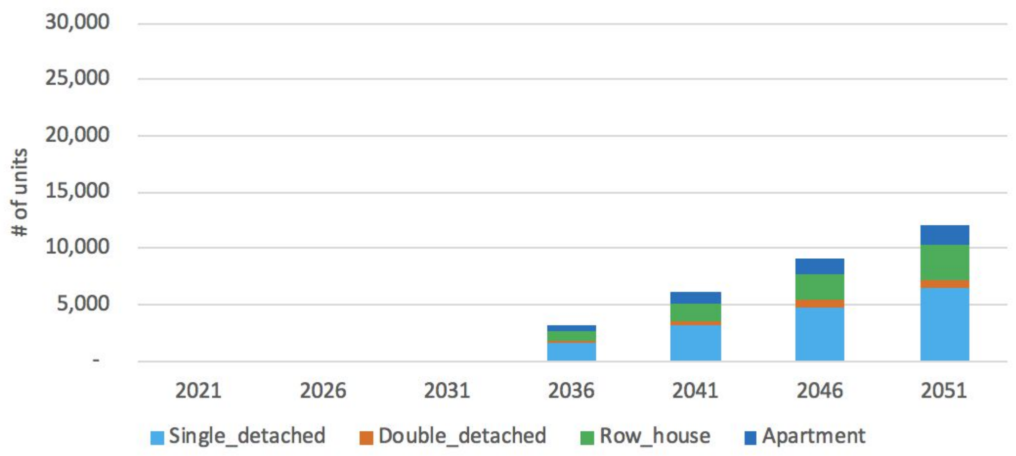

Table 5. Energy and GHG emissions results of the conservative existing buildings pathway.

Action	Description	Cumulative emissions reductions 2018-2050 (kt CO2eq)	Emissions reductions 2050 (kt CO2eq)	Cumulative energy reductions 2018-2050 (TJ)	Energy reductions 2050 (TJ)
Efficiency of new homes	Apply a 5% increase in energy performance every ten years	-725	-53	-17,376	-1,298
Net zero homes	Increase the percent of new construction which is net zero energy from 0% in 2030 to 50% in 2050	308	36	1,938	234
Dwelling Mix	Maintain existing shares of dwelling types consistent with 2016	No change	No change	No change	No change
Size of new homes	Maintain 2016 size of dwellings	No change	No change	No change	No change

Moderate

Figure 8. Number of new dwellings that meet Passive House standard in five year increments in the moderate scenario.

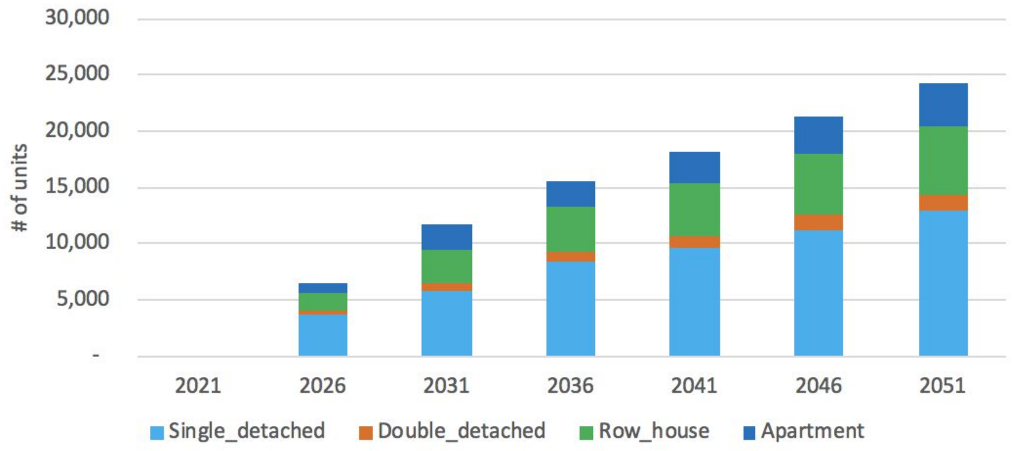

Table 6. Energy and GHG emissions results of the moderate existing buildings pathway.

Action	Description	Cumulative emissions reductions 2018-2050 (kt CO2eq)	Emissions reductions 2050 (kt CO2eq)	Cumulative energy reductions 2018-2050 (TJ)	Energy reductions 2050 (TJ)
Efficiency of new homes	100% of new buildings are Passive House compliant by 2050	128	17	2,586	344
Net zero homes	Increase the percent of new construction which is net zero energy from 50% in 2030 to 100% in 2050	1,207	89	11,746	889
Dwelling Mix	Decrease the share of new single family homes to 10% by 2050	1	1	27	14
Size of new homes	Decrease the average dwelling size by 10% by 2050	501	23	9,977	470

Aggressive

Figure 8. Number of new dwellings that meet Passive House standard in five year increments in the aggressive scenario.

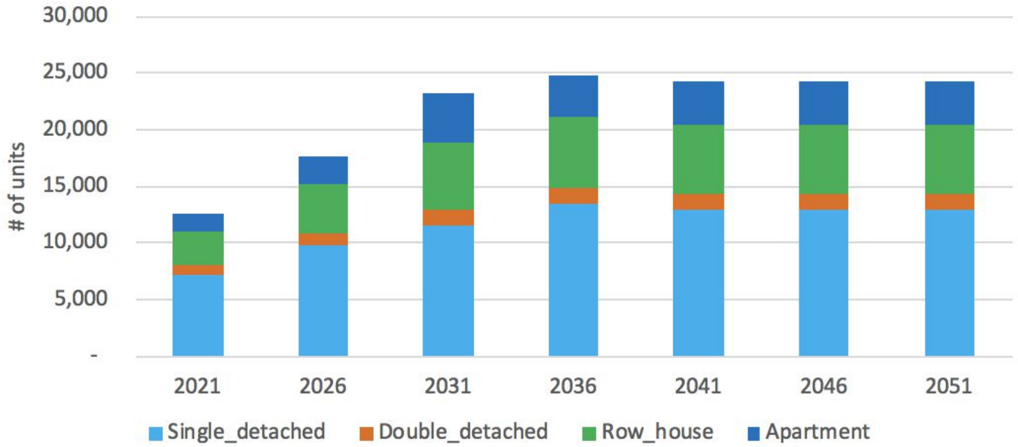

Table 6. Energy and GHG emissions results of the aggressive existing buildings pathway.

Action	Description	Cumulative emissions reductions 2018-2050 (kt CO2eq)	Emissions reductions 2050 (kt CO2eq)	Cumulative energy reductions 2018-2050 (TJ)	Energy reductions 2050 (TJ)
Efficiency of new homes	100% of new buildings are Passive House compliant by 2030	1,038	63	22,636	1,405
Net zero homes	Increase the percent of new construction which is net zero energy from 100% in 2030	1,967	114	22,636	1,405
Dwelling Mix	Decrease the share of new single family homes to 10% by 2030	43	3	1,191	96
Size of new homes	Decrease the average dwelling size by 16% by 2050	836	39	16,627	785

Ways to Advance this Pathway

The following are ways in which this pathway can be encouraged:

- Green standard: A green standard can be used to require net zero buildings by 2030. This could influence multi-unit residential buildings.

- Financial Incentives: Provide a range of financial incentives to support efficient buildings, including cash incentives in coordination with utilities, expedited permitting process, reduced or eliminated permitting fees, discounted service or utility fees, and reduced property taxes.

- Density / Floor Space: Permit increased floor space, or waive a proportion of floor space if builders choose to pursue a green building standard. For example, a waiver in basement floor space can help builders maximize floor area but meet green building requirements. With this incentive, an examination of increased thermal energy compared to additional floor space granted needs to be completed. Floor space waivers may be more effective for duplexes or small row houses which have floor area ratio maximums.

- Education: Invest in training and education programs to increase the literacy of the development and construction industries and the uptake by homeowners. In this vein, the City of Vancouver has published a guidebook on passive house design to support home buildings in the City.[45] Workshops and training for builders and other tradespersons who are involved in the construction industry can also increase construction industry capacity

- Advocacy to Province: Continue to identify gaps in decision making ability in the context of detached housing, and ask for similar powers to Toronto to regulate the sector.

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[45] City of Vancouver. (2009). Passive design toolkit. Retrieved from https://vancouver.ca/files/cov/passive-home-design.pdf

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Pathway Study on Transportation in Ottawa

Presented to:
The City of Ottawa
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Ottawa, ON K1P 1J1

In relation to:
The City of Ottawa's Energy Evolution Strategy (Phase 2)

By:
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February 2019

Contents

Executive Summary

This pathway paper estimates and models transportation energy use in Ottawa and the associated GHG emissions, using 2016 as a baseline year. Nine best practice transportation strategies and their ability to reduce transportation-related emissions are reviewed in three scenarios with increasing levels of ambition. The conservative scenario reflects a business-as-planned outlook, plus some acceleration of vehicle electrification. The moderate scenario reflects interventions on enhanced transit, increased commercial electric vehicles, and increases to car sharing and active transportation. The aggressive scenario includes electrification of personal and commercial transportation, car free areas, expanded transit, and greater car sharing and active transportation.

In the moderate scenario, greenhouse gas emissions are reduced to about 50% of their projected level in a “business as usual” future. In the aggressive scenario, Ottawa’s transportation sector would be essentially carbon free by 2050.

Vehicle electrification has the largest emissions reduction impact of any single transportation measure, but given the interdepencies and synergies between the various strategies and measures, the scenario results are best regarded as the integrated results of all the emission reduction actions included.

Section 1: Present Assessment of Transportation

Pathway description

This pathway examines transportation technologies and strategies in the City of Ottawa that will help the sector meet emissions reduction goals in Ottawa's Energy Evolution Strategy.

Phase 1 of the Energy Evolution Strategy explored a pathway to encourage personal electric vehicles in the city and modelled how city-wide emissions may be affected. This pathway study expands upon the initial Phase 1 analysis by identifying and evaluating nine additional strategies that support energy reductions or fuel switching in the transportation sector, including greater active transportation, enhanced transit, car sharing, and road pricing. The work in the Energy Evolution Strategy and this pathway will complement the goals set out in the City's Transportation Master Plan.

Pathway Boundaries

Several transportation emission reduction strategies are researched, modelled, and evaluated in this paper. The table below details the strategies and their key considerations that the modelling tool (CityInSight) takes into account in projecting energy use and emissions to 2050.

Table 1: Study parameters for transportation.

Strategy	Summary	Key Considerations
Impact of land-use change	Model the emissions effects of creating compact communities.	• VKT reduction • Increase in walking, cycling, and transit usage
Electrification of commercial vehicles	Model incentives or regulations that increase the number of commercial electric vehicles.	• Increased market share of electric vehicles and reduction of traditional fossil-fuel based vehicles
Transportation Demand Management (TDM)/ behaviour change policies	Model various TDM policies to identify effective methods in changing behaviours to encourage transit use or active transport.	• Reduction of VKT • Increase in walking, cycling, and transit use
Parking management	Model parking management, as a particular dimension of TDM, to assess how changes to access of parking can change transportation behaviours.	• VKT reduction • Increase in walking, cycling and transit use

Car-free areas	Model how car-free areas can encourage active transportation rather than personal vehicles in different areas of a city.	• The location of car-free areas near retail or mixed-use neighbourhoods • Number of people who previously accessed the areas by personal vehicle • VKT reduction where car-free areas are introduced
Congestion charge	Estimate assumed transportation behaviour response to price signals (e.g. a mode share shift for specific OD pairs) in order to model the impact on energy use and emissions.	• The extent to which traffic is diverted to other roads, thereby increasing congestion in other locations • The response to the increase in the price of driving, which will vary based on the existing traffic levels and the availability of alternatives • The scope and timing of pricing, which may encourage shifts in travel by time of day, rather than a reduction in driving • Whether drivers take shorter trips rather than eliminating them completely • Implications to AV deployment
Enhanced transit	Following the lead of the Confederation Line in Ottawa, model the impact of increased transit routes, increased frequency, and different modes.	• The number of additional buses in operation and their type • The extent to which the new service causes an increase in transit ridership • The extent to which new transit riders previously drove alone • Length of vehicle trips reduced
Autonomous vehicles (shared)	Model the effects of autonomous vehicles and their rates of penetration within the community. Using previous studies, possible emission reduction strategies will be identified.	• Market share within a community • Impact on car mode share • Load factor, utilization and impact on size of vehicle stock • Rate of electrification for AVs • Impacts of reduced need for parking
Car share/ride share/car co-ops	Uptake projections in car share companies and trips.	• Reduction in personal vehicle ownership • Reduced VKT • Mode shift
Enhanced Bicycle Infrastructure	Various policies and infrastructure investments are described and reviewed for their effectiveness to increase cycling.	• Shift vehicle travel toward active transportation

Methodology

The Business As Planned (BAP) scenario parallels the Conservative Scenario and incorporates current City practice and policy that may affect GHG emissions within the city towards 2050. The Moderate Scenario begins to scale up actions found in this pathway paper such as intensified land-use, decreased reliance on fossil fuels for transport and increased active transport. The Aggressive Scenario further electrifies commercial vehicles, maximizes opportunities for cycling infrastructure, adds more car share services, and increases the relative amount of infill vs. greenfield development. More information on these scenarios including summary tables can be found in the Current Pathway Analysis and Projected Pathway Analysis sections of the paper.

CityinSight modelling includes a spatially explicit passenger transportation sub-model that responds to or accounts for changes in land-use, transit infrastructure, vehicle technology, travel behavior and other factors. CityinSight incorporates transportation emissions modelling methodology from the Global Protocol for Community-Wide GHGs (GPC).

Trips are divided into four types (home-work, home-school, home-other, and non-home-based), each produced and attracted by different combinations of spatial drivers (e.g. population, employment, classrooms, non-residential floorspace). Trip volumes are specified for each zone by origin and zone of destination pairing. For each origin-destination pair, trips are shared over walk/bike (for trips within the walkable/bikeable distance thresholds), public transit (for trips whose origin and destination are serviced by transit), and automobile.

The energy use and emissions associated with personal vehicles are calculated by assigning VKT to a stock-turnover personal vehicle model. All internal and external passenger trips are accounted for and available for reporting according to various geographic conventions.

Emission Types and Units

Tabel 2 provides common vehicle emissions types and their respective Global Warming Potential.

Table 2: Vehicle emission types.

Name	Abbreviation	Global Warming Potential
Carbon Dioxide	CO_2	1
Methane	CH_4	28
Nitrous Oxide	N_2O	298
Air Conditioning Refrigerant	HFC-134a	1,430

The Global Warming Potential (GWP) determines the relative global warming impact of different greenhouse gases, on a per unit mass basis. Carbon dioxide has a GWP of unity, and other gases are measured relative to that benchmark. For example, methane's GWP is 28, which means that one tonne of methane has the same global impact as 28 tonnes of carbon dioxide and would be described as 28 tonnes of CO2e. Note that because carbon dioxide emissions are so much greater than emissions of the other greenhouse gases, it has by far the greatest impact, even though the other gases are more powerful on a per tonne basis.

Other Common Unit Types

Terajoule (TJ): a unit of energy generally used to express large quantities of energy used over a period of a year. In Phase 1 of Ottawa's Energy Transition Strategy, transportation accounted for 31,200 TJ of energy used out of 114,200 TJ total.

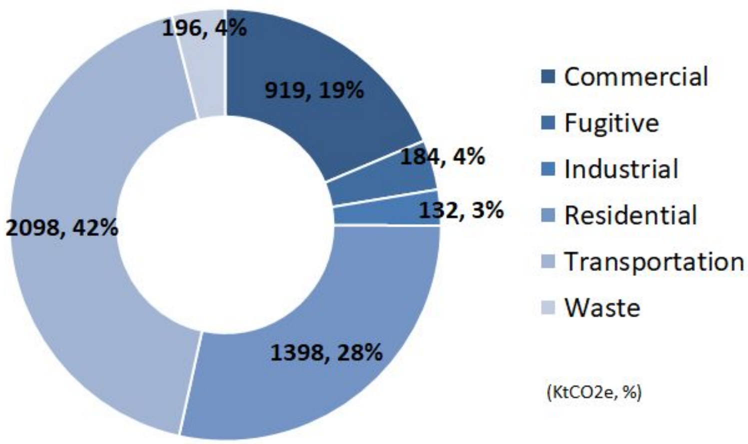
Tonnes/ kilotonnes/megatonnes Carbon Dioxide equivalent (tCO2e or ktCO2e or MtCO2e): a unit of measurement common in measuring the amount of total emissions over a period of year or years.

Background Information

Transportation Energy Use and Emissions Production

On-road community transportation activities generated 2,098 kilotonnes of CO2e in 2016, making it the second largest source of GHG emissions in the city, after buildings emissions (residential + industrial + commercial). Emissions from the transportation sector are growing more quickly than other sources and in the absence of new mitigation policies or programs, transportation emissions will become the largest GHG source in Ottawa.[1] Transportation accounted for 30,612 TJ of energy use, or 29% of total city-wide energy consumption in 2016.

Figure 1: Total Emissions by Sector in Ottawa, 2016.



There are really two transportation systems – one to provide personal mobility and one to support the movement of goods and services in the economy. They share the same infrastructure, but otherwise are quite different. There is an overlap with regard to light duty trucks, but personal and commercial transportation are generally provided by different types of vehicles with different technological possibilities. More important from a local government policy perspective, the personal mobility and commercial transportation systems are driven by different motivational dynamics (household decision making regarding trip-making and travel behaviour vs. business decisions to manage supply chains and meet customer expectations).

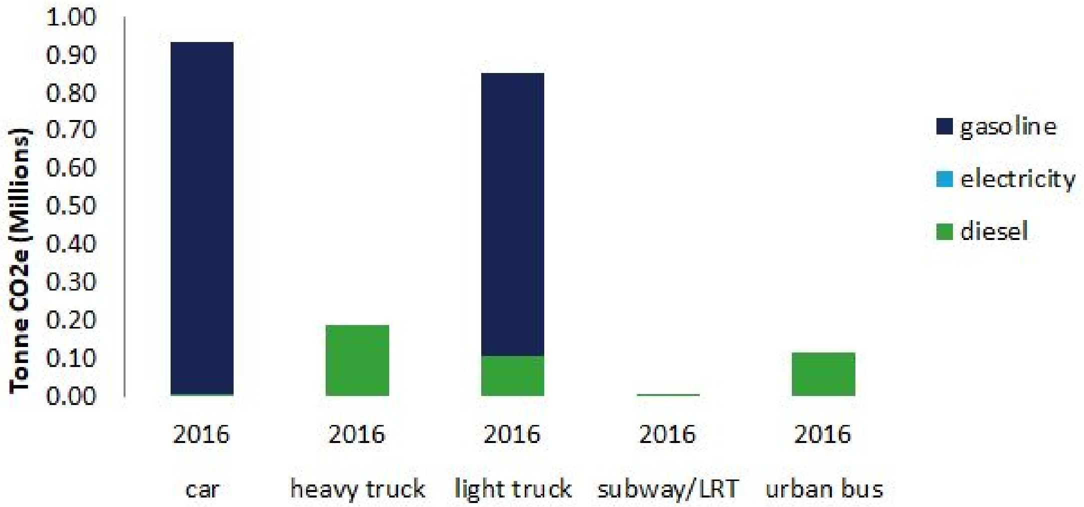
Commercial transportation energy use and emissions are comparable in size to personal transportation on a national or provincial scale, but in Ottawa, with its post-industrial, service oriented economy, personal transportation dominates both the energy consumption and the greenhouse gas emissions from transportation. In 2016, tailpipe emissions of greenhouse gases

[1] Energy and Emissions Plan for the CCP, 2012. http://www.ottawa.ca/calendar/ottawa/citycouncil/ec/2012/02-21/03-Document%204%20-%20CoF_Energy%20Plan_FINAL%5B1%5D.pdf

from gasoline-powered cars and light trucks, totalled 1,790 kilotonnes CO2e, fully 85.4% of total transportation-related emissions in the city, transit buses 5.6% and diesel powered heavy trucks the remaining 9%. If we assume light vehicle commercial traffic consumes the same amount of energy as heavy truck transportation in Ottawa[2], then 83% of transportation-related greenhouse gas emissions are due to personal mobility and 17% to commercial transportation.

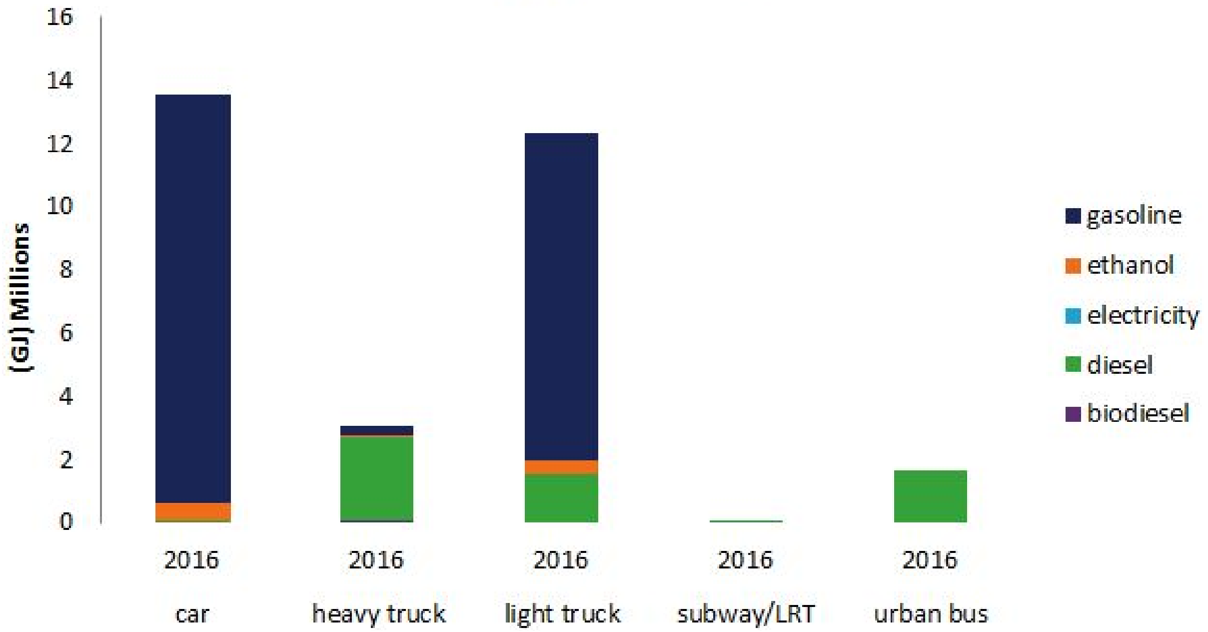
The figures below summarize energy consumed and emissions by vehicle type in 2016.

Figure 2. Transportation emissions in Ottawa by Vehicle Type and Fuel Ottawa, 2016.



[2] This assumes per capita light vehicle commercial traffic in Ottawa is 25% lower than in the GTHA, based on research done in the Greater Toronto-Hamilton area, a major hub for continental commercial transport. (McMaster Institute for Transportation and Logistics, "Estimating Urban Commercial Vehicle Movements in the Greater TorontoHamilton Area", prepared for Metrolinx, the share of light July 2010. http://mitl.mcmaster.ca/reports/MITL_Metrolinx_Report.pdf.)

Figure 3: Energy use by vehicle type and Fuel, 2016.



Transportation energy use and emissions are driven by the underlying demands for personal mobility and the delivery of goods and services, but are equally determined by the carbon intensity of the vehicles employed. Both of these emissions drivers—the demand for transportation services and the carbon intensity of the vehicles—are being affected by transformational technological, social and business model innovations. Vehicle electrification eliminates tailpipe emissions, and provided the electricity is sourced from carbon-free generation, could single-handedly bring about a carbon-free transportation sector, at least at the point of end use. The digital revolution is spawning a range of technologies and business models that could reverse the longstanding trend of growth in personal and commercial transportation demand, while at the same time increasing the vehicle utilization rate several-fold from its current average of about five percent. Similarly, trends in urban settlement patterns and infrastructure design that favour densification, mixed use zoning and active transportation are contributing further to a reduction in motorized vehicle traffic.

These trends are generally mutually reinforcing. Electrification of the vehicle fleet will be achieved sooner and at a lower cost in the context of a shift to mobility-as-a-service (Maas) business models. The mobility-as-a-service model reduces the size of the vehicle fleet and frees up vast amounts of parking land that can be repurposed to support the growth of more vibrant, mixed use neighbourhoods, which in turn improve the feasibility of mobility-as-a-service. The growth of artificial intelligence and telepresence technologies reduces the amount of personal mobility required for day-to-day access to employment, goods, services and amenities, and can facilitate growth in neighbourhood-level interactions and economic activity. Other innovations in mobility and digital technology improve the efficiency of logistics, and reduce the need for commercial transportation in both supply and demand chains.

With all these interacting moving parts, it is particularly challenging to model low-carbon transition pathways or to assign emission reduction potentials to individual measures. The nine strategies for reducing transportation emissions considered in the scenarios presented below should be viewed in this context. For example, vehicle electrification plays a larger role in these scenarios than other strategies, and there is no question it is an effective way to reduce emissions provided that the carbon intensity of the electricity can be kept to zero or very low levels. Calculating the emission reductions from vehicle electrification is quite straightforward, unlike some other measures whose impacts are less direct (e.g. land-use changes), where there is still much uncertainty with regard to their net impact on emissions (e.g. autonomous vehicles), or where their successful implementation depends on the success of other measures (e.g. the potential for active transportation increases as urban form and spatial structure allow more goods and services to be obtained with shorter trips). This does not mean they have low potential for reducing emissions, only that more assumptions are required in their quantitative analysis, assumptions which tend to err on the side of underestimating their potential impacts.

Finally, it should be noted that the electrification of transportation is itself a transition of enormous magnitude that will be occurring simultaneously with efforts to eliminate carbon emissions from other sectors, efforts that will also put new demands on the electricity supply. The transition to a low-carbon future generally and the electrification of the vehicle fleet specifically will be greatly assisted by strategies that reduce the demand for vehicle kilometres of travel or the size of the vehicle stock.

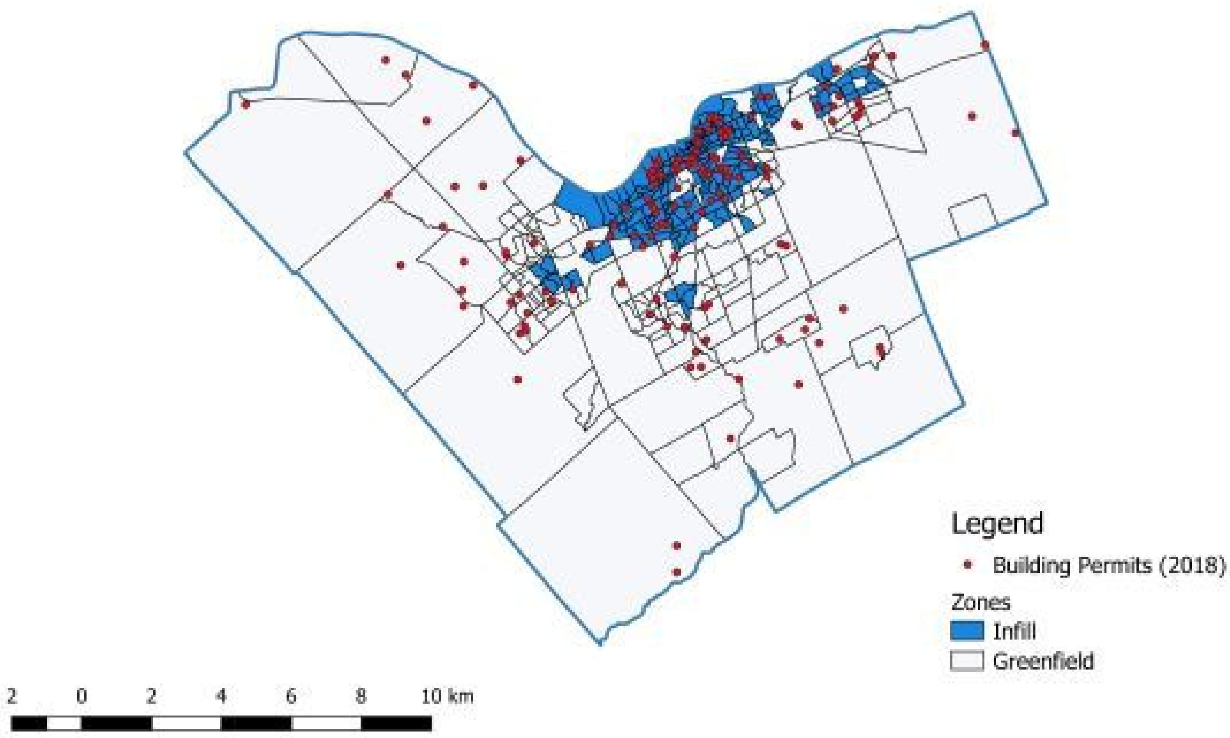
Strategies Assessment

This section discusses several strategies and technologies to reduce energy use and the resulting emissions from the transportation sector. The sub-sections provide background summaries, and policy and action discussions.

Land-use Change

Mixed land-use allows citizens to live near employment centres, commercial centres, or recreation, thereby reducing trip lengths. For trips that can be made short enough to facilitate walking and cycling, emissions can be eliminated altogether. There is currently a mix of infill and greenfield development in Ottawa. Towards 2050, this mix continues with an assumption that 50% of new development will be greenfield, and 50% as infill. In the integrated, low-carbon scenario, a shift towards greater infill development will occur and reduce the VKT correspondingly. The figure below shows construction of new units occurring as of 2018.

Figure 4: Comparing Infill to Greenfield Development in Ottawa, 2018.



Making cities more compact with mixed land-uses at the neighbourhood level results in reduced car ownership, increased active transportation, makes public transport more attractive, and can reduce VKT by as much as 15-30%.[3,4] Travel surveys of communities can help set benchmarks and show behavioural and emissions differences between compact and non-compact communities. An example is shown in Table 3.

Table 3: Travel decisions made by citizens depending on their location and land use.[5]

	Urban	Inner Suburb	Outer Suburb
Cars Per Household	1.3	1.8	2.2
Number of destinations within 1km	44.3	26.2	12.9
Mean distance to closest retail (km)	0.6	1.5	2.1
Non-auto modes used in a typical week			
• Walk to work	33%	4%	2%
• Walk to do errands	47%	20%	12%
• Cycle	44%	24%	24%
• Use Transit	45%	12%	5%

When considering land-use and transportation energy and emissions, the greatest impact that cities can make over the long run is prioritizing infill and brownfield development, and creating a transit-oriented development (TOD) strategy. Infill and brownfield development will prioritize development opportunities on lands that are underutilized, abandoned, or were previously zoned for one use such as office-commercial. Infill and brownfield development take development pressure off of the urban periphery and greenfield land. TOD can be implemented in densifying neighbourhoods, offering transit nodes where frequent service is present.

Sample modelling by the Centre for Clean Air Policy shows the impact of land-use decisions that prioritize infill development and implement a TOD strategy. Each policy had the potential to dramatically increase transportation use, reduce trip distance, and cut emissions. A summary table of this modelling is provided below.

Table 4: Transportation impacts of land use and emissions change.[6]

	VKT (%)	Emissions (Mt CO2e)
TOD	-21	-717
Infill / Brownfield Prioritization	-39	-1375

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[3] Dierkers, G., Silsbe, E., Stott, S., Winkelman, S., and Wubbem, M. "CCAP Transportation Emissions Guidebook- Part One: Land-Use, Transit & Travel Demand Management." Center for Clean Air Policy, 2008. http://www.ccap.org/guidebook/CCAP%20Transportation%20Guidebook%20(1).pdf.

[4] *Transport Energy and CO2*. 2009. Paris, France: International Energy Agency / OECD. https://www.iea.org/publications/freepublications/publication/transport2009.pdf.

[5] Horning, Jessica, Ahmed El-Geneidy, and Kevin Krizek. 2007. "Perceptions of Walking Distance to Neighborhood Retail and Other Public Services." Montreal: Mcgill University. http://tram.mcgill.ca/Research/Publications/distance_perception.pdf.

[6] CCAP Transportation Emissions Guidebook- Part One: Land-Use, Transit & Travel Demand Management.

Through Ottawa's Official Plan, policies have already been identified to make the city more compact and multi-modal. Ottawa identifies these goals under Section 1.6 of the Official Plan: A City of Distinct Livable Communities:[7]

- A mix of land uses, housing types, compact and inclusive development, clustering of neighbourhood facilities and services and excellent pedestrian connections make communities more complete as well as walkable. Their attractiveness and pedestrian functions are increased by proactive urban design that improves the relationships between public and private land uses, built forms and the surrounding landscape.

- Liveability is addressed by accommodating new growth and development in a more sustainable manner utilizing compact, mixed-use built form principles, including a moderate increase in density.

- In underdeveloped areas, density is increased by adding more buildings in appropriate locations.

The Ottawa Pedestrian Plan (2013) identifies the goal to increase walking and walkability in the city. Along with better infrastructure, changes in land-use can help Ottawa reach 2031 targets, as shown below:

Figure 5. Ottawa goals for walking as indicated in the Ottawa Pedestrian Plan.

Exhibit 1.6 Walking Mode Shares for Internal Trips: 2011 Observations and 2031 Targets Established in TMP (morning peak period)

		Modal shares for 2011 and 2031					
		Inner Area	Inner Suburbs	Orléans	Riverside South/ Leitrim	Barrhaven	Kanata/ Stittsville
Walking	2011	51%	14%	19%	18%	23%	22%
	2031	52%	16%	20%	21%	24%	23%

Transportation decisions interrelate with the above policies and impact the urban environment. Decisions and policies that favour decentralized land-use (sprawl) will generally favour personal automobile use and result in the greatest amount of emissions. Contrarily, decisions that favour compact and mixed use communities served by transit will favour walking, cycling, or transit and result in fewer emissions.[8]

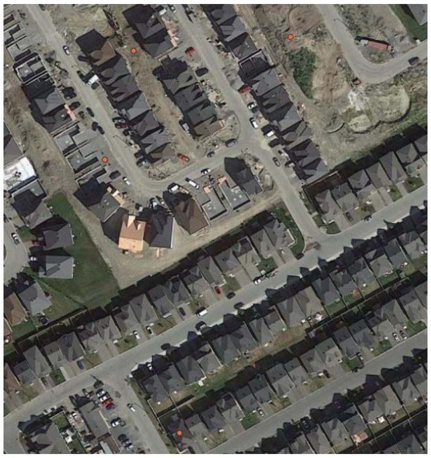
[7] "Ottawa Official Plan - Volume 1." Government. Ottawa, May 2003. https://ottawa.ca/en/city-hall/planning-and-development/official-plan-and-master-plans/official-plan/volume-1-official-plan.
[8] Litman, Todd. "Evaluating Transportation Land Use Impacts Considering the Impacts, Benefits and Costs of Different Land Use Development Patterns." Victoria Transportation Policy Institute, July 2017. http://www.vtpi.org/landuse.pdf.

Uptake Scenarios

Ottawa currently has a mix of infill and greenfield development. Greenfield development has tended to be low-density, favouring single-detached housing and taking place in areas such as Orleans, Barrhaven, or Kanata. Ottawa has also pursued infill initiatives such as the Richmond/Midway/Hartleigh development (Figure 5). The City has also pursued initiatives for TOD near the Confederation Line Stations. Infill initiatives are projected in the Integrated Scenario.

Figure 6. Sample new developments in Ottawa.

BAP/Conservative Scenarios



Bridlewood, West Ottawa
Units/ha: 16-20
Development Type: Single family detached. Front/back yards and attached/detached garages.

Orleans, East Ottawa
Units/ha: 10-17
Development Type: Single family detached. Front/back yards and attached/detached garages.

Moderate / Aggressive Scenarios

Richmond/Midway/Hartleigh
Units/ha: 50-70
Development Type: 3-Storey infill, multi-family rowhouses, and plex, at-grade parking.

Metcalf & Argyle, Centretown
Units/ha: 300-500
Development Type: High Density, 5-15 Storeys, underground parking, mixed-use.

Table 5: Uptake scenarios for land-use.

Action	Conservative	Moderate	Aggressive
Land-use	Official plan until 2031	70% of new development is in urban centres or adjacent to existing or new LRT, BRT by 2025.	90% of new development is in urban centres or adjacent to existing or new LRT, BRT by 2025.
Walking	No change in city-wide modeshift	For 2km trips, Mode shift to 20% of the walking and cycling potential away from vehicles and driving.	For 2km trips, Mode shift to 50% of the walking and cycling potential away from vehicles and driving.

Electrification of Commercial Vehicles

Commercial vehicles account for a significant proportion of transportation emissions. Without significant intervention, emissions from commercial vehicles will likely increase as Ottawa's population continues to grow.

Roughly all emissions in the commercial vehicle sector could be avoided through electrification of commercial fleets. Diesel is the major source of fuel as of 2016 for commercial vehicles in Ottawa, accounting for 60% of energy use, followed by gas at 37%. An insignificant amount of commercial vehicles were electric in 2016.

The major technologies for electrifying transportation include: fuel cell technology— which can be charged from multiple energy sources—and battery-electric. Battery-electric vehicles are better suited to vehicles making short trips within the city, while fuel-cell technology can be more effective for longer-range trips. Each technology has advantages and disadvantages, but both may be needed to successfully electrify the majority of commercial vehicles. A summary graphic of tradeoffs is provided in Figure 7.

Figure 6. Commercial vehicles by energy use, 2016.

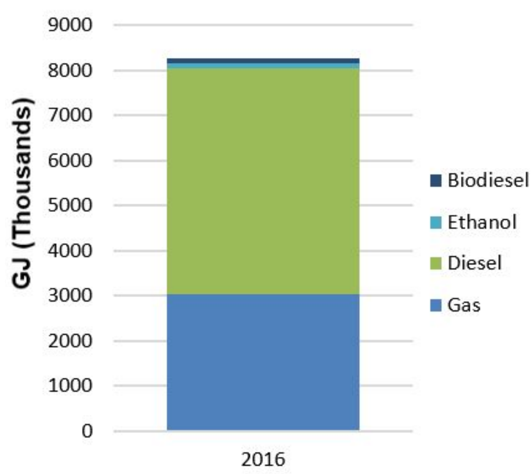
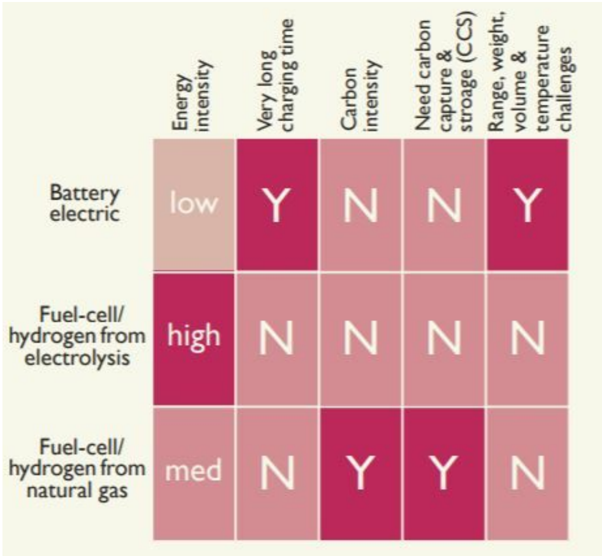


Figure 7. Comparison of large vehicle electrification options in BC.[9]



[9] Talebian, Hoda, Omar Herrera, Tran Martino, and Walter Merida. 2018. "Electrification of Road Freight Transport: Policy Implications in British Columbia." Energy Policy. Vancouver, BC: UBC. https://pics.uvic.ca/transportation-futures-british-columbia.

Infrastructure Options

1. Electric road systems (ERS): This infrastructure works with commercial vehicles that can receive electricity from installed power stations along the road. Inductive charging places power stations within the road and vehicles drive over them to charge. This technology is still being piloted but has shown to be less efficient than overhead lines, and higher costs per kilometre.[10]

2. Overhead catenary lines: This technology has already been established in urban areas as it connects transit lines, including the upcoming Confederation Line. This technology will require a connection on the trucks themselves, along with regulation stating that trucks must use them. To date, pilot programs are being run in Sweden, Germany, and the US.[11]

3. Charging stations: Charging stations might be required for commercial vehicles that are battery powered and making multiple deliveries in various areas of the city. Demand may vary depending on the location of warehouses and how companies organize their routes.

Other Actions and Bylaws

Table 6: Policies and actions for electrification of commercial vehicles.

Policy or Strategy	Description	Level of Difficulty to Implement
Carbon tax	Adding charges for use of carbon-emitting fuels can incentivize business to become more efficient and choose carbon-free technology.	Difficult: This must be led and implemented by the Province of Ontario or the Federal Government.
Fuel station regulations	A bylaw can require new or redeveloped stations to provide alternative fuel. The City of Surrey (BC) has adopted such a regulation.	Low: Normal city process to create new bylaws.
Off-street parking requirements	Cities can require commercial businesses to be equipped with electric vehicle charging stations as a first step toward creating the infrastructure needed for electric vehicles.	Low: Many cities are adopting new parking bylaws to encourage personal and commercial electric vehicles.
Street design	Cities can design streets to be narrower to decrease vehicle accessibility or add car-free areas. These design measures direct companies to choose smaller delivery vehicles such as bicycle courier or small electric cargo vehicles. Enforcing parking regulations to prohibit double parking can also signal companies to choose other vehicles.	Medium-Difficult: Cities can begin designing new streets and retrofitting existing streets to be more narrow and decrease vehicle access. Street retrofits require strategy for consultation and diverting traffic flows.
Transforming City Fleets	City fleets perform several core functions such as garbage pickup, roads and water servicing and maintenance. Other vehicles that may fall in city purview are ambulance, fire, and police. Transforming city fleets can be a model for commercial vehicle electrification	Medium: Adding electric vehicles will require a larger budget but may lower life cycle costs.

[10] "The Future of Trucks: Implications for Energy and the Environment." International Energy Agency, 2017. www.iea.org/publications/freepublications/publication/TheFutureofTrucksImplicationsforEnergyandtheEnvironment.pdf.
[11] Ibid.

Figure 8. An electric bike makes a delivery during winter in Stockholm, Sweden[12]

Figure 9. Shift Delivery Co-op uses electric bikes in Downtown Vancouver.[13]

Boundaries and Barriers of Strategy

Barriers to this strategy are noted below, with additional boundaries and barriers provided near the end of the paper.

Jurisdiction
If strong actions or policies need to be taken, Ottawa must work with Provincial and Federal governments to establish regulations to electrify a greater proportion of commercial vehicles. There will also be upfront costs of new infrastructure that may be difficult for Ottawa to finance alone.

Further study is needed to understand capacity issues in providing enough electricity to electrify 50% to 100% of commercial vehicles in Ontario. In British Columbia's case, 64% of commercial vehicles will be required to be electric in order to meet climate goals in the transportation sector.[14] This will be completed with a combination of fuel-cell and battery-electric technologies. Modelling for BC projects reports an energy shortfall to reach the 64% target; for every 1% of reduced GHG emission from commercial trucks, an additional 1.5 to 3.8% of additional hydroelectric, or renewable, energy is required.[15] This amounts to approximately 33 Terawatt hours (TWh) of additional electricity over 2015 levels.[16] In Ontario, the IESO anticipates the ability to meet increasing electrical demands stemming from electrified transport, but will require continued growth from low-carbon sources as well as nuclear energy and natural gas to do so.[17]

Market Barriers and Technology
Commercial vehicles and providers of service have an interest in reducing their costs—including the cost of gasoline—and should be motivated to make the transition to electricity where feasible. However, if there is no financial cost to continue operations as usual, there is less incentive to

[12] The life of cargo bike delivery heroes during winter in Sweden https://www.youtube.com/watch?v=1UzNI3kgSO4
[13] "Women in Urbanism." Modacity, 12. 20, 2016. http://www.modacitylife.com/blog/women-in-urbanism-robyn-ashwell
[14] "Electrification of Road Freight Transport: Policy Implications in British Columbia." Energy Policy. Vancouver, BC: UBC.
[15] Ibid.
[16] Ibid.
[17] "Preliminary Outlook and Discussion: Ontario Supply/Demand Balance to 2035." 2016. IESO, March 23. http://www.ieso.ca/-/media/Files/IESO/Document-Library/sac/2016/SAC-20160323-Ontario-Planning-Outlook.pdf?la=en

change to electric vehicles. Cities can add road pricing measures with reduced costs for electric vehicles, or a carbon tax can change business cases but will require policy from senior levels of government.

Electrictrifying commercial vehicles presents a larger technological challenge than personal vehicles due to truck and cargo weights, the distance of daily travel, and the absence of widely-distributed vehicle charging stations. Commercial vehicles that operate solely within urban areas face lower barriers due to shorter trips and greater availability of charging stations. The more intensive use of commercial vehicles (high annual distances travelled) can work in favour of the economics of electrification. There is promise for new technologies as major companies, such as Daimler and Tesla, announce the launch of electric semis able to operate over similar distances to most long distance freight trucks operating today.[18]

The full network of energy supply must be accounted for when considering electrifying commercial vehicles. Ottawa and Ontario have the advantage of plentiful hydroelectric energy and other low-carbon electricity sources, such as nuclear power, which would result in near zero emissions for electric commercial vehicles.

Scope Limitations
In this strategy, there will be some travel that is out of scope for Ottawa. Trips that originate from outside the city, and trips that have origins inside the city but destinations outside the city are difficult to account for and regulate and therefore are not modelled.

Uptake Scenarios

Table 7: Uptake scenarios for commercial vehicles.

Action	Conservative	Moderate	Aggressive
Commercial Vehicles	10% of heavy trucks are zero emissions by 2030; 40% by 2040.	20% of heavy trucks are zero emissions by 2030; 60% by 2040.	40% of heavy trucks are zero emissions by 2030; 100% by 2040.
City Fleet	Municipal fleet is 20% electric by 2020; 40% by 2040.	Municipal fleet is 40% electric by 2020; 60% by 2040.	Municipal fleet is 60% electric by 2020; 100% by 2040.

[18]Lambert, Fred. “Daimler Unveils Electric E-Cascadia Semi Truck to Compete with Tesla Semi, Launches Electric Truck Group.” Electrick, June 9, 2018. https://electrek.co/2018/06/07/daimler-electric-semi-truck-ecascadia-tesla-semi.

Transportation Behaviour Change/TDM Program

Changing behaviours around transportation is the goal of Transportation Demand Management (TDM) programs. TDM can be targeted to only reduce peak-hour traffic, or can be part of a city-wide traffic management program. TDM makes walking or taking transit as appealing as driving. It originates from the idea that citizens make multiple trips daily and base their travel decisions on factors including convenience, time, and safety. If driving to meet friends nearby, to get a coffee, to exercise, or run an errand is accompanied by free and plentiful parking, plentiful travel lanes, and direct door-to-door access, then a vehicle trip is chosen. The externalities of traffic, congestion, pollution, and sprawl occur as people choose the vehicle trip. TDM can help alter this mode choice.

A TDM program has the ability to move a city towards a low-carbon future by reducing VKT, reducing demand for travel, and increasing alternative modes of transportation. Not all actions are equal, but cities are recommended to take a holistic approach. A list of researched TDM actions is shown in the table below.

Table 8: Impact of TDM strategies.[19]

Strategy	Details	Vehicle Trip Reduction Impact (for commuting to work)
Parking Charges	Paying for parking	20-30%
Information Alone	Information on alternatives to driving alone	1.4%
Services Alone	Ridematching, shuttles, guaranteed rIde home (for emergency)	8.5%
Monetary Incentives Alone	Subsidies for carpool or transit	8-18%
Service & Monetary Incentives	Transit voucher and guaranteed ride home	24.5%
Cash Benefit	Cash benefit offered in lieu of accepting free parking	17%

Ottawa has already recognized TDM as a strategy to change travel behaviour, and notably has a program for TD Place at Lansdowne Park. With the goal of having vehicle trips account for less than 50% of travel. TD place offers a shuttle service, additional bike parking, and off-street parking away from the site. Further, since 2010 Ottawa has implemented several city-wide TDM strategies that include more and safer bicycle infrastructure, advertising programs for cycling, transit passes for the University of Ottawa, connecting car share service to transit with one pass, ridesharing, and other actions.[20] Ottawa also has TDM guidelines where new development applications for commercial or mixed-use building must comply. Having a TDM coordinator for the operations of a building is a notable strategy in Ottawa's guidelines.[21]

[19] Table Adapted from Nelson/Nygaard, "TDM: State of the Practice" 2013.
[20] "Transportation Demand Management Strategy (Draft)." 2012. Noxon Associates Limited: City of Ottawa. http://ottawa.ca/calendar/ottawa/citycouncil/trc/2012/05-02/02%20-%20Doc%201.pdf.
[21] Ibid.

TDM Policies and Strategies

Many of the policies described in the Transportation Pathway are included in typical TDM programs, including congestion charging, car-free areas, and parking management.

1. Fees and Charges: Charging users to use roads and parking is a major way to shift the balance from personal vehicle trips, especially single occupant trips. Fees such as fuel taxes or carbon taxes can also be applied to realize full costs of driving.

2. Greater Information: The use of newer technologies, particularly smartphones and transportation apps, can greatly encourage alternatives to personal automobiles. Transit riders can get real-time transit data through smartphone applications, create a more accurate picture of the length of time required to reach a destination, and make travel decisions accordingly.[22]

3. Enhanced Bicycle/Pedestrian Infrastructure: Many design considerations can be made to ensure walking or cycling is comfortable and attractive, including proper, well-maintained sidewalks and street lighting, attractive landscaping or art, seating, bicycle accommodation in parkades, secure bicycle storage, and employee shower and changing facilities.[23]

4. Transit Passes: Employee and student transit passes can be provided by employers and institutions to encourage transit use. Furthermore, housing developers can provide passes to new housing developments in lieu of providing parking.

5. Parking Management: This method of TDM removes the convenience of abundant and free parking, and is analyzed further in the following section.

<u>Uptake Scenarios</u>

The TDM strategy has strong relationships with land-use, road/congestion charging, and parking management and will be modelled under those strategies.

[22] Nelson/Nygaard Consulting. 2013. "Transportation Demand Management: State of the Practice." Michigan: Smart Growth America. https://smartgrowthamerica.org/app/legacy/documents/state-of-the-practice-tdm.pdf.
[23] Ibid.

Parking Management

Parking requirements are within City control and are implemented during the development of new buildings, homes, temporary structures, events, and transit stations. Cars are parked 95% of the time, and can use numerous parking spaces within a week. Plentiful and accessible parking encourages vehicle ownership and operation. Firm policies paired with strict enforcement of parking regulations can encourage citizens to reduce personal automobile use and ownership. Trip-making decisions and modal choices are sensitive to both the availability of parking and its costs, making parking management strategies particularly effective in changing behaviour.

When considering transportation emissions, parking policies have been shown to reduce demand for personal vehicles trips and reduce community VKT. The table summarizes a study that shows how different parking policies reduced VKT over different periods of time.

Table 9: Parking policies and measures, and VKT reductions.[24]

Measure	Reduction of VKT Potential	Time for Implementation
Resident (priced) parking permits for on-street	0-10%	1-2 Years
Park and Ride systems	10-25%	2-5 Years
Parking Cash Out for workplaces	10-25%	1-2 Years
Reduce Off-street parking requirements for new construction	10-25%	5+ years
Double Parking charges in busy areas	10-25%	1-2 Years
Car-Free Zones	25%+	2-5 Years
Compact Communities	25%+	5+ Years

The parking strategies below can encourage citizens to reconsider trips taken by vehicle, share rides, or decide against owning a vehicle at all.

1. On-street parking fees: a strong pricing program that is regularly reviewed and studied can encourage citizens to choose other methods of travel, while improving parking availability in cities.

2. Implement maximum off-street parking requirements for new developments: reducing or eliminating parking requirements for residential developments, workplaces and shopping areas can change norms and encourage behaviours and development patterns that reduce automobile dependence.

[24] *Transport Energy and CO2*. 2009. Paris, France: International Energy Agency / OECD. https://www.iea.org/publications/freepublications/publication/transport2009.pdf.

3. Zero off-street parking requirements near destinations served by transit: developments near transit, under TOD strategies, can encourage modal shifts from personal vehicles to transit..

4. Parking cash out: employees are offered a cash equivalent to the cost of a free parking spot at their workplace if they choose not to drive to work.

5. Increase enforcement for illegal parking: within city centres or dense areas, citizens may attempt to double park in a travel lane beside a parked car, or park in undesignated areas. This can be a safety concern as emergency vehicles may have trouble getting to their destination, or other cars may need to maneuver around them.

6. Eliminate or redevelop surface parking lots: surface parking can act as an agent for sprawl, act as a cue to incentivize driving, and delay more dense developments within a community.

7. Compact communities: parking has a connection to land use. As more destinations and activities are closer together there is an increase towards walking, cycling, and transit.

Uptake Scenarios

No major change is anticipated in the BAP scenario. An action was developed to increase parking rates by a factor of 1.5 in City-owned lots and on-street parking using the City's transportation model as part of an integrated scenario; the action works in unison with a suite of land use changes. As a result, the parking management aggressive scenario is modelled as an action under the aggressive Land-use Actions (Table 10). Further actions to increase walking and cycling and increased development near transit stations are combined in the Aggressive Land-use Scenario, thereby reducing the need for personal vehicle trips.

Table 10: Uptake Scenarios for parking management.

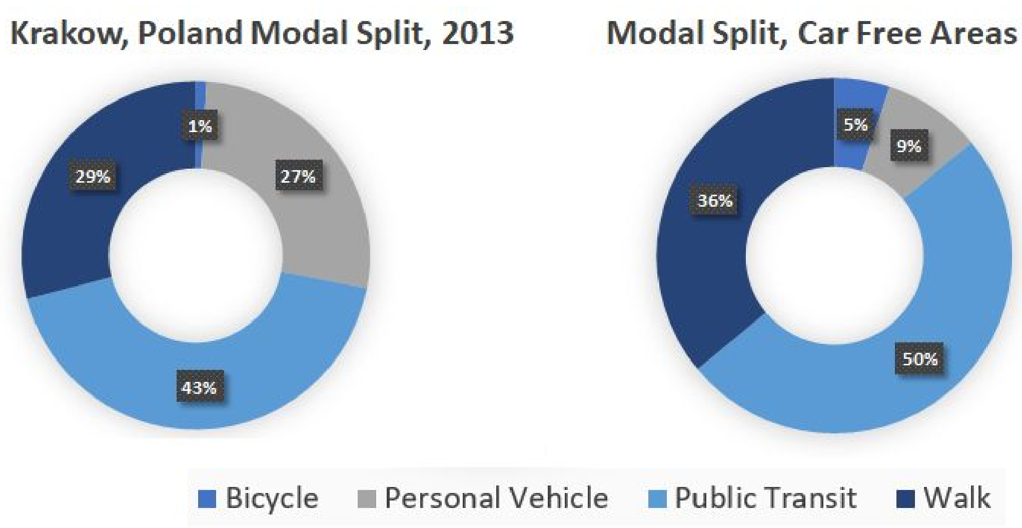
Action	Conservative	Moderate	Aggressive
Parking Management	No change	No change	Increase on-street parking fares during peak hours by a factor of 1.5 by 2050.

Car-free Areas

A car-free zone/area or pedestrian area/corridor is an area vehicles cannot access. They typically use barriers or a change in streetscape treatment to indicate restricted vehicle access. Car-free areas support the goals of sustainable transportation planning by increasing the proportion of citizens who will walk or cycle to their destination. One such example is Sparks Street in Ottawa, which plays a role within the community as a cultural and event centre, and where residents can meet for lunch or dinner, to take in a festival, to relax in the public space, or to walk home.

Car-free areas can often create a sense of place in a neighbourhood. Studies conducted in Krakow, Poland showed that citizens accessed new public squares and car-free areas increasingly by foot, bicycle, or transit when compared to non car-free areas. In three car-free areas, approximately 50% of citizens walked to the areas, 10% cycled, 35% of citizens used public transit , and car use was below 5% on average.[25] This is contrasted against a normal modal split of 43% transit, 29% walking, 27% personal vehicle, and 1% bicycle.[26] When surveyed on the reason that people chose to visit the car-free areas, the most common reason was a lack of vehicles.[27]

Figure 10. Normal modal split vs. car-free areas, Krakow, Poland.



Another benefit of car-free areas is the creation of more opportunities for planting and landscaping, therefore reducing urban temperatures resulting from overly paved areas—the "urban heat island effect". When landscaped, car-free areas can act as natural air conditioners. Exceptional cases such as Seoul, South Korea exist where an urban freeway was removed and a naturally occuring river was uncovered resulting in 3-4 degrees Celsius lower temperatures than nearby areas.[28]

[25] Szarata, Andrej, Katarzyna Nosal, Urszala Duda-Wiertel, and Lukzak Franek. 2017. "The Impact of the Car Restrictions Implemented in the City Centre on the Public Space Quality." *20th EURO Working Group on Transportation Meeting*, September. https://ac.els-cdn.com/S2352146517309158/1-s2.0-S2352146517309158-main.pdf?_tid=718b0618-fb06-4f0c-9177-5fbb685812ee&acdnat=1533133189_9b3bd0d41a650e2da38869272ec17316.

[26] Szarata, Andrej. 2013. "Accessibility of Public in Krakow." Powerpoint, Krakow. http://www.accessibilityplanning.eu/wp-content/uploads/2014/02/Krakow-presentation_Szarata_23May13.pdf.

[27] Ibid

[28] Meinhold, Bridgette. 2010. "Seoul Transforms a Freeway Into A River and Public Park." Inhabitat. 2010. https://inhabitat.com/seoul-recovers-a-lost-stream-transforms-it-into-an-urban-park.

Car-free Policies and Strategies

The City has a vision to make a pedestrian area in Kanata. Kanata has a commercial centre which favours pedestrian movement in the shopping streets. Future development can densify and mix uses to include residential development. Future planning can permit full pedestrian infrastructure that is car-free.

Creating car-free areas in neighbourhoods, recreational or commercial areas that already have active streetscapes can encourage a shift away from car travel. Indicators can be low-parking vacancies, full bicycle racks, new shops or restaurants opening frequently, or a high-density of restaurants or bars.

The Gehl Institute developed 12 Criteria for evaluating public spaces, which can be used as a strategy to evaluate public spaces or develop them further to make them car-free. The 12 criteria are listed in Appendix 1 and are based on making pedestrians feel safe, welcome, and protected from harsh climates and the noise, pollution, and high speeds of vehicles.

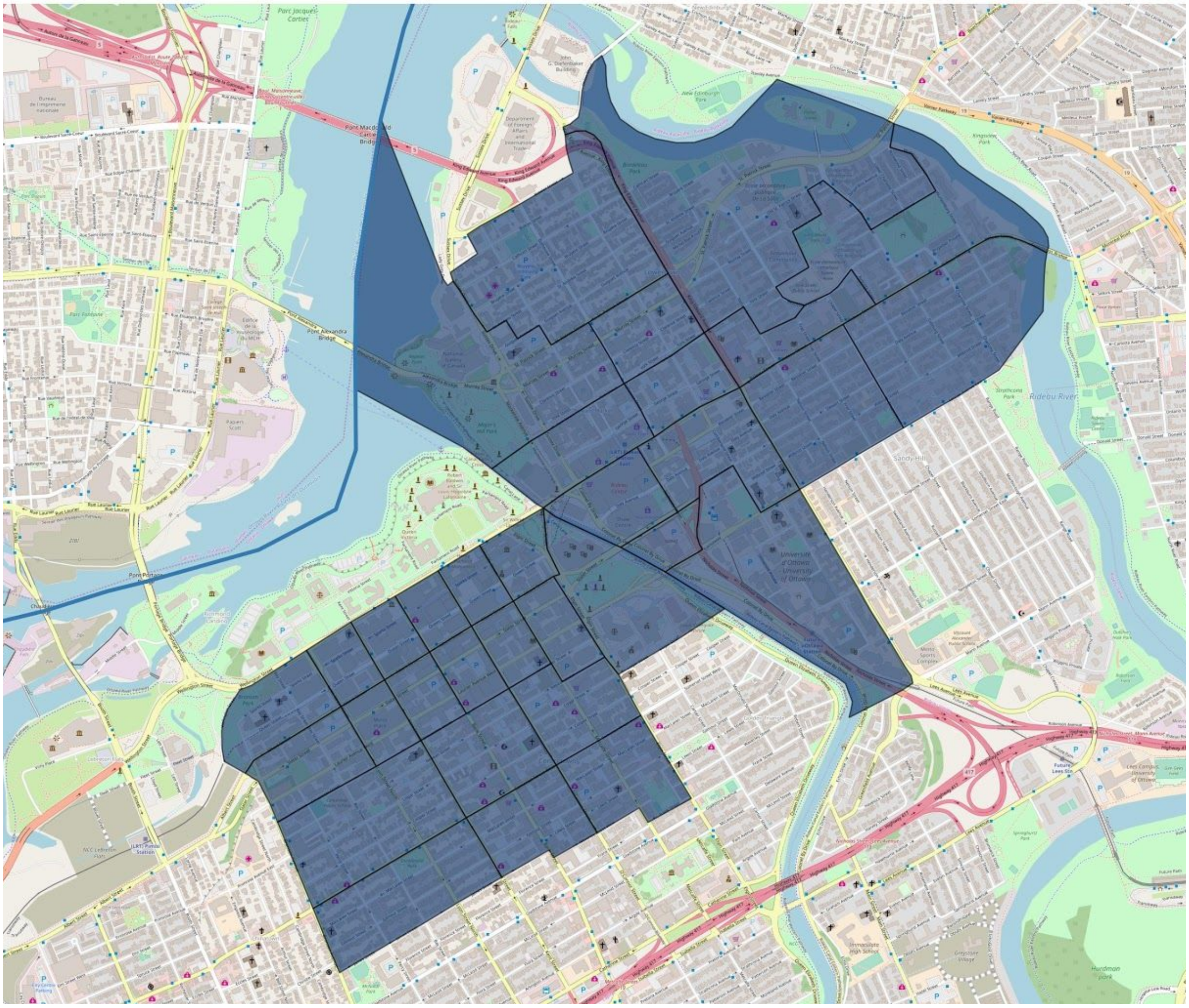
Uptake Scenarios

The Integrated Scenario identifies areas in Ottawa with high concentrations of commercial resources and housing density. Two notable indicators for placement of a car free area include areas where the population densities exceed 5000 people per square kilometre, and areas where 70% of residents commute to work by walking or cycling. The map below shows an aggregation of these indicators to include Byward market and downtown Ottawa, Wellington-Rideau, Sparks and Bank streets, and the University of Ottawa campus. Appendix 2 provides background maps for population densities and active transportation.

Table 11: Uptake scenarios for car-free areas.

Action	Conservative	Moderate	Aggressive
Car Free Areas	None	None	Care-free areas in: Byward Market Downtown Wellington-Rideau Sparks Bank Street Ottawa-U campus

Figure 11. Car-free areas in Ottawa



Congestion Charges

Congestion charges are fees for entering a specific area by car, and are a method of reducing peak time traffic in a city that is considered a form of Transportation Demand Management (TDM). Traffic congestion has a cost to motorists because their trip duration increases. Traffic congestion also has several external costs that should be noted:

- Other road users such as cyclists or transit users may have to bear similar costs of traffic congestion that are not directly caused by them.
- Pollution and climate impacts caused by traffic congestion are costs borne by an entire community, not just drivers;
- Busy streets with traffic hinder walking or cycling as there may be perceived danger, poor air quality, or poor ambience/environmental factors; and
- Economic Costs that are borne by entire cities occur due to congestion. In a previous report, Transport Canada modelled the economic cost of non-recurrent congestion, where congestion is caused by irregular events, and found the Ottawa-Gatineau region loses between $100 and $250 million yearly depending on congestion levels in 2006 dollars.[29] A study of recurring congestion, a result of road capacity and driving behaviour, costs the region between $39 and $89 million in 2002 dollars.[30]

Vehicles operate most efficiently when travelling at a constant speed (and that efficiency is highest around 60 km/hour). Congestion increases greenhouse gas emissions due to vehicle idling, low speeds and stop-and-go acceleration cycles. A study produced in California modelled emissions from traffic and various speeds, and is shown in the table below.

Table 12: Climate emissions related to traffic rates.[31]

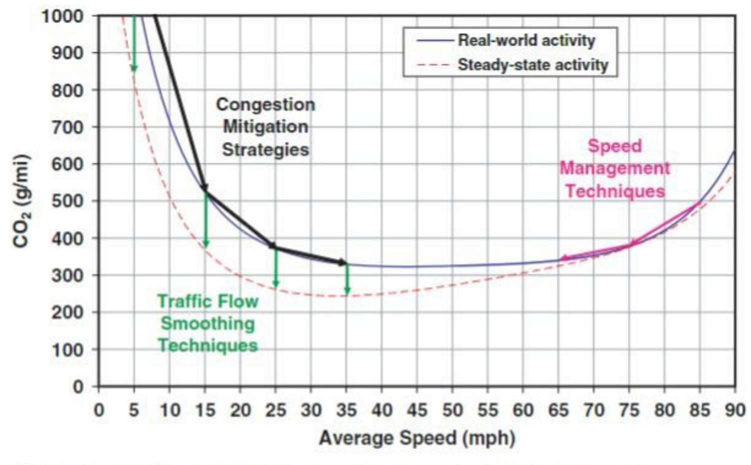
Speed Range	8-24 kph (congestion)	32-100 kph	100-130 kph (speeding)
Emissions Rate in Grams of CO2/km	500-800	200-500	300-500

The same study modelled emissions from traffic and found a possible 7-12% reduction in each of the three following methods:

[29] "Costs of Non-Recurrent Congestion in Canada Report." 2006. Technical. Transport Canada Economic Analysis. Canada: Transport Canada. http://www.bv.transports.gouv.qc.ca/mono/0964770/01_Report.pdf.
[30] "The Cost of Urban Congestion in Canada." 2006. Transport Canada. https://pdfs.semanticscholar.org/ae2c/c8a3231b62525af11e01f2d7e2a4a7c13a80.pdf.
[31] Barth, Matthew, and Kanok Boriboonsomsin. 2010. "Real-World Carbon Dioxide Impacts of Traffic Congestion," May. https://escholarship.org/uc/item/07n946vd.

1. Congestion mitigation strategies (Congestion Charging) that reduce severe congestion so higher average speeds are achieved and maintained;
2. Speed management techniques that can bring down excessive speeds to more moderate speeds of approximately 85 kph (e.g., by enforcement, road design to limit speeding); and
3. Traffic flow smoothing techniques that can suppress shock waves and thus reduce the number of acceleration and deceleration events (e.g., variable speed limits, autonomous vehicles).

Figure 12. Strategies to reduce traffic related emissions and the modelled effect.[32]



Stockholm, Singapore, London, and Milan provide notable examples of cities implementing congestion charges and changing travel behaviour. Each city experimented with different methods of implementing congestion charges such as charging flat or variable rates, targeting specific roads (road-pricing) or entire urban areas (cordon pricing), and charging all day or only peak hours. The experience of these cities is summarized in Appendix 3. Congestion charges require tailoring to specific city cultures and environments. There are continuous research efforts on how congestion pricing may affect businesses and what effect it has for people of different incomes.

Each case city described above is different than Ottawa as the populations are generally larger and there are more people per square kilometre, however congestion charging was successful in reducing traffic counts by 14% in Stockholm and Milan, and 45% in Singapore.[33] The transit mode share increase ranged from 5% in Stockholm to 13% in Singapore (Table 13).[34]

[32] Ibid
[33] Jarl, Valfrid. "Congestion Pricing in Urban Areas - Theory and Case Studies." Thesis. Lund University: Department of Technology and Society, 2009. http://www.tft.lth.se/fileadmin/tft/dok/publ/5000/Thesis183_VJ_scr.pdf.
[34] Ibid

Table 13: Transportation and traffic changes after congestion charges in major cities.[35]

	Singapore	London	Stockholm	Milan
Target Reduction	-25-30%	-10-15%	-10-15% in AM & PM	-10%
Actual Reduction:				
Traffic-Overall	-45%	-14%	-22%	-14%
Traffic - AM Peak	-45%	No Data	-16%	No Data
Cars-Overall	-75%	-36%	-22%	No Data
Mode-share - AM Peak				
Transit / Car Before (AM)	37/63	87.5/12.5	70/30	No Data
Transit / Car After (AM)	50/50	89/11	75/25	No Data

Congestion Charge Policies and Strategies

The following tools, suggested by the Victoria Transport Policy Institute, could be implemented in Ottawa.

Table 14: Policy tools for traffic congestion and other road pricing systems. (Adapted from Littman).[36]

Name	Description	Objectives
Road toll	A fixed fee for driving on a particular road.	To raise revenues for transit and discourage single-passenger trips
Congestion pricing (time-variable)	A fee that is higher under congested conditions than uncongested conditions, intended to shift some vehicle traffic to other routes, times and modes.	To raise revenues and reduce traffic congestion.
Cordon fees	Fees charged for driving in a bounded area of a city such as City Centre	To reduce congestion in major urban centers.
HOV lanes	A high-occupancy-vehicle lane that accommodates a limited number of lower-occupant vehicles for a fee.	To favour HOVs compared with a general-purpose lane, and to raise revenues compared with an HOV lane.
Distance-based fees	A vehicle use fee based on how many kilometres a vehicle is driven.	To raise revenues and reduce various traffic problems.
Pay-As-You-Drive insurance	Pro-rates premiums by mileage so vehicle insurance becomes a variable cost.	To reduce various traffic problems, particularly accidents.

[35] Ibid.

[36] Littman, Todd. n.d. "Road Pricing: Congestion Pricing, Value Pricing, Toll Roads and HOV Lanes." Victoria Transport Policy Institute. http://www.vtpi.org/tdm/tdm35.htm.

Uptake Scenarios

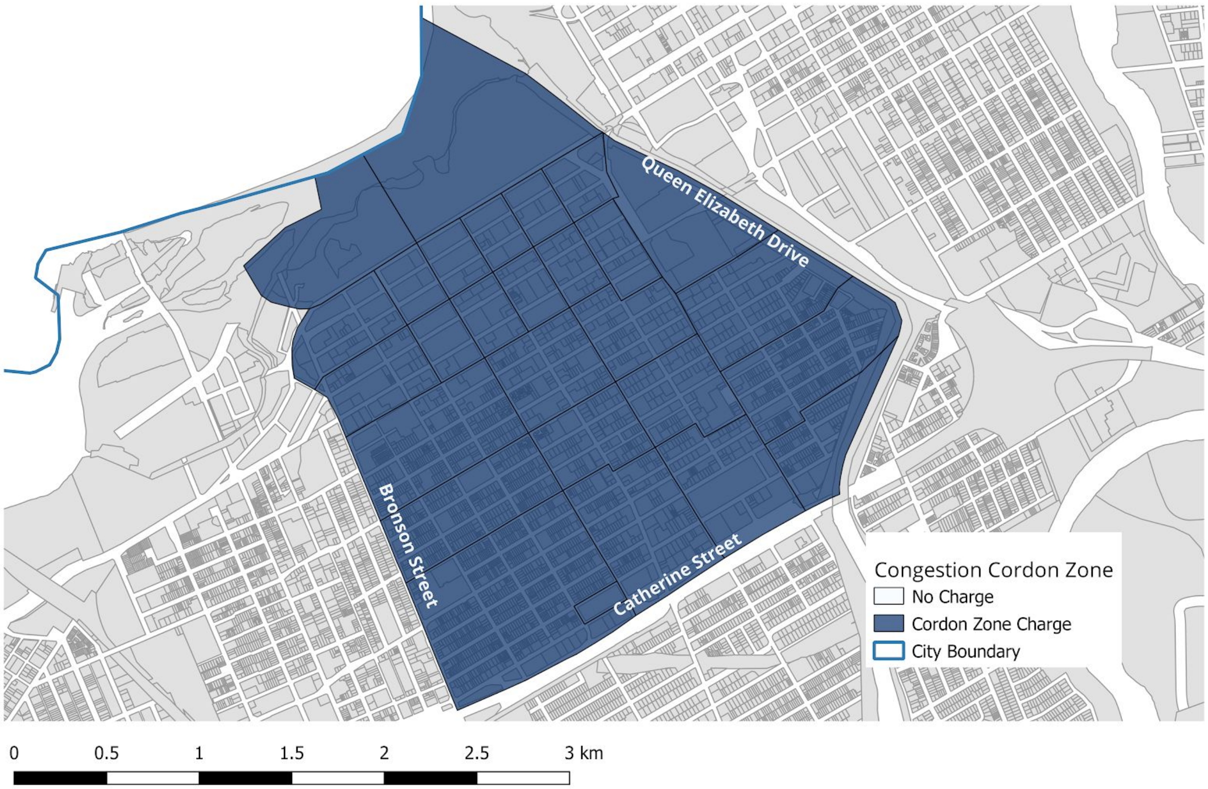
In the Aggressive Scenario, a Cordon Congestion Charge is applied in Ottawa's downtown core, with bounding streets: Bronson (West), Catherine (South), and Queen Elizabeth Drive (East), the north boundary extends to the Ottawa River (Figure 13). A congestion charge of $20 (higher than London, UK in order to test the policy)[37] is assumed between 6:00 am and 10:00 am on weekdays.

This action was developed using Ottawa's transportation model in an Integrated Scenario and responds to a suite of land-use changes.

Table 15: Uptake scenarios for congestion charges.

Action	Conservative	Moderate	Aggressive
Congestion Charges	None	None	$20 congestion charge applied to the downtown core between 6:00 am and 10:00 am on weekdays.

Figure 13. Modelled congestion charge zone for Ottawa.



[37] "Congestion Charge" Transport for London. https://tfl.gov.uk/modes/driving/congestion-charge

Enhanced Transit

Quality transit is the backbone of any sustainable transportation plan and will often impact land-use decisions, requiring a more dense urban form and mix of land-uses. Quality transit service is a significant strategy to reduce GHG emissions and keep them low; the Confederation Line as a transit enhancement in Ottawa will reduce an estimated 94,000 tonnes of GHG emissions by 2031.[38] A shift away from personal vehicle use towards transit usage can reduce household emissions up to 2,177 kg of CO2 per year according to the American Public Transit Institute.[39]

In addition to reducing greenhouse gas emissions, enhanced transit can have many other important benefits to a community, including greater public space, a less noisy environment, greater accessibility for persons with different physical abilities, and less urban space dedicated to roads. Higher ridership of transit can result in reduced energy use within a community, greater options for walking and cycling, and reduced VKT.

Well designed transit systems work best in compact and mixed use communities, which implies a relation to land-use. When transit and land-use work well together, further gains in walking and cycling use can be realized and community emissions from transportation are further reduced.

Transit Policies and Strategies

Many strategies exist to enhance transit within a community, including:

- Improving system performance through additional routes, coverage area, frequency of service and hours of operation;
- Increasing efficiency through the introduction bus only lanes during peak times;
- Using Bus-Rapid Transit systems with permanent dedicated bus lanes to increase travel speed and rider convenience;
- Increasing the share of transit vehicles that are electric;
- Reducing fares for weekends and holidays;
- Keeping fares low;
- Enhancing design of transit stations and stops to provide safety and comfort for riders. Making efforts for placemaking (see Car-Free Areas);
- Developing phone apps for more rider information, use one-tap cards for transit and other services; and
- Allowing flexibility in the system for the “last-mile” by introducing better pedestrian design and bicycle facilities. Partnering with car-share operators to provide parking near transit stations or use transit tap cards (see car share options).

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[38] *Transforming our Nation’s Capital: The Benefits of Light Rail.* City of Ottawa. 2012. http://www.ligneconfederationline.ca/media/pdf/The%20Benefits%20of%20Light%20Rail%20-%20Web.pdf

[39] “Public Transportation Greenhouse Gases and Conserves Energy.” n.d. American Public Transport Association. https://www.apta.com/resources/reportsandpublications/Documents/greenhouse_brochure.pdf.

Fuel Types in Transit

Low-carbon transit also requires a shift in fuels. Transit fleets today rely heavily on diesel buses, but a shift towards electric vehicles will reduce emissions. Other options can be considered in the mid-term such as compressed natural gas (CNG), hydrogen, biodiesel, or hybrid buses.

Ottawa currently has 936 buses in its fleet not including Para Transpo, as recorded by OC Transpo.[40] Fuel costs are a significant operating cost for bus operations and therefore there is an incentive to be as efficient as possible. Hybrid buses can be a step towards reducing fuel use and emissions (Ottawa currently runs 177 hybrid buses), but the final step is moving towards full electrification of a transit fleet. Hybrid and electric bus technologies can have a capital cost that is 50% or greater than a diesel bus.[41] Previous studies have quantified different fuel types on regular transit runs and found that hybrid buses emit roughly 40% less GHG emissions (CO2, NOx) than diesel, and electric can emit zero emissions depending on how electricity is generated. A summary table is provided below.

Table 16: Bus fleet GHG emissions by fuel source for a New York transit run (adapted from Translink Hybrid Bus Showcase Study).[42]

Transit Route	Diesel	CNG	Hybrid	Electric*
New York Bus Cycle	7,076	5,685-6,602	4,251	0
Central Business District Cycle	2,779	2,360-2,809	2,262	0
Manhattan Cycle	4,268	3,457	2,841	0
% Reduction from Diesel		0-20%	18-40%	100%*

*When using/charging with Hydro Power in New York State

[40] "OC Transpo Bus Fleet." Government. OC Transpo, n.d. http://www.octranspo.com/about-octranspo/bus_fleet.
[41] *Transport Energy and CO2*. Paris, France: International Energy Agency / OECD, 2009.
[42] Rees, Stephen, Christine DeMarco, Tamim Raad, and Joanna Brownwell. 2003. "Sustainable Region Showcase for Metro Vancouver." Vancouver: Translink.
https://www.translink.ca/~/media/Documents/plans_and_projects/urban_showcase/general/urban_showcase_proposal.ashx.

Uptake Scenarios

The City's affordable transit network[43] and ultimate transit network[44] as shown in the Transportation Master plan are used as templates for the moderate and aggressive scenarios respectively, to identify high density neighbourhoods lacking frequent transit, and increase speeds and frequency of transit.

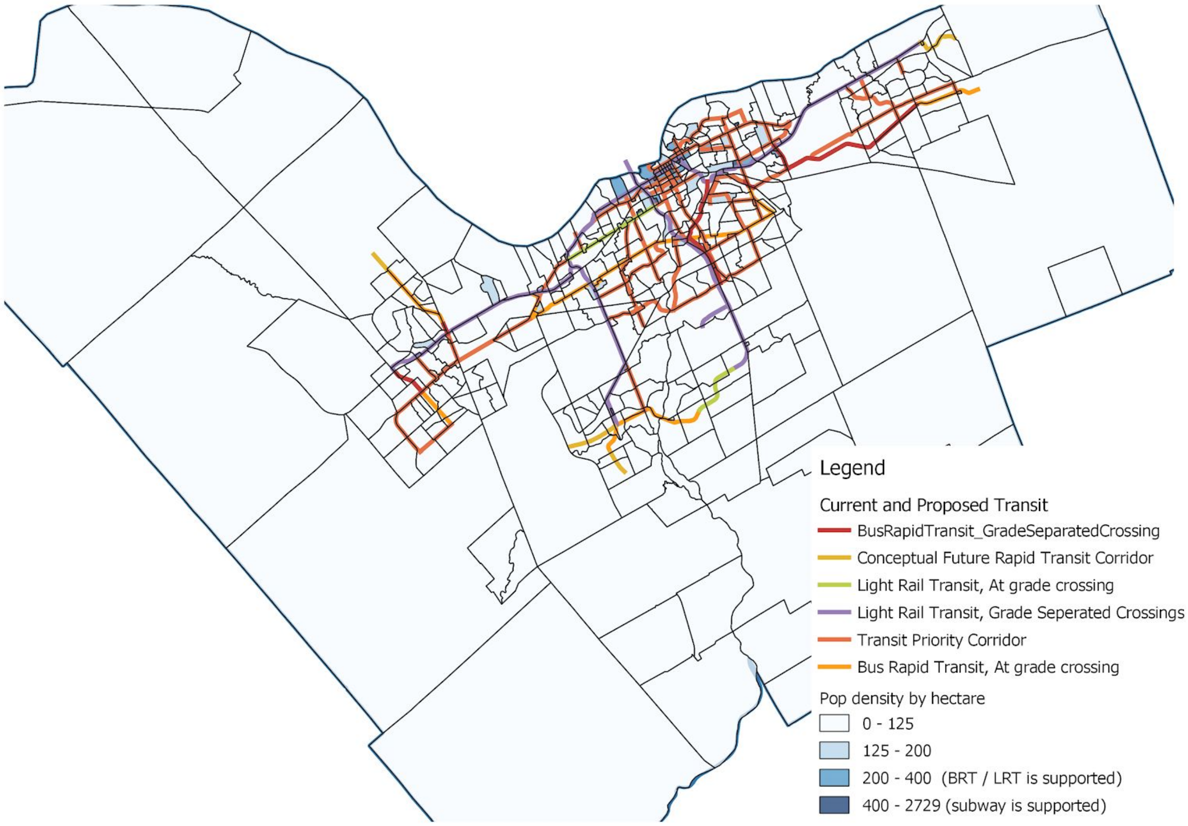
Table 17: Uptake scenarios for enhanced transit.

Action	Conservative	Moderate	Aggressive
Enhanced Transit	Completion of the Confederation Line- Phase 1 and 2	The Affordable Network is completed, and accompanied by a 10% transit modal increase. 100% of Transit vehicles are electric by 2050	Identify high density neighbourhoods without sufficient transit and increase transit share by 25% in these neighbourhoods The frequency of LRT is increased to every 90 seconds in downtown areas, and outer areas are increased to match. BRT speed is increased by 20% through prioritized lanes and stop lights where separated infrastructure is available. 100% of Transit vehicles are electric by 2050 Complete "Ultimate Transit" Network as shown in Transportation Master Plan

As part of Enhanced transit pathway, analysis of the future transit system proposed under the Ottawa Transportation Master Plan was undertaken with the aim of identifying zones that were underserved by the transit system, articulated in Figure 14. Zones would be considered underserved if they contained sufficient density for a higher level of transit than what is currently provided to the zone, using best practice thresholds for the Greater Toronto Area.[45] To commence this analysis, a GIS layer of all of the proposed transit lines was prepared and overlaid on a spatial analysis of density in the City. This analysis, illustrated in Figure 14, indicated that the proposed 2050 transit system provides generally appropriate coverage for the City and that no additional rapid transit beyond existing city plans was modelled.

[43] Ottawa Transportation Master Plan, Affordable Network: https://documents.ottawa.ca/sites/default/files/documents/tmp_map5_afford_network_en.pdf
[44] Ottawa Transportation Master Plan, Ultimate Network: https://documents.ottawa.ca/sites/default/files/documents/tmp_map_3_en.pdf
[45] Higgins, C. D. (2016). Benchmarking, planning, and promoting transit-oriented intensification in rapid transit station areas. Retrieved from https://macsphere.mcmaster.ca/handle/11375/20228

FIgure 14. Transit expansion possibilities in the Ottawa region.



Autonomous Vehicles (Shared)

Autonomous vehicles (AVs), or driverless vehicles, represent a newer technology that has the potential to radically transform urban mobility. Depending on how they are adopted, whether they are privately owned or shared, and the regulatory and other infrastructure that is built to support them, they have the potential to reduce vehicle ownership rates, VKT and related greenhouse gas emissions. The Province of Ontario has been a leader in Canada in testing the technology. Cities today are considering policy or are piloting programs to review whether autonomous vehicles can operate safely and effectively in their respective urban environments.

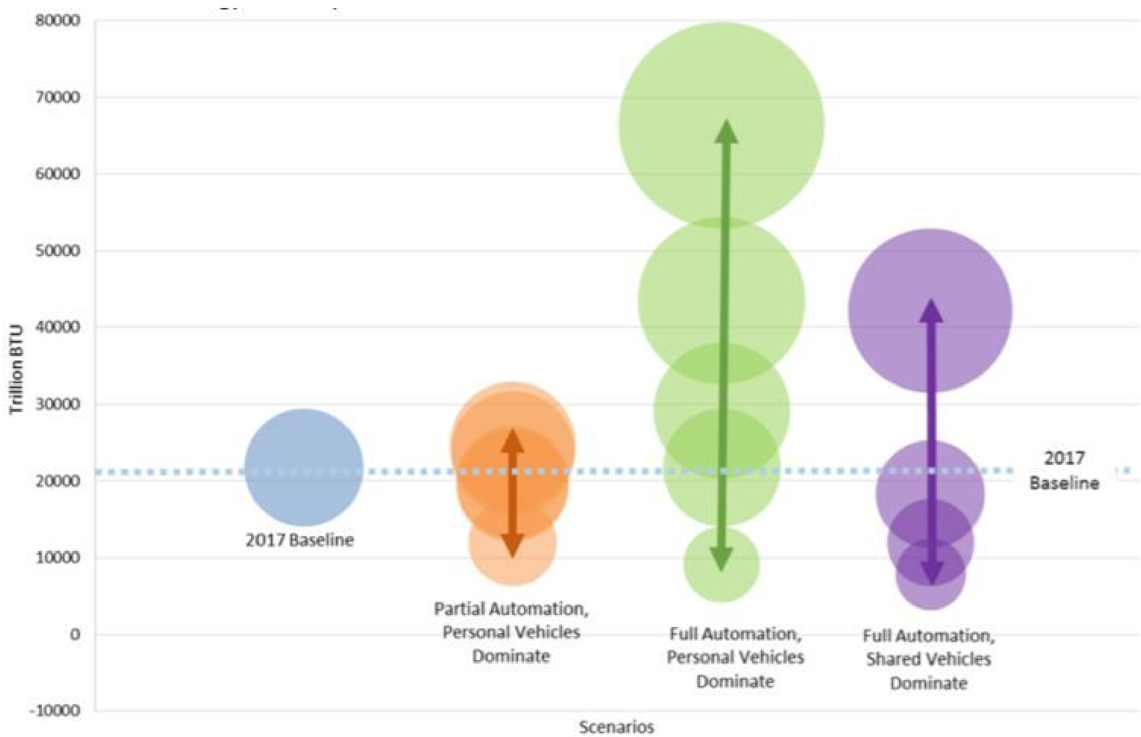
Many transportation planners and urban thinkers are skeptical about the potential benefits of autonomous vehicles.[46,47] Autonomous vehicles may cost less to operate and own, so this may have a rebound effect of more vehicles being on the road or encouraging people to live further away from city centres.

[46] Littman, Todd. 2018. "Autonomous Vehicle Implementation Predictions: Implications for Transport Planning." Victoria, BC: Victoria Transportation Policy Institute. https://www.vtpi.org/avip.pdf.
[47] Speck, Jeff. 2017. "Jeff Speck: Autonomous Vehicles & the Good City." Lecture presented at the Congress for New Urbanism, Savannah, Georgia, July 6. https://www.youtube.com/watch?v=utnPEbDNbrE.

Based on a scenario developed by the Rocky Mountain Institute, the action assumes that personal vehicle ownership declines by 50% by 2050 but personal VKT increases by 20%.[48] The increase in VKT results as new cohorts of the population (young and elderly, for example) have access to vehicles, and the convenience of private vehicles increases, with the cost of travel decreasing.[49]

Benefits to the climate can be achieved through the use of autonomous vehicles, although it is not guaranteed without regulation from a public entity. Any benefits will come from a combination of emission free or light vehicles, the ability for the moving vehicles to reduce distances from one another (platooning), and policy requirements or incentives for sharing vehicles. Emissions projections can vary considerably because there is no prediction of technology take-up (full vs. partial), and whether the majority of AVs will be shared in a carpooling or taxi method, or be personal vehicles. In some scenarios, AV's will induce more demand, attract new user groups (perhaps at the expense of transit), and increase VKT and energy demand.[50] A sample trendline is shown below showing a range of energy consumption rates under different scenarios.

Figure 14. Energy consumption comparisons of different AV scenarios in the US.[51]



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[48] Johnson, C., & Walker, J. (2016). Peak car ownership: The market opportunity of electricity automated mobility services. Rocky Mountain Institute. https://rmi.org/Content/Files/CWRRMI_POVdefection_FullReport_L12.pdf
[49] Ticoll, D. (2015). Driving changes: Automated vehicles in Toronto. https://www1.toronto.ca/City%20Of%20Toronto/Transportation%20Services/TS%20Publications/Reports/Driving%20Changes%20(Ticoll%202015).pdf
[50] Ross, Catherine, and Subhrajit Guhathakurta. 2017. "Autonomous Vehicles and Energy Impacts: A Scenario Analysis." Energy Procedia. Georgia Institute of Technology. https://www.sciencedirect.com/science/article/pii/S187661021736410X.
[51] Ibid.

AV Policies and Strategies

In order to make autonomous vehicles work for cities such as Ottawa, the current best practices include:

1. Maintaining goals for compact communities that prioritize walking, cycling, and transit usage;
2. Finding opportunities to redesign infrastructure for cars such as parking lots, on-street parking, alleys/lanes;
3. Making autonomous vehicles internalize their own costs through congestion charges;
4. Ensuring that autonomous vehicles emit less or do not emit at all through better efficiency or electrification;
5. Ensuring that a local government can access data and reports on vehicles usage in order to adjust community and development goals; and
6. Being conscious of risks that come from collisions and mass system failures common to any technology.

Uptake Scenarios

As suggested by Rocky Mountain Institute's research, increased availability of AVs can greatly reduce personal vehicle ownership. However, the attractiveness and convenience of AVs can attract new cohorts (young and elderly) to automobiles, and reduce other forms of transport such as transit, walking, or cycling, while increasing automobile VKT. In response to the pathway stakeholder meetings, the VKT increase was increased to 150% from 2016 levels to reflect a rapid uptake of AVs, rather than 20% indicated by the RMI research paper. The aggressive scenario is the only uptake scenario that will model AVs where the City has permitted them and regulated them to be 100% electric.

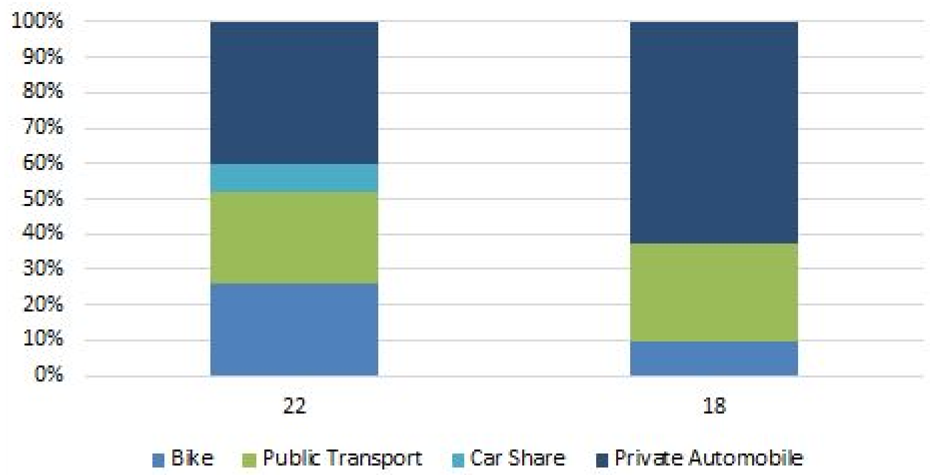
Table 18: Uptake scenarios for AVs.

Action	Conservative	Moderate	Aggressive
Autonomous Vehicles	No AVs	No AVs	Personal vehicle ownership declines by 50% by 2050; Per Capita VKT increases by 150%; AVs are electric only.

Ride Sharing, Car Co-ops

A recent technology to change the realm of transportation in urban environments has been car sharing. Car-sharing promotes a car-free or car-light lifestyle by allowing citizens of a city to reach destinations that are not accessible by transit or are inconvenient. People who do not own a car but may need to run errands may also find car sharing convenient. Generally, the vehicles are shared by a private company for profit and so more efficient vehicles are chosen resulting in less emissions. When paired with behaviour change options (i.e. TDM) car sharing can reduce personal vehicle ownership and vehicle kilometres travelled (VKT). A study conducted on a popular car-share provider, Car2Go, found that membership contributed to a reduction of vehicle ownership, members were more multimodal (taking more than one transportation method) than car owners, and the distance travelled was lower for members than non-members.[52] The mode share for car share users compared to non car share users is shown in Figure 15.

Figure 15. Modal split of car share users (left column) and non car share users (right column).



The two common methods for implementation of car sharing are: one-way trips (free-floating) or two-way trips. One-way trips allow a user to book a vehicle then drop it off at their destination with no further action needed (i.e. Car2Go). The one-way vehicles may be found in designated areas or in any area of a city where parking is permitted. The two-way vehicle requires the user to book the car and pick it up at designated area then return the vehicle to that designated area to complete the transaction (i.e. Zipcar). Ottawa currently features the following:

Table 19: Car-share providers operating in Ottawa.

Provider	Implementation Method	Fleet Size
Zipcar	Two-Way	13-15 Vehicles
Vrtucar	Two-Way	170 Vehicles (20 in Gatineau)

[52] Kopp, J., Gerike, R., & Axhausen, K. (2015). Do sharing people behave differently? An empirical evaluation of the distinctive mobility patterns of free-floating car-sharing members. Transportation.

Car sharing is an important factor in TDM measures because it can reduce VKT. Previous studies suggest that the reduction of personal car use along with a reduction in VKT can result in reduced personal emissions of 146 to 312 kg CO_2/year.[53] In its analysis of car share systems, Metro Vancouver estimates that 1 car share vehicle can take 3 personal vehicles off of the road.[54]

Car-Share Policies and Strategies

Car sharing is in a growth stage in Ottawa as there is no one-way service currently available, and major providers such as Car2Go have not yet entered the city. car share providers generally look for the following options in order to launch their service in a community:[55]

1. Visibility & Availability: car share organizations need to be visible in residential, commercial, and mixed-use neighbourhoods to be seens as a available and reliable option for residents. This is often a matter of permission from local governments and issue of parking permits. In commercial areas, parking lots dedicated to car share services that are visible encourage citizens to use the service.

2. Access to Transit/Walkable neighbourhoods: car share services can integrate with a transit network by providing a short journey from a rapid transit station to home or a destination. This is often called the "last mile."

3. Affordability of Service: Car sharing needs to be as or more affordable than owning a private vehicle. The affordability often comes intrinsically as parking is often free for users, and paid for by the car share company.

Actions a city can take to promote car sharing often mirror what a car share service needs to thrive. Most commonly a city can:

1. Permit Car Share Services to buy parking spaces in neighbourhoods - Having available car sharing within your neighbourhood adds convenience and accessibility for those who do not own a car. Prioritizing parking in commercial centres allows car share users to feel secure that they can park easily and conveniently at their destination, and another user can take that car away;

2. Integrate with Transit Service - Ottawa currently works with Vrtucar to allow citizens to integrate their transit pass with the car share service. This feature is convenient for users and can help Ottawa gain ridership for their transit service;

3. Require Parking Reductions in new Developments - Local governments can reduce parking requirements for new multi-family housing developments when a developer provides a car

[53]Do sharing people behave differently?
[54] "Metro Vancouver Car Share Study: Technical Report." 2014. Technical Report. Vancouver: Metro Vancouver Regional District.
http://www.metrovancouver.org/services/regional-planning/PlanningPublications/MetroVancouverCarShareStudyTechnicalReport.pdf. pg 22
[55] Metro Vancouver Car Share Study.
http://www.metrovancouver.org/services/regional-planning/PlanningPublications/MetroVancouverCarShareStudyTechnicalReport.pdf

share service. This is considered a Transportation Demand Management (TDM) option and described in the Behaviour Change Program; and

4. Set goals to create walkable neighbourhoods: The addition of car share services can incentivize households to remain car-free knowing that they have the option of renting a vehicle rapidly. This would follow the roll-out of the Ottawa Pedestrian Plan.

Uptake Scenarios

The car sharing uptake scenarios work in tandem with land use, transit, and autonomous vehicles uptake scenarios. As shown below, there will be greater uptake of car sharing in zones with frequent transit and greater density currently and in the future as land use becomes more compact and transit is increased. Further, the Aggressive Scenario of AVs will replace car sharing as the service becomes the norm.

Table 20: Uptake scenarios for car-share users.

Action	Conservative	Moderate	Aggressive
Increased Car Share	Car share increase in Centretown and LRT stations; car ownership declines by 5% in these zones and mode share by 10%.	Car share increase in Centretown and LRT stations; car ownership declines by 10% in these zones and mode share by 25%.	Replaced by Autonomous Vehicles

Bicycle Infrastructure

Prioritizing bicycle use has been an initiative many North American cities have been pursuing in recent transportation strategies. Bicycle infrastructure is a very broad term, but can be summarized as any item or initiative that encourages or supports citizens who choose cycling as a mode of transport. This can include separated lanes, prioritized signaling, intersection design, location of bike racks, or calmed streets. All partners and sectors can play a role by providing end-of-use facilities like secure bike racks, shower/changing rooms, bike-share systems, and electric bikes to suit different ages/abilities of riders.

Ottawa's Transportation Master Plan identifies a goal of building a great cycling city. It will commence designing more infrastructure such as greenways, separated lanes, and other infrastructure. The following policies and goals are currently in place:

- Increase cycling lanes, of different standards, across the city-region;
- Increase peak time/morning mode share of cyclists from 2.7% to 5% in the city as a whole, and 8% within the Ottawa Greenbelt;
- Update the Zoning by-law to ensure cycling facilities in new developments are designed to a high standard; and
- Promote cycling facilities in the city and increase safety year-round.

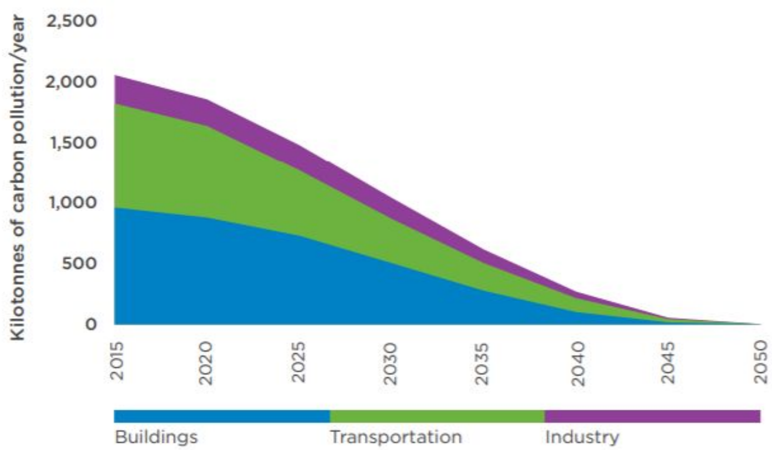
As a winter city, Ottawa will tend to see a decline in cycling during the colder months , however regular snow removal along major cycle corridors can encourage winter cycling.

New strategies and theories regarding bicycle infrastructure are being discovered at an increasing rate. However, the consensus of city practice is that quality infrastructure can make a city more livable, environmentally sustainable, and boost the local economy.[56]

The City of Vancouver targets 50% or more of all trips to be taken by cycling, walking, or transit, with 12% by bicycle. In response to the target, the city has modelled emissions reductions and found a potential emission reductions from 1500 kt CO2e to below 500 kt CO2e.[57] This includes the use of a greater number of electric bicycles.

With increased walking and cycling, Vancouver has already achieved an emissions reduction of 36% from the 2007 baseline year, and 10% cycling mode share.[58]

Figure 16. City of Vancouver emissions modelling, 2015-2050.



Bicycle Infrastructure Policy and Strategies

Cycling ridership within cities is highly correlated with greater cycling infrastructure investment. Many cycling studies also show that ridership has less correlation to weather patterns than one would think.[59] Canadian cities such as Vancouver and Montreal are often considered leaders in implementing new bike infrastructure and have begun to see record increases in riding and bicycle commuting. Vancouver has added several protected lanes in key areas of the city, including the downtown island, and currently features greater than 300 km of bike lanes.[60] These initiatives have made cycling the fastest growing form of transportation within the city, capturing 10% of the mode share to work as of 2017.[61]

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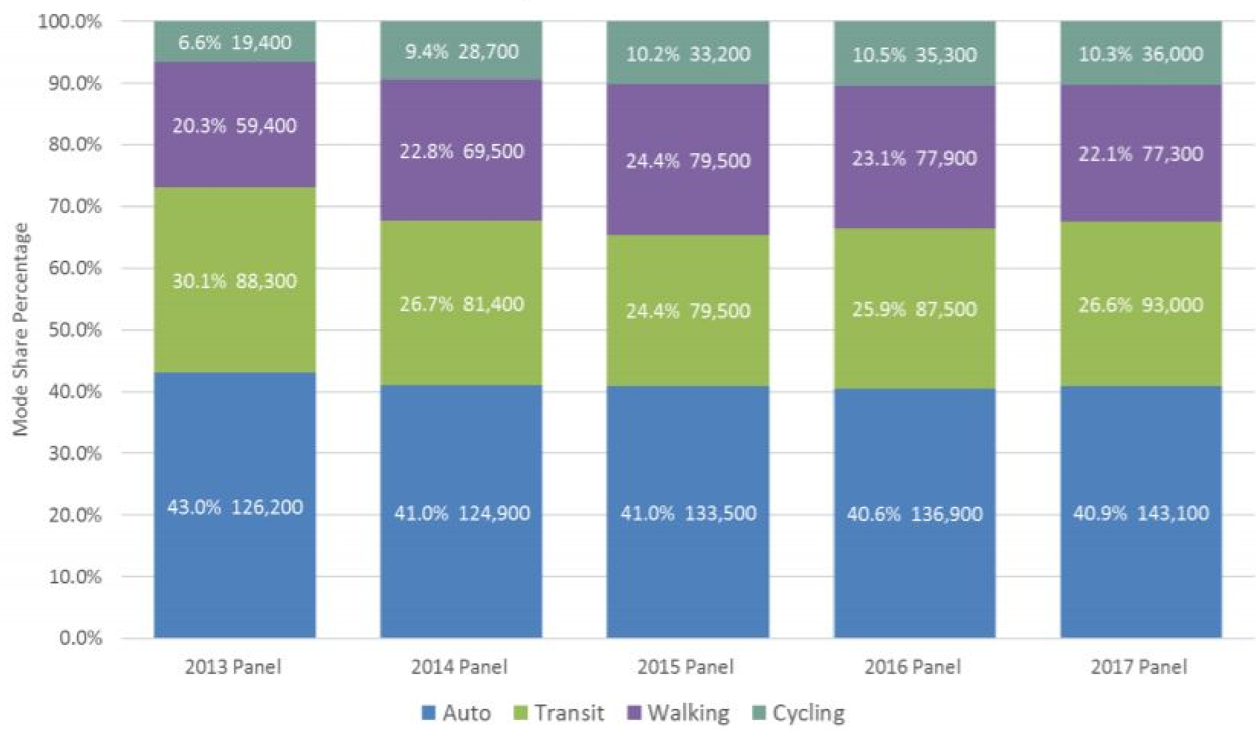
[56] "Protected Bike Lane Statistics." 2018. People For Bikes. 2018. http://peopleforbikes.org/our-work/statistics/statistics-category/?cat=protected-bike-lane-statistics.
[57] "Renewable City Action Plan." 2016. Greenest City. Vancouver. https://vancouver.ca/files/cov/energy-and-emissions-forecast-final-report.pdf.
[58] Ibid.
[59] Dill, Jennifer, and Theresa Carr. 2014. "Bicycle Commuting and Facilities in Major U.S. Cities: If You Build Them, Commuters Will Use Them." *Transportation Research Record*. https://doi.org/10.3141/1828-14.
[60] "Walking + Cycling in Vancouver Report Card." 2017. Greenest City. Vancouver. https://vancouver.ca/files/cov/walking-cycling-in-vancouver-2016-report-card.pdf.
[61] "2017 Vancouver Panel Study: Transportation." 2018. Greenest City Action Plan. City of Vancouver. https://vancouver.ca/files/cov/2017-transportation-panel-survey-final-draft-20180516.pdf.

Figure 17. Vancouver's increasing cycling mode share.



Bicycle Lanes

A city can choose many different types of bicycle lanes depending on road conditions, nearby land uses, levels of traffic, and road speeds. The National Association of City Transportation Officials (NACTO) provides relevant guidance for implementing and designing bicycle lanes in North American Cities. As determined by NACTO, the separated lane or "cycle track" provides the most comfortable and accessible lane for bicycle travel and can encourage cyclists of all ages and abilities to cycle for their needs.[62] A description of lane types and respective benefits, and recommended areas of implementation is included in Appendix 4.

Ottawa currently has a bicycle network with greater than 200km of lanes during summer periods. The goal of the city is to increase separated lanes, or cycle tracks, and maintain them year round in an effort to keep ridership in the winter months. The city is targeting spending $70 million by 2031 to increase the network, as shown in the table below.

[62] "NACTO: Urban Bikeway Design Guide." Cycle Tracks. 2011. NACTO. http://www.ocpcrpa.org/docs/projects/bikeped/NACTO_Urban_Bikeway_Design_Guide.pdf.

Table 21: Cycling expenditures in Ottawa.[63]

Exhibit 5.1 2031 Cycling Network projects – Capital Costs by Facility Type ($ millions)

Facility type	Phase 1: 2014-2019	Phase 2: 2020-2025	Phase 3: 2026-2031	*Total*
Cross-town bikeways	7.8	11.7	2.0	***21.5***
Transit-oriented development links	1.8	1.5	2.3	***5.6***
Institutional and employment links (outside downtown)	1.9	2.5	0.0	***4.4***
Community links (neighbourhood bikeways, missing links)	9.7	7.5	17.0	***34.2***
Bicycle parking and city-wide enhancements	0.4	0.8	2.8	***4.0***
Recreational links	0.3	0.0	0.0	***0.3***
Total	***22.0***	***24.0***	***24.0***	***70.0***

Note: All costs are in 2013 dollars.

Bicycle Parking

Cities are increasingly requiring new developments to have both short-term and long-term cycling parking facilities. These requirements can be for residential or nonresidential buildings. Short-term bicycle racks are generally outside and racks for longer term parking are provided for users of a building who intend to stay 2 or more hours.

Table 21: Criteria for short-term and long-term bike parking.[64]

Criteria	Short-term	Long-Term
Parking Duration	2 hours or less	2 hours or more
Fixture Types	Standard outdoor racks	Lockers, racks in secured areas
Weather Protection	Unsheltered	Sheltered or enclosed
Security	Unsecured, passive, surveillance (eyes on the street)	**Unsupervised**
		Individual-secure such as lockers
		Shared-secure such as bicycle room or cage
		Supervised
		Valet bicycle parking
		Paid area of transit station
Typical Land Uses	Commercial or retail, medical/healthcare, parks and rec. areas, community centres	Residential, workplace, transit

Many cities are offering guidance on bicycle parking design for on-street and off-street parking spaces. In the case of on-street bicycle parking, this can be a local initiative where racks can also

[63] Ottawa Transportation Master Plan.
[64] Adapted from Association of Pedestrian and Bicycle Professionals.

serve as source of public art and local pride. Off-street bicycle parking should be designed to be functional and secure; off-street parking rates vary from city to city but can be based on dwelling units or an amount of commercial space. Cities can also require shower and changing facilities based on similar criteria. Ottawa currently has zoning requirements for off-street spaces in different building types. This can range from .50 spaces per dwelling unit or 1 per 250m^2 for commercial buildings.[65]

Other Policies:

1. Complete Streets Framework - In newly developing urban areas ensure cycling infrastructure is included in street design to promote cycling for new residents. This can be paired with parking reductions for new developments

2. Street Retrofits in busy cycling areas - The City can observe streets that already have high number of cyclists without infrastructure, and retrofit the street with appropriate infrastructure.

3. Bicycle Share - Many cities, including Ottawa, are adding a public bicycle share in urban areas to add convenience for citizens to choose a bike if they don't own one, replace vehicles for low-distance trips, or augment transit trips.

4. Wayfinding, Signalling, and Street Signs - Cities can help encourage cycling by adding clear signals for where a cyclist can go and be away from high traffic areas. Cyclists can also be given priority in busy intersections to ensure they can establish their path before traffic.

5. Traffic Calming in neighbourhoods - Additions of roundabouts, or closing direct paths through streets with exceptions for cyclists can reduce traffic levels and encourage citizens to cycle within their own neighbourhood.

Uptake Scenarios

Increased cycling uptake will occur as Ottawa's Cycling Master Plan continues to be built out, and uptake scenarios will also work in tandem with the Land Use uptake scenario. Areas that densify, are more compact and mixed-use, and have greater public transit will be identified as areas with higher rates of cycling.

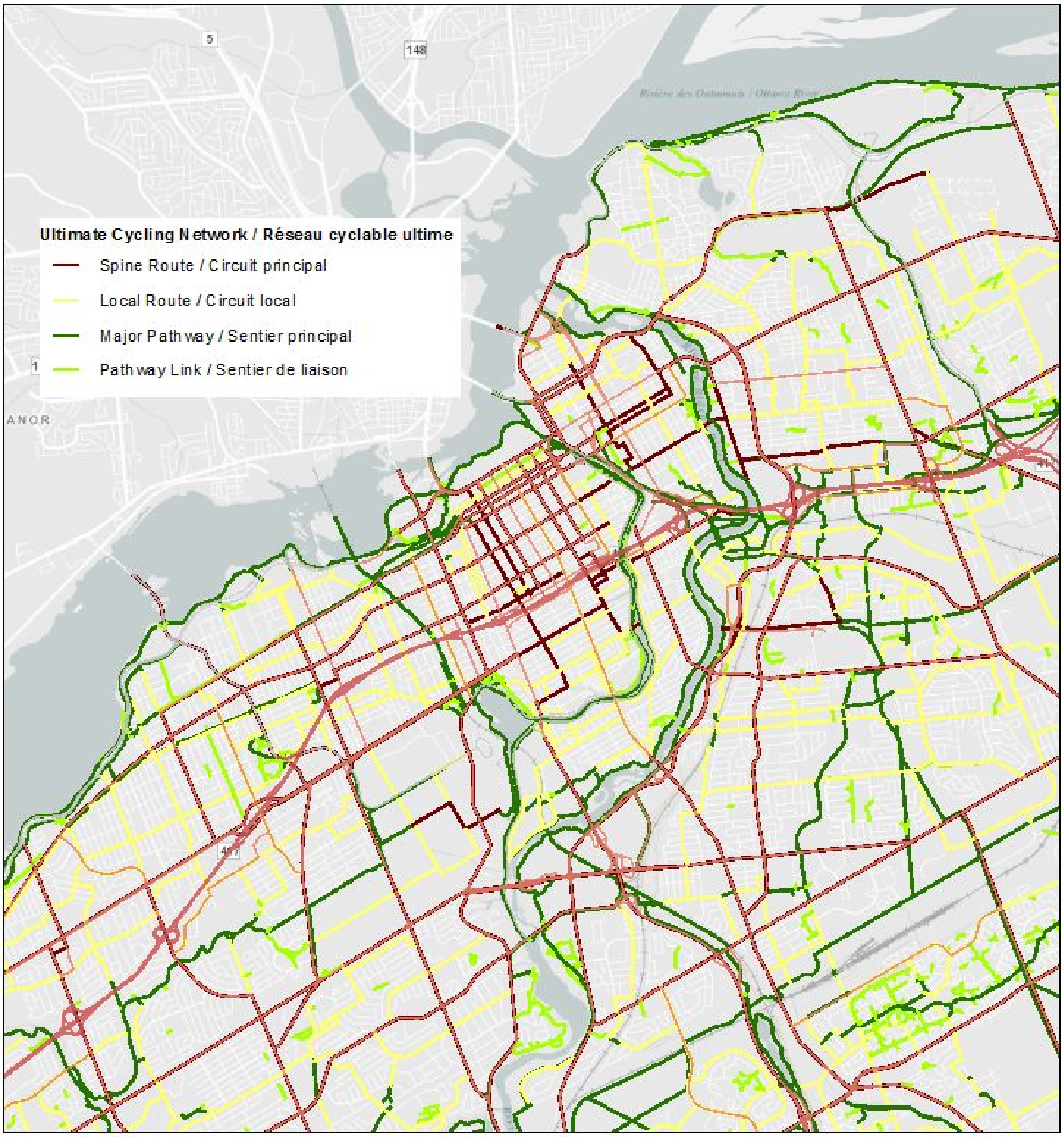
Table 22: Uptake scenarios for increased bicycle infrastructure.

Scenario	Conservative	Moderate	Aggressive
Enhanced Bicycle Infrastructure	None	Mode shift to 20% of the cycling away from vehicles and driving for trips up to 5km	Mode shift to 50% of the cycling away from vehicles and driving for trips up to 5 km.

65 "Part 4 - Parking, Queuing and Loading Provisions (Sections 100-114)." City of Ottawa, n.d. https://ottawa.ca/en/part-4-parking-queuing-and-loading-provisions-sections-100-114.

Ottawa's ultimate cycling plan is shown in the figure below.

Figure 18. Ottawa's ultimate cycling network.[66]

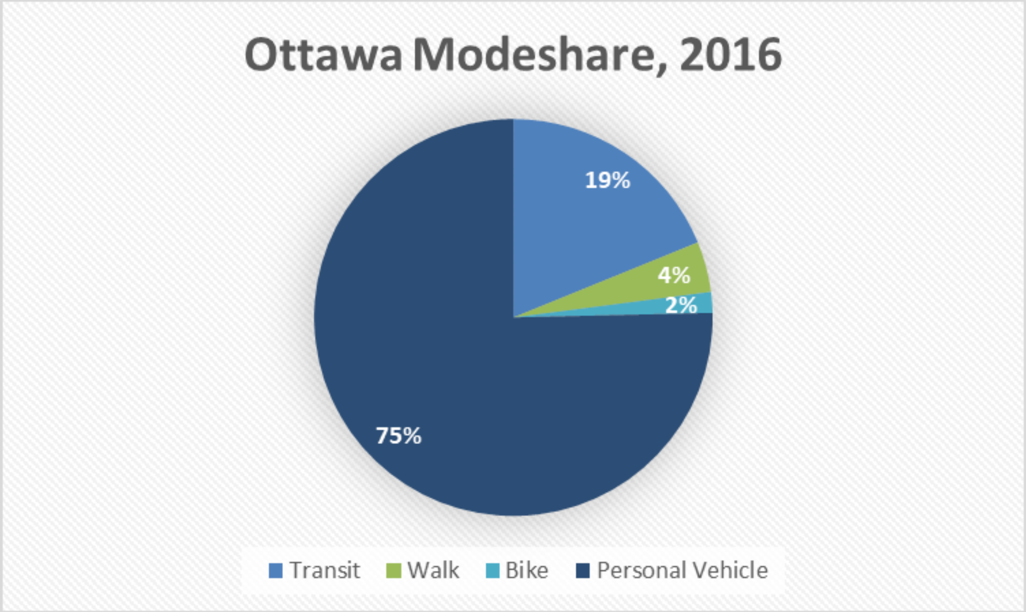


[66] "Ottawa Cycling Master Plan." geoOttawa, 2018. http://maps.ottawa.ca/geoOttawa/.

Current Pathway Assessment

Through policies like the Transportation Master Plan and Cycling master plan, Ottawa has already begun to build the pathway toward a more sustainable transportation future. Ottawa continues to add options to increase the share of walking, cycling, and transit use, however the community still favours the use of the personal automobile. Mode share analysis completed for the year 2016 shows 75% of personal trips are made by personal vehicle.

Figure 19. Ottawa mode share, 2016.



With notable additions to public transit through the Confederation Line and cycling network, Ottawa is poised to reduce the amount of energy and emissions used in the transportation within the community.

A comparison of Ottawa's transportation policy and the transportation pathways presented in this paper is shown below.

Table 24: Comparing pathway strategies to Ottawa's transportation policy.

Transportation Pathway	Ottawa's Existing Policy
Impact of land-use change	Official Plan: ● The City will manage growth by directing it to the urban area where services already exist or where they can be provided efficiently. ● Growth in the existing designated urban areas will be directed to areas where it can be accommodated in compact and mixed-use development, and served with quality transit, walking and cycling facilities. ● The central area, designated mainstreets, mixed use centres and town centres will be compact, liveable, and pedestrian-oriented with a vibrant mix of residential uses, and social, cultural and economic activity. ● Infill and redevelopment will be compatible with the existing context or planned function of the area and contribute to the diversity of housing, employment, or services in the area.
Electrification of Commercial Vehicles	No policy currently
Transportation Demand Management (TDM) / Behaviour Change Policies	Ottawa Transportation Plan
Parking Management	Ottawa Municipal Parking Management Strategy ● Set off-street and on-street parking rates based on local parking studies and stakeholder consultation
Car Free Areas	Ottawa Pedestrian Plan
Congestion Charge	No policy currently
Enhanced Transit	Ottawa Transportation Master Plan, OC Transpo Confederation Line Extensions
Autonomous Vehicles (AVs) (Shared)	No policy currently
Car Share / Ride Share/ Car Co-ops	No policy currently
Enhanced Bicycle Infrastructure	Ottawa Cycling Master Plan ● Invest $70 Million in cycling infrastructure by 2031

Section 2: Projected Pathway Assessment

The projected pathway will accelerate policies and actions in the current pathway, or Business as Planned (BAP) Model. The conservative scenario will mirror the BAP, and the moderate scenario will accelerate policy and actions taken in the BAP, notably in enhanced transit, electric commercial vehicles and bicycle mode share. The aggressive scenario will further electrify commercial vehicles, maximize opportunities for cycle infrastructure, add more car share services, and model scenarios where the majority of development is infill rather than greenfield.

Table 25: Low carbon pathway and assumptions.

Action	Conservative Scenario	Moderate Scenario	Aggressive Scenario
Impact of land-use change	No Change (Official plan until 2031)	50% of new development is in urban centres or adjacent to existing or new LRT, BRT by 2025, under affordable transit network.	90% of new development is in urban centres or adjacent to existing or new LRT, BRT by 2025, under ultimate transit network.
Walking as impacted by Land-Use change	No change	For 2km trips, Mode shift to 20% of the walking and cycling potential away from vehicles and driving.	For 2km trips, Mode shift to 50% of the walking and cycling potential away from vehicles and driving.
Electrification of Commercial Vehicles	10% of heavy trucks are zero emissions by 2030; 40% by 2040	20% of heavy trucks are zero emissions by 2030; 60% by 2040.	40% of heavy trucks are zero emissions by 2030; 100% by 2040.
TDM)/Behaviour Change Policies	Modelled under parking management and road pricing	Modelled under parking management and road pricing.	Modelled under parking management and road pricing.
Parking Management	No change	No change	Increase parking fees for on-street and city-owned lots by a factor of 1.5 by 2050.
Car Free Areas	None	None	Byward market and downtown Ottawa are car free; Wellington-Rideau, Sparks, Bank, Ottawa-U campus.
Congestion Charge	None	None	Congestion charge of $20 applied to the downtown core between 6:00 am and 10:00 am on weekdays.

Enhanced Transit	Completion of the Confederation Line-Phase 1 and 2	The Affordable Network is completed, and accompanied by a 10% transit modal increase. 100% of Transit vehicles are electric by 2050	Identify high density neighbourhoods without sufficient transit and increase transit share by 25% in these neighbourhoods The frequency of LRT is increased to every 90 seconds in downtown areas, and outer areas are increased to match. BRT speed is increased by 20% through prioritized lanes and stop lights where separated infrastructure is available. 100% of Transit vehicles are electric by 2050 Complete "Ultimate Transit" Network as shown in Transportation Master Plan
Autonomous Vehicles (AVs) (Shared)	No AVs	Personal vehicle ownership declines by 50% by 2050; VKT increases by 20%; AVs are electric only	Personal vehicle ownership declines by 50% by 2050; VKT decreases by 10%; AVs are electric only
Car Share / Ride Share/ Car Co-ops	Car share increase in Centretown and LRT stations; car ownership declines by 5% in these zones and mode share by 10%. AVs may cancel this out.	Car share increase in Centretown and LRT stations; car ownership declines by 10% in these zones and mode share by 25%. AVs may cancel this out.	Car share increase in Centretown and LRT stations; car ownership declines by 15% in these zones and mode share by 50%. AVs may cancel this out.
Enhanced Bicycle Infrastructure	None	Mode shift to 20% of the walking and cycling away from vehicles and driving. Use 5km for cycling.	Mode shift to 50% of the walking and cycling away from vehicles and driving. Use 5km for cycling.

Uptake Projections

The following tables detail the energy use and emissions reductions based on the actions and assumptions described in this pathway paper.

Conservative

Table 26. Energy and GHG emissions results of the conservative transportation pathway.

Action	Description	Cumulative emissions reductions 2018-2050 (kt CO2e)	Emissions reductions 2050 (kt CO2e)	Cumulative energy reductions 2018-2050 (TJ)	Energy reductions 2050 (TJ)
Spatial Distribution	Official plan until 2031	No change	No change	No change	No change
Increase/improve cycling & walking infrastructure	No Change	N/A	N/A	N/A	N/A
Car Free Zone	None	N/A	N/A	N/A	N/A
Congestion Charge	None	N/A	N/A	N/A	N/A
Expand Transit	Completion of the Confederation Line-Phase 1 and 2	No change	No change	No change	No change
Electrify Transit	2016 fuel shares are held constant	N/A	N/A	N/A	N/A
Electrify Municipal Fleets	Municipal fleet is 20% electric by 2020 and 40% electric by 2040	149	7.25	1,328.32	66.63
Electrify personal vehicles	33% of new vehicle sales by 2050	2,619	302.34	22,723.84	2,786.95
Car Share	Car ownership declines 5% and car mode share declines 10% in Centretown and LRT stations car share zones	95	2.29	1,351.63	33.31
Autonomous vehicles	No Change	N/A	N/A	N/A	N/A
Parking management	No Change	N/A	N/A	N/A	N/A
Electrify commercial vehicles	10% of heavy trucks are zero emissions by 2030; 40% by 2040	2,726	161.39	27,940.02	1,752.61

Moderate

Table 27. Energy and GHG emissions results of the moderate transportation pathway.

Action	Description	Cumulative emissions reductions 2018-2050 (kt CO2e)	Emissions reductions 2050 (kt CO2e)	Cumulative energy reductions 2018-2050 (TJ)	Energy reductions 2050 (TJ)
Spatial Distribution	50% of new development is in urban centres or adjacent to existing or new LRT, BRT by 2025.	2,052	115	35,072	1,989
Increase/improve cycling & walking infrastructure	Mode shift to 20% of the walking and cycling potential away from vehicles and driving. Use 2 km for walking and 5km for cycling.	264	13.14	3,653.62	191.16
Car Free Zone	None	N/A	N/A	N/A	N/A
Congestion Charge	None	N/A	N/A	N/A	N/A
Expand Transit	Build out Affordable Transit Network by 2050	2,634	147	43,098	2,452
Electrify Transit	100% electric by 2050	2,986	150.44	31,913.47	1,691.20
Electrify Municipal Fleets	Municipal fleet is 40% electric by 2020 and 60% electric by 2040.	242	10.87	2,168.10	100.02
Electrify personal vehicles	40% of new vehicle sales by 2040; 50% by 2050	5,772	515.11	51,553.54	4,863.03
Car Share	Car ownership declines 10% and car mode share declines 25% in Centretown and LRT stations car share zones	151	5.78	2,106.23	84.1
Autonomous vehicles	None	N/A	N/A	N/A	N/A
Parking management	None	N/A	N/A	N/A	N/A
Electrify commercial vehicles	20% of heavy trucks are zero emissions by 2030; 60% by 2040	4,262	242.09	43,817.43	2,628.91

Aggressive

Table 28. Energy and GHG emissions results of the aggressive transportation pathway.

Action	Description	Cumulative emissions reductions 2018-2050 (kt CO2eq)	Emissions reductions 2050 (kt CO2eq)	Cumulative energy reductions 2018-2050 (TJ)	Energy reductions 2050 (TJ)
Spatial Distribution	90% of new development is in urban centres or adjacent to existing or new LRT, BRT by 2025. Congestion charge of $20 applied to the downtown core between 6:00 am and 10:00 am on weekdays. On-street parking fares increase by a factor of 1.5 during peak hours by 2050.	1,485	77	31,165	1,664
Increase/improve cycling & walking infrastructure	Mode shift to 50% of the walking and cycling potential away from vehicles and driving. Use 2 km for walking and 5 km for cycling.	1,878.26	34.69	9,809.11	504.83
Expand Transit (Transit Enhancement)	Complete "Ultimate Transit" Network as shown in Transportation Master Plan LRT frequency increased to 90 seconds in downtown areas, and outer areas are adjusted to match. BRT speed is increased by 20% in areas where separated infrastructure is available.	4,430	284	71,537	4,633

Electrify Transit	100% electric by 2030	3,588	150.45	40,350.62	1,691.22
Car Free Zone	Byward market and downtown Ottawa are car free; Wellington-Rideau, Sparks, B ank, Ottawa U. campus	7	0.19	102.52	2.77
Electrify Municipal Fleets	Municipal fleet is 60% electric by 2020 and 100% electric by 2040.	392	18.14	3,496.48	166.66
Electrify personal vehicles	88% of new vehicle sales by 2030; 90% by 2050	18,665	1,136.73	171,791.09	11,038.04
Car Share	None, replaced by autonomous vehicles	N/A	N/A	N/A	N/A
Autonomous vehicles	Personal vehicle ownership declines by 50% by 2050; VKT per capita increases by 150%; AVs are electric only	5,728	283.29	23,187.00	235.02
Electrify commercial vehicles	40% of heavy trucks are zero emissions by 2030; 100% by 2040	4,262	242.09	43,817.43	2,628.91

Constraints

Legal/Jurisdiction

A major driver to moving towards a sustainable transportation system is the use of taxation policy such as carbon pricing in order to shift economic norms away from fossil based energy. Carbon pricing requires a joint partnership between different levels of government, from set-up to implementation. The first step with this measure is for Ottawa to work with the province to bring in such a policy, however political climates may not be favourable for such measures at this time.

Road pricing is similar to carbon pricing but can be led by a municipality. However, other levels of government will need to participate and generally agree with the strategy.

Funding/Fees

Infrastructure requires large amounts of funding and may need coordination with higher levels of government or different methods of fee collection. Pathways towards autonomous vehicles and car sharing may lead to a reduction in the fees that are collected for transportation infrastructure (e.g. gas taxes). Long-term planning for low-carbon transportation needs to occur in order for the pathway to be successful.

Behavioural/Cultural

Changing travel behaviours and norms is difficult. Mode choices are personal and relate to individuals' core beliefs. For example, a driver may wish to drive to their destination because of a perceived lack of safety. Many design initiatives can change these fears, such as using CEPTD measures for new buildings, or improving street lighting.

Changing street design and patterns to include cycling infrastructure can include removing existing lanes, or on-street parking spaces. This can be a conflict for residents of a neighborhood and businesses who may not agree with the change or fear a reduction of business. Even with proper consultation, bike lanes can be rejected due to political pressure.

Furthermore, there is a cultural norm to live in a single detached home that is away from the noisiness of the city. Planners can underestimate the desire for low-density living, and the resistance encountered by planning initiatives to provide other housing options.

Technological

There can be technological constraints in the adoption of new infrastructure or new types of vehicles. For example, the full electrification of heavy-duty commercial trucks may be delayed by the lack of fast chargers that work with larger batteries for trucks travelling long distances. Cities may need to rapidly implement new and faster charging systems within their communities to encourage demand for electric light-duty vehicles, commercial fleets, or heavy duty trucks.

There are also gaps when considering autonomous vehicles. Implementation of AVs will need to be coordinated with different levels of government. This will require different types of infrastructure that support the safe operation of AV's in the urban environment.

Ways to advance this pathway

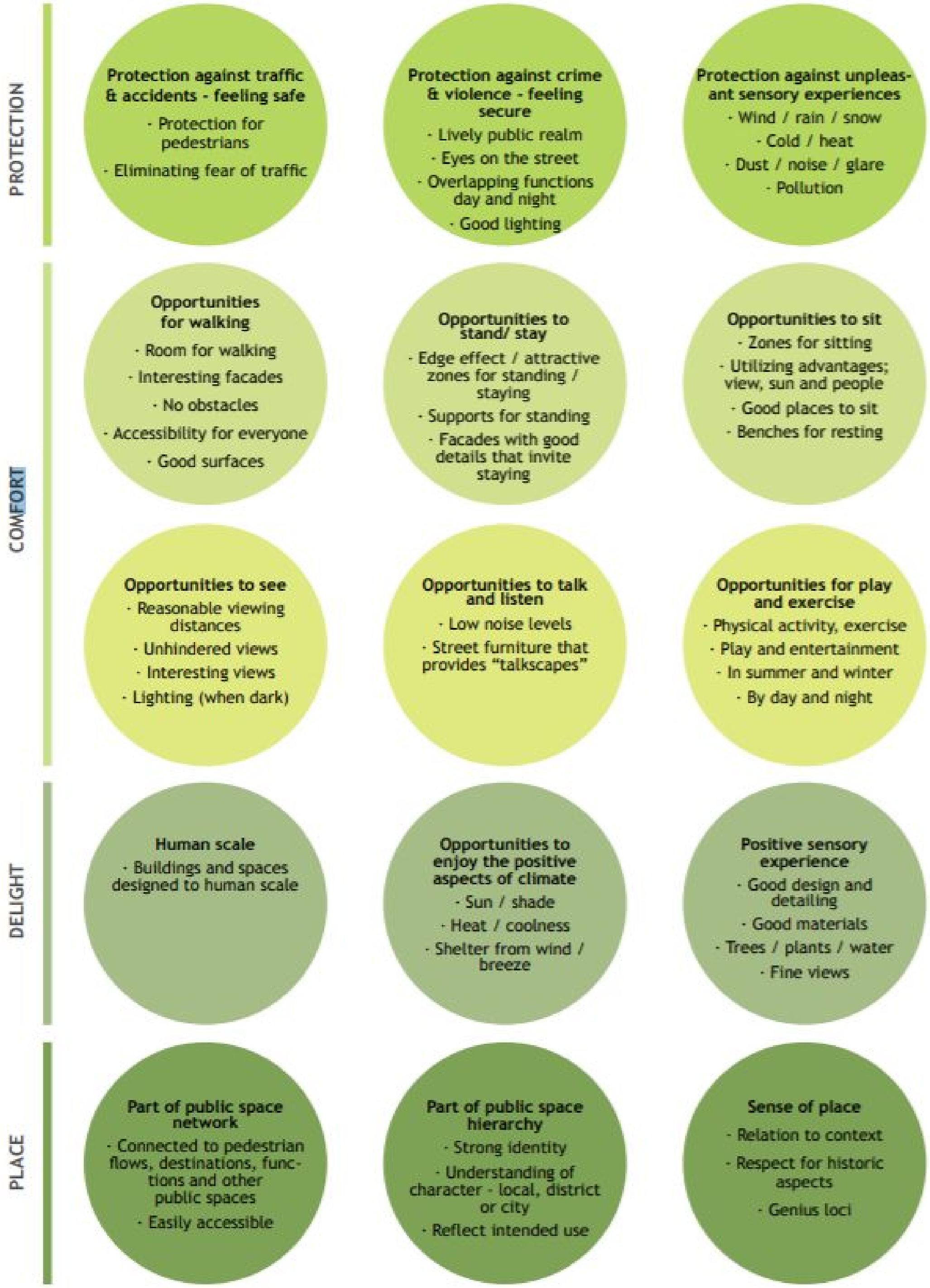
The following are considered "Quick-Start" approaches and are recommended to Ottawa and its partners to reduce transportation emissions, and are in addition to recommendations made in Phase 1.

1. Community consultation and analysis to add more car-free areas in the urban boundary and in Village Centres.
2. Continue to build cycling infrastructure and promote this form of active transportation.
3. Reduced or zero parking for new buildings near destinations served by transit stations.
4. Increased paid parking zones and increased rates near Village Centres.
5. Public EV charging keeps pace with demand.
6. Increased enforcement of bylaws prohibiting double parking beside a parked car
7. Greater effort to work with car share providers such as Car2go or Vrtucar to add to their fleet and move towards allowing one-way trips.
8. Work to ensure that autonomous vehicles in the city are electric.

Modelling by CityInSight will determine the most effective approach to ensure transportation related emissions will meet the goals of the ETS and reduce GHG emissions to 80% below 2012 levels.

Appendices

Appendix 1: 12 Quality Criteria for Public Spaces and Car Free Areas[67]



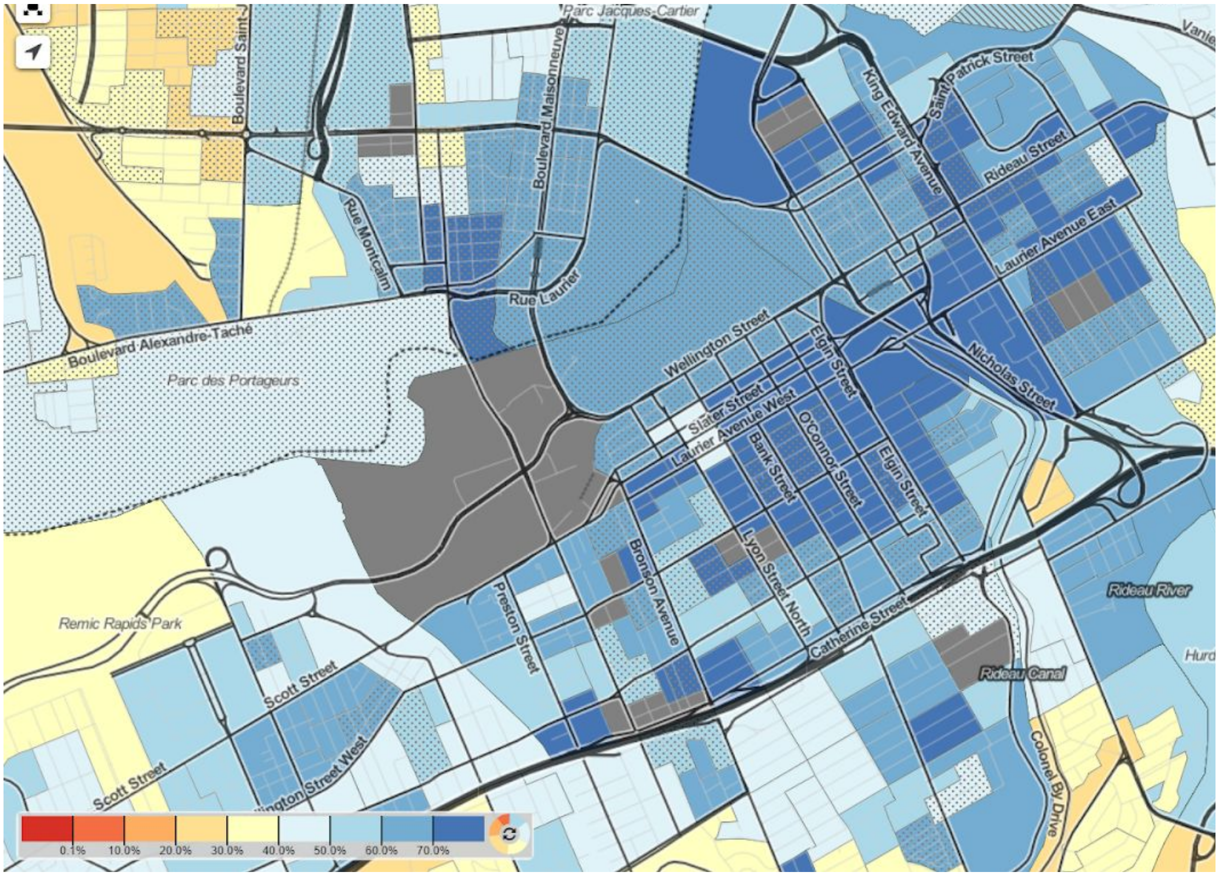
[67] "12 Quality Criteria" Gehl Institute. Adapted by Seattle Department of Transportation. 2009 https://www.seattle.gov/dpd/cs/groups/pan/@pan/documents/web_informational/s048430.pdf

Appendix 2: Car Free Indicators Map (Population Density and Active Transport)[68]

Population Density (Green identifies areas where population density exceeding 5000 km^2).

[68] "Ottawa Active Transport." and "Population Density" Census Mapper. Mountain Math, n.d. https://censusmapper.ca.

Areas of Ottawa where 70% of residents use active transport to work, marked in dark blue.



Appendix 3: Congestion Charging Methods in International Cities

Table 26: Congestion Schemes in International Cities.[69]

	Singapore	London	Stockholm	Milan
Other Measures	Increased Transit, Park & Ride	Increased Transit	Increased Transit, Park & Ride	Increased Transit
Charge Varies by: Vehicle Type Time Place	 No No No	 No No No	 No Yes No	 No No No
Passage / Day Fee	One Fee	Day Fee	Passage	Day Fee
Principal Objectives	Congestion	Congestion	Congestion Environment	Environment Congestion
Times	M-Sat 7:30am - 10:15am	M-F &am-6:30pm	M-F 6:30am-6:30pm	M-F 7:30am-7:30pm
Exemptions: Residents Other	 No Carpools, Commercial Trucks	 90% No	 No No	 Annual Card Multiple Entrance Discounts
Affected Area	6-7km^2	22km^2	34.5Km^2	8km^2

[69] Table Adapted from: Jarl, Valfrid. “Congestion Pricing in Urban Areas - Theory and Case Studies.” Thesis. Lund University: Department of Technology and Society, 2009. http://www.tft.lth.se/fileadmin/tft/dok/publ/5000/Thesis183_VJ_scr.pdf.

Appendix 4: Bicycle Lane Types

Table 26: Bicycle lane standards, areas of application, and benefits.[70]

Bicycle Lane Type	Criteria of Implementation	Benefits
Conventional Bike Lanes - Exclusive spaces that are created through pavement markings and signage only	• Roads with less than 3000 vehicles per day • Speeds less than 50km/h • High Transit Volume is present	• Increased cyclist comfort on busy streets • creates a visual separation from vehicles • Increases predictability of bicycle movement and interaction
Buffered Bike Lanes - Similar to conventional with a designated buffer space separating bicycles from traffic	• Similar to conventional bike lanes • On streets that have greater widths	• Provides a greater distance from vehicles • Provides space for cyclists to pass each other without entering traffic lane • Cyclists can be out of door-swing zone of parked vehicles • Cyclists can bike in pairs
Contra-Flow Bike Lanes - Lanes designed to allow cyclists to ride in opposite direction of motor vehicle traffic	• Observed areas of cyclists already travelling the wrong way • Corridors where alternate routes require excessive out-of-direction travel • Where alternative corridors subject cyclists to high volumes of traffic • Low-speed, low-volume streets	• Increased connectivity and access to cyclists in both directions • Reduces dangerous wrong-way riding • Decreases sidewalk riding • Decrease trip distances • Slow motor vehicle traffic down
Cycle Tracks / Separated Lanes - One-way or two-way protected bicycle lanes that are completely separate from motor vehicles	• Along higher speed streets with few driveways and cross streets • Streets with higher traffic rates • Curving streets where vehicles may encroach cycle lanes more frequently • Streets that are observed to have high bicycle volumes	• Provides the greatest comfort and safety for cyclists • Reduces risks and safety issues with parked cars or car attempting to park • Offers room for cyclists to pass or ride in pairs • Most attractive to riders of all ages and abilities • Reduced interference with transit / buses

[70] NACTO: Cycle Lane Types.

Appendix 5: Transportation Modelling Assumptions for Business as Planned

	Data/Assumption	Source	Summary approach/methodology
Transit			
Expansion of transit	Transit mode shares by O-D zones in 2011 and 2031 model data Hold mode shares constant after 2031 through 2051	Ottawa transportation model data for 2011 and 2031	It is assumed the modelled 2031 trips by mode reflects planned transit expansion
Electric vehicle transit fleet	No electrification of transit vehicle fleet assumed 2016-2050.		No electrification of transit vehicle fleet assumed 2016-2050.
Active			
Cycling & walking infrastructure	Active mode shares by O-D zones in 2011 and 2031 model data Hold mode shares constant after 2031 through 2051	Ottawa transportation model data for 2011 and 2031	It is assumed the modelled 2031 trips by mode reflects planned cycling and pedestrian infrastructure expansion
Private & commercial vehicles			
Vehicle KM travelled	No data from City or other transportation agencies. Derived by the model.		Vehicle kilometres travelled projections are driven by buildings projections. The number and location of dwellings and non-residential buildings over time in the BAP drive the total number of internal and external person trips. Person trips are converted to vehicle trips using the baseline vehicle occupancy. Vehicle kilometres travelled is calculated from vehicle trips using the baseline distances between zones and average external trip distances.

Vehicle fuel efficiencies	Vehicle fuel consumption rates reflect the implementation of the U.S. Corporate Average Fuel Economy (CAFE) Fuel Standard for Light-Duty Vehicles, and Phase 1 and Phase 2 of EPA HDV Fuel Standards for Medium- and Heavy-Duty Vehicles.	EPA. (2012). EPA and NHTSA set standards to reduce greenhouse gases and improve fuel economy for model years 2017-2025 cars and light trucks. Retrieved from https://www3.epa.gov/otaq/climate/documents/420f12050.pdf http://www.nhtsa.gov/fuel-economy	Fuel efficiency standards are applied to all new vehicle stocks starting in 2016.
Vehicle share	Personal vehicle stock share changes between 2016-2050. Commercial vehicle stock unchanged 2016-2050.	CANSIM and Natural Resources Canada's Demand and Policy Analysis Division.	The total number of personal use and corporate vehicles is proportional to the projected number of households in the BAP.
Electric vehicles	2-3% of Market Share in 2040	Canada's Electric Vehicle Policy Report Card 2016. Axsen, Goldberg, Melton (Simon Fraser University)	The Ontario Long-Term Energy Plan predicted 5% of new vehicles sold being electric by 202 however all incentive programs have been eliminated at this time. The BAP will use a similar market share to other provinces who lack distinct policy to support EV (Alberta, Saskatchewan, Manitoba) as established by the Canada's Electric Vehicle Policy Report Card 2016. Axsen, Goldberg, Melton (Simon Fraser University)

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

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

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January 2019

Contents

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.
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[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]

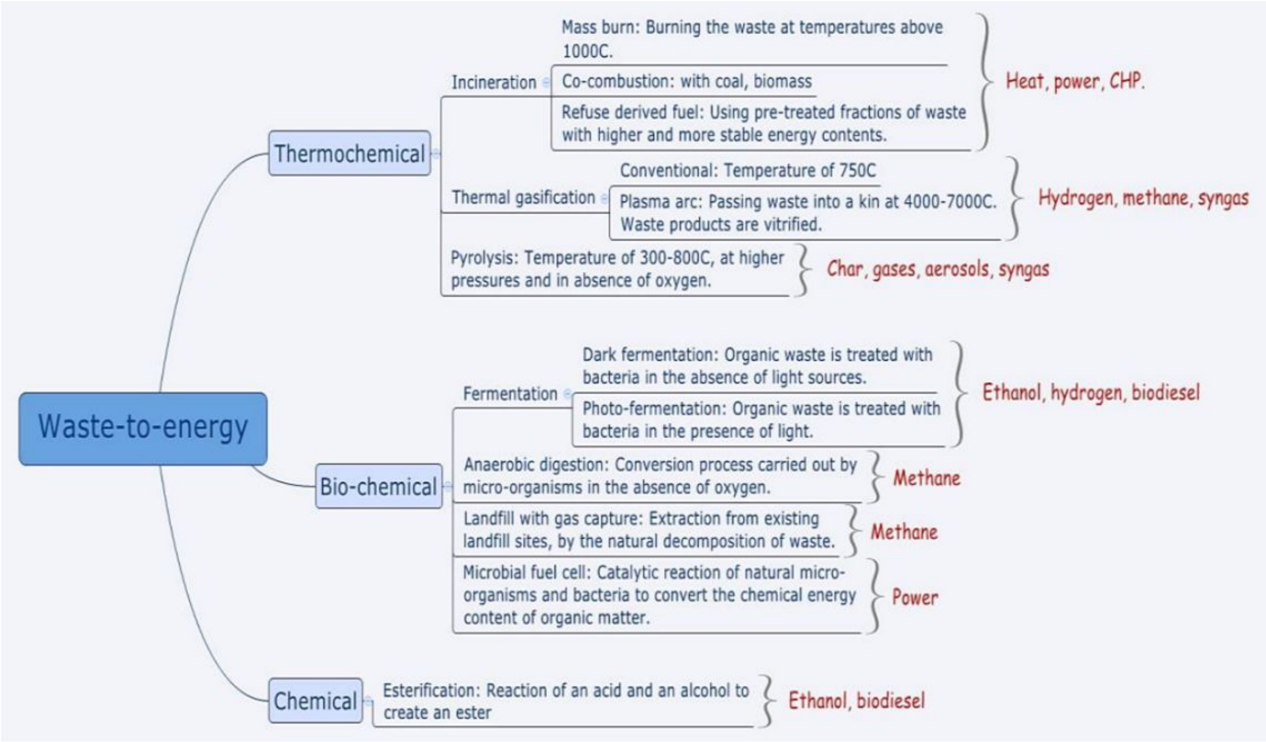
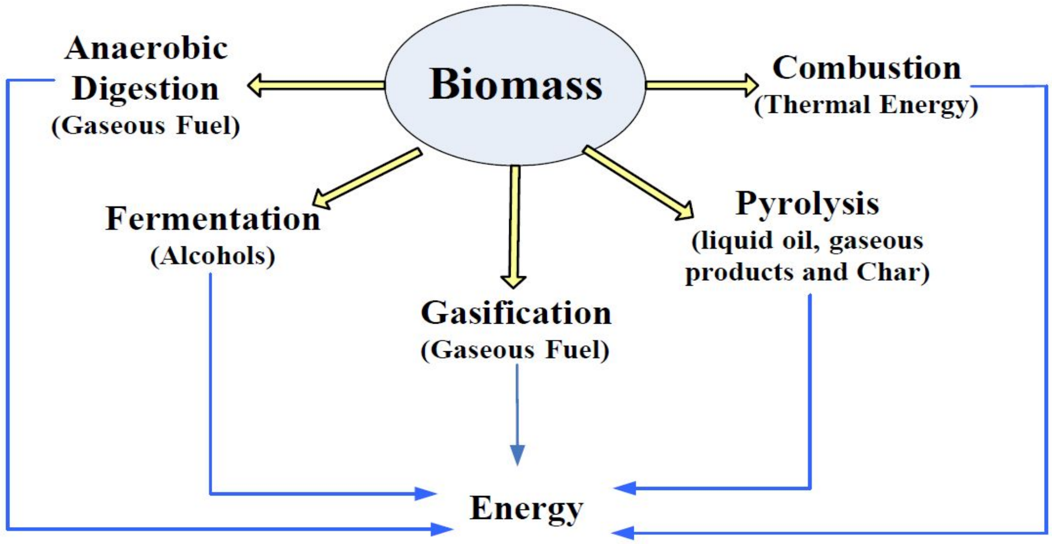


Figure 2: Biomass-energy conversion pathways.[8]



[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]

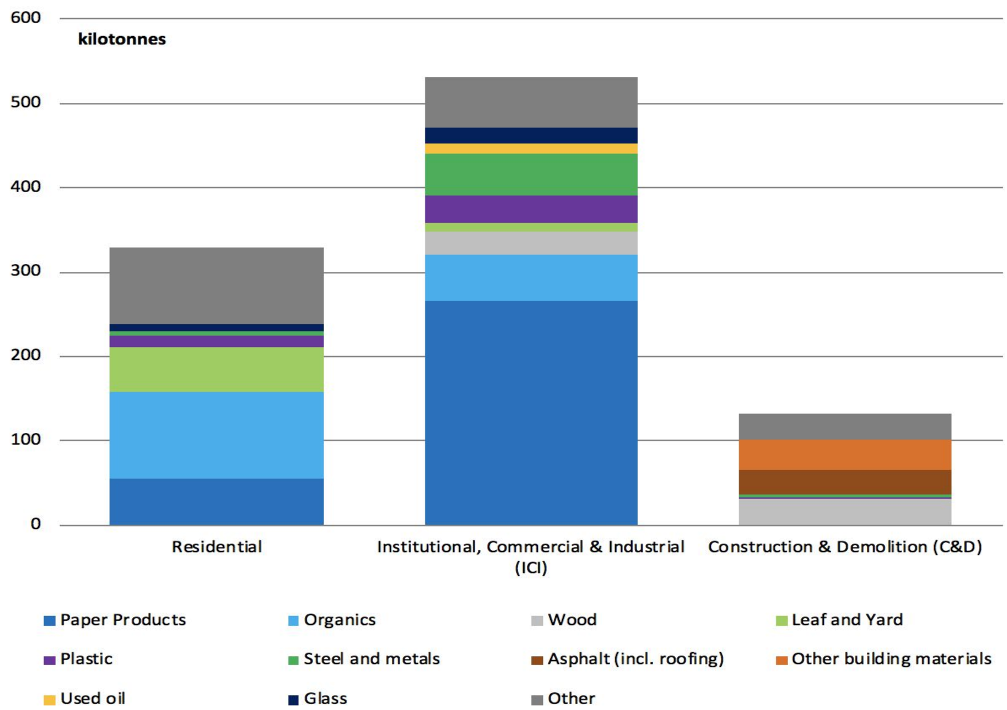
Put out as: → / Waste type: ↓	Garbage	Blue Box	Black Box	Green Bin	Leaf/Yard	Total	Diverted
Glass, metal, plastic	8,852	**16,969**	410	-	-	**26,231**	16,969
Fibre (paper, cardboard)	11,435	847	42,327	1,019	-	**55,628**	43,346
Organics (food, yard)	64,877	642	496	**36,982**	**52,707**	**155,705**	89,690
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%		

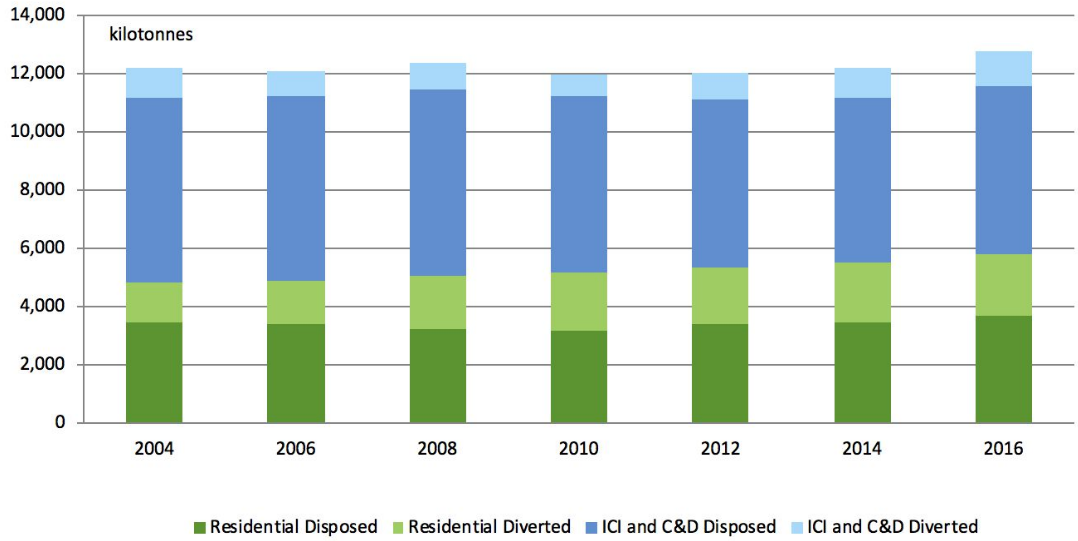
Trends in Ottawa Waste Generation

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.

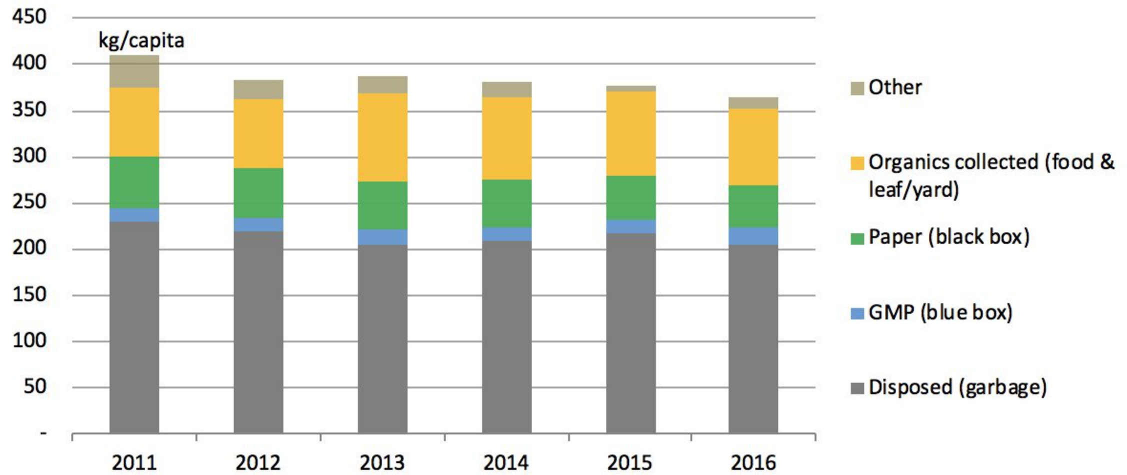
Figure 4: Ontario waste generation.



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.

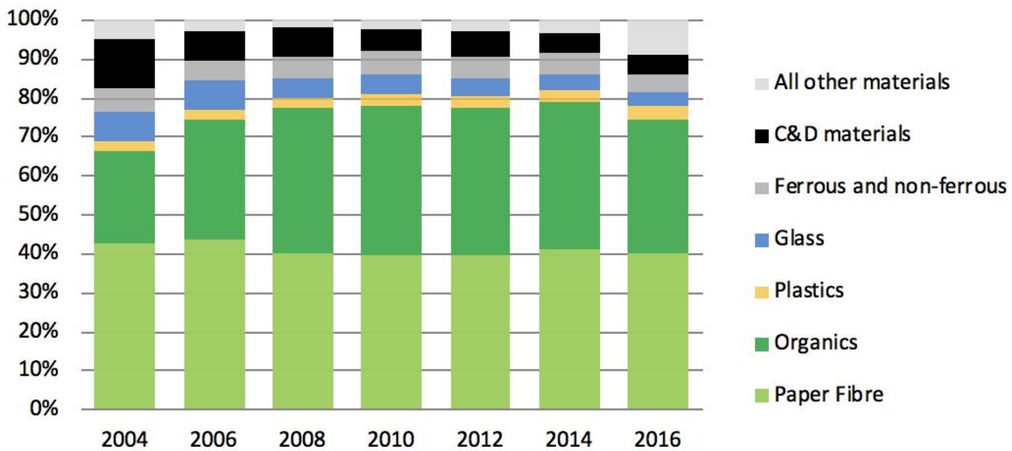
There are also changes taking place in the composition of the waste stream that have implications to both waste managers and the prospects for energy extraction. Paper waste, and especially newsprint, has dropped significantly and this may be the most important contributor to the moderation in the absolute 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.

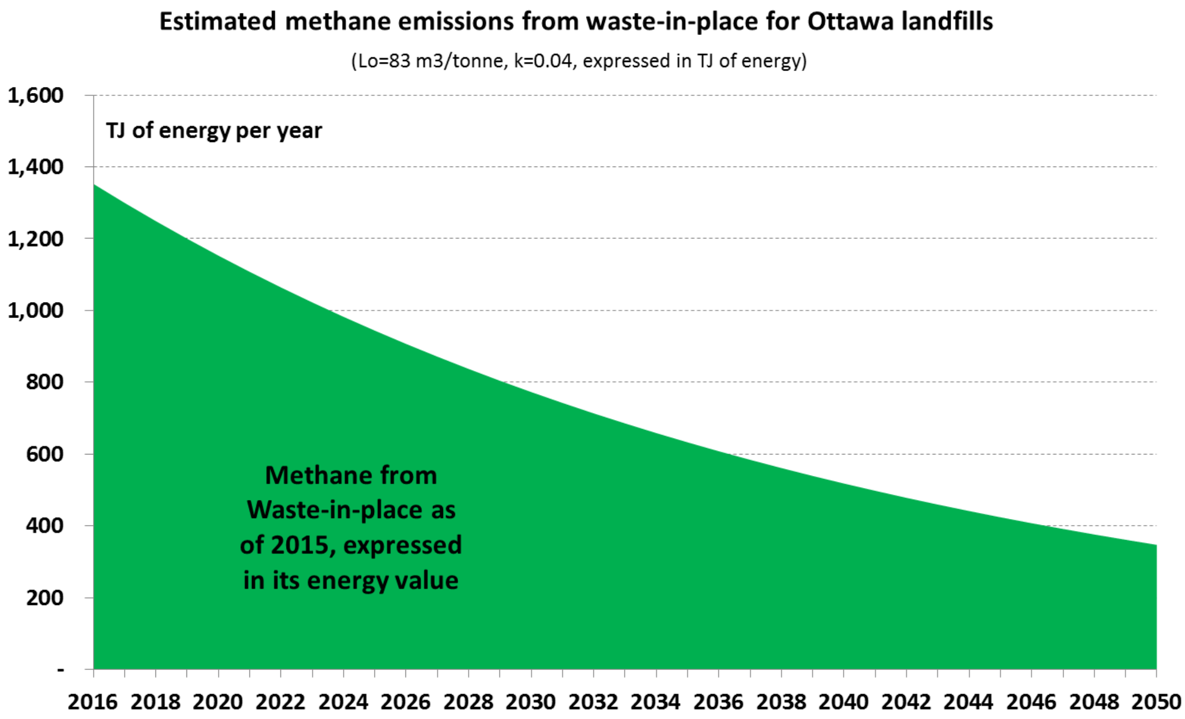


Table 8 summarizes the current energy recovery from landfills and waste streams in Ottawa. Landfill gas recovery from waste-in-place accounts for 70% of the biogas energy and 64% of the useful energy, with the ROPEC facility accounting for 22% and 28%, respectively. The utilization of heat and power 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.

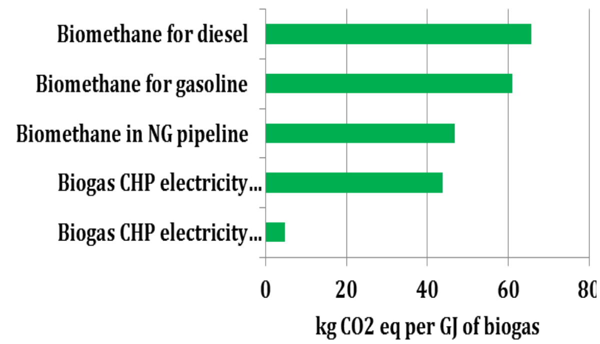
Facility	Waste Source	Methane energy recovered (est.) (TJ)	Electricity of CHP generated (TJ)
Jockvalley Farms*	Manure residues	40	12
Carleton Corner Farms*	Manure residues	40	12
Schouten Cornerview Farms*	Manure residues	40	12
ROPEC AD with CHP	Wastewater treatment sludge	310	Electricity 68 Heat 61
Trail 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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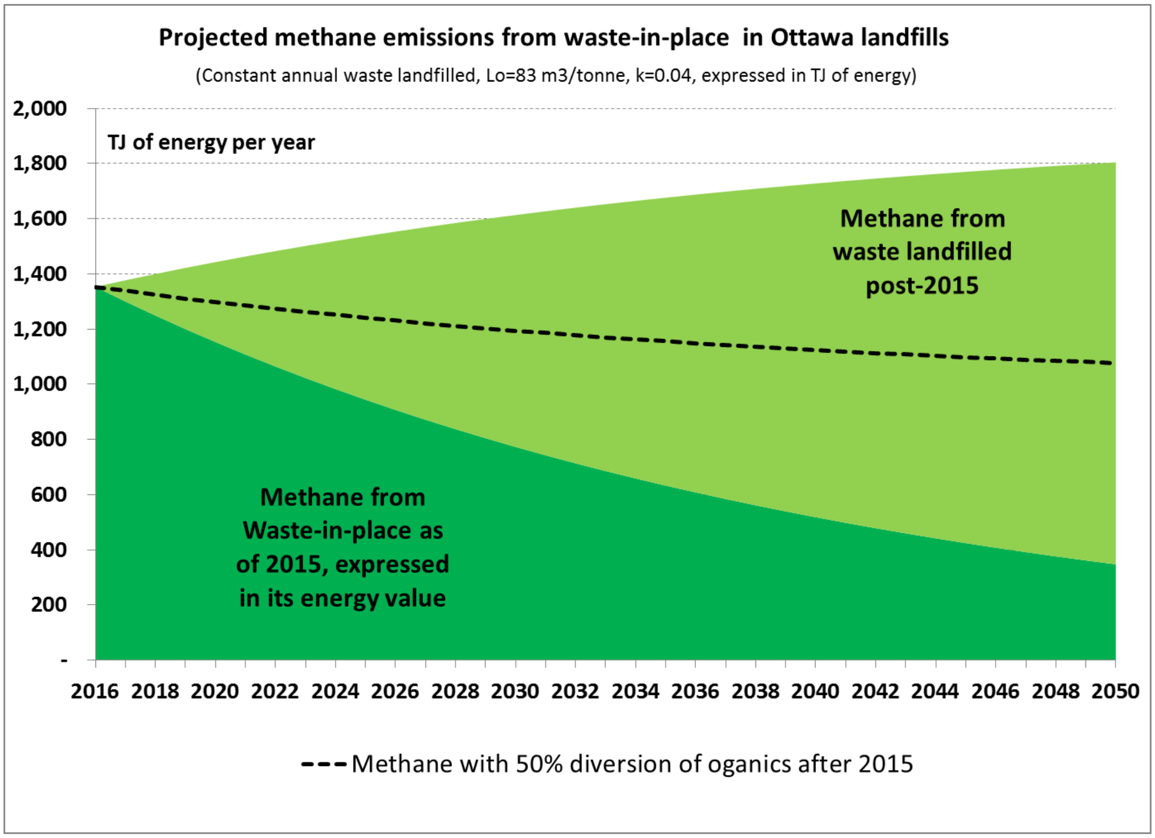
[36] Torrie R. et. al., (2015). "Greenhouse Gas Emissions and the Ontario Waste Management Industry", report for Ontario Waste Management Association. Access at: https://www.researchgate.net/publication/300485656_Greenhouse_Gas_Emissions_and_the_Ontario_Waste_Management_Industry.

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.