DRAFT

ReCharge Hamilton

A Propsperous, Equitable, Post-Carbon City

Our Community Energy + Emissions Plan

2022

Hamilton

SSG

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1.0 Land Acknowledgement

The City of Hamilton is situated upon the traditional territories of the Erie, Neutral, Huron-Wendat, Haudenosaunee, and Mississaugas. This land is covered by the Dish With One Spoon Wampum Belt Covenant, which was an agreement between the Haudenosaunee and Anishinaabek to share and care for the resources around the Great Lakes. We further acknowledge that this land is covered by the Between the Lakes Purchase, 1792, between the Crown and the Mississaugas of the Credit First Nation.

Today, the City of Hamilton is home to many Indigenous people from across Turtle Island (North America) and we recognize that we must do more to learn about the rich history of this land so that we can better understand our roles as residents, neighbours, partners, and caretakers.

2.0 Letter from the Mayor

3.0 Acknowledgements

Sincere thank you to the dozens of members of the community that participated on the Stakeholder Advisory Committee (SAC), giving their time and energy over nearly two years. SAC members spent hours learning about Hamilton's energy and emissions profile, as well as climate action best practices. Members shared their expertise to create a Plan for all Hamiltonians.

Hamilton Community Stakeholder Advisory Committee organizations:

- Alectra Utilities
- ArcelorMittal Dofasco
- Bay Area Climate Change Council
- CityHousing Hamilton
- Centre for Climate Change Management at Mohawk College
- Clean Air Hamilton
- Enbridge
- Environment Hamilton
- Faith and the Common Good
- Hamilton Burlington Society of Architects
- Hamilton Chamber of Commerce
- Hamilton Health Sciences
- Hamilton Industrial Environmental Association
- Hamilton Community Enterprisesises Inc.
- Hamilton Oshawa Port Authority
- Hamilton-Wentworth Catholic District School Board
- Hydro One
- McCallumSather Architects
- McMaster University
- Mohawk College
- Neighbour 2 Neighbour Centre
- Smarter Alloys
- Sustainable Hamilton Burlington
- Stelco
- West End Home Builders Association

As a major stakeholder in this Community-wide initiative, the City of Hamilton has provided staff resources from the following departments and sections to assist in the development of this Plan:

- Planning and Economic Development Department (Transportation Planning, Transit, Planning, Growth Management, Building, and Economic Development Divisions)
- Corporate Services Department (Financial Planning, Administration and Policy Division)
- Public Works Department (Environmental Services, Office of Energy Initiatives)
- Healthy and Safe Communities Department (Health Hazards and Vector Borne Diseases, and Neighbourhood Development Divisions).

In addition, the City would like to thank other organizations that provided their expertise and advice during one-on-one interviews, including:

- NRCan Canmet MATERIALS Lab at McMaster Innovation Park;
- Independent Electricity System Operator (IESO);
- Green Venture;
- the Canadian Steel Producers Association;
- Hamilton Community Enterprises;
- Federation of Canadian Municipalities; and
- The Atmospheric Fund

Acknowledgement also goes to the Province of Ontario, which provided funding support through the Ministry of Energy's Municipal Energy Plan program.

Executive Summary

4.0 Executive Summary

ReCharge Hamilton is a Community Energy and Emissions Plan (CEEP) that lays out a major component of the City of Hamilton's strategy for responding to the climate emergency. With the input of local industry, academia, utilities, local non-profits, and the public this plan aims for Hamilton to achieve net-zero carbon emissions, citywide, by 2050 and become a prosperous, equitable, post-carbon city.

Hamilton will be well on its way to becoming net-zero by focusing on the plan's **5 Low-carbon Transformations**:

1. INNOVATING OUR INDUSTRY: Actions focused on supporting the City's industry in decarbonizing and increasing the energy efficiency of their industrial processes.

2. TRANSFORMING OUR BUILDINGS: Actions that support the retrofitting of existing buildings to be more energy efficient and to encourage fuel switching. It also includes actions that support improving the energy efficiency and GHG profile of new buildings within the City.

3. CHANGING HOW WE MOVE: Actions that focus on increasing the modal split of transit and active transportation and decreasing the number of trips taken in personal vehicles. These actions also focus on decarbonizing the remaining personal and commercial vehicles and the City's vehicle fleet.

4. REVOLUTIONIZING RENEWABLES: Actions that promote renewable energy generation. This includes reviewing the City's development policy and regulatory framework to remove barriers for the development of renewable energy projects. The City can also explore local, alternative ownership structures for renewable energy projects, such as cooperatives. It also includes leveraging existing renewable energy initiatives in the City such as expanding and decarbonizing our district energy system (with the potential to include industrial residual heat), and investigating increasing our household organic waste diversion from landfills to anaerobic digesters to increase biogas and RNG production.

5. GROWING GREEN: Actions that promote carbon sequestration through the growth of the City's tree canopy and preserving the City's existing natural heritage features through land use planning processes.

The detailed actions, including timelines and targets, that enable these **5 Low-carbon Transformations** are spelled out in greater detail throughout this report and in the Implementation Strategy attached as Appendix C.

This plan builds on growing climate action momentum across the community, from youth activists to the carbon-intensive steel sector. It is also bolstered by national and international calls to action, including the federal government's decision to cut emissions by 40-45% by 2030 and achieve net-zero by 2050, as well as the International Energy Agency's landmark 2021 report that advises against all new investments in fossil fuels.[1] Policies, programs, funding, and private investment are increasingly focused on net zero. This Plan will help leverage these investments to protect the environment, support the local economy, and promote community wellbeing.

ReCharge Hamilton provides a foundation for a community-wide effort to help prevent the most catastrophic impacts of climate change.

4.1 The Vision

The community was integral in designing the following vision for this Plan:

> *ReCharge Hamilton identifies a pathway to net zero GHG emissions by 2050 that increases the resilience of the energy system and improves economic prosperity for all. Drawing on a history of work, policies, and initiatives in this area, ReCharge Hamilton builds on Hamilton's historic and current strengths as an industrial leader in the midst of a rich natural environment, and as a caring community.*

4.2 An Evidence-Based, Community-Informed Pathway

ReCharge Hamilton is informed by a detailed energy use and greenhouse gas (GHG) emissions model of the City. The sources and amounts of Hamilton's GHG emissions were collected for the year 2016 to build a thorough inventory of the City emissions. Emissions data was then combined with other important data from 2016, like population, number and types of houses, number of cars, and working hours, to create a picture of what Hamilton's activities and emissions looked like in 2016. Using this picture as a base year, the City's GHG emission future was then modelled using current trends out to 2050 in a business-as-planned (BAP) scenario. This business-as-planned scenario illustrates the scope of the problem, i.e. how much carbon Hamilton could emit between now and 2050 if no actions are taken to lower emissions. It's against this possible future that the net-zero scenario—the basis of ReCharge Hamilton—was built.

The industrial sector, primarily steel, is by far the city's largest source of emissions. It represents 64% of emissions in 2016 (the base year), and in 2050 if Hamilton follows the BAP scenario. Transportation represents 19% of emissions in the base year, then reduces to 17% by 2050 in the BAP. Buildings (residential and commercial) together represent about 15% of Hamilton's emissions in the base year, but those increase to 17% by 2050 in the BAP. Figure ES1 shows the City's projected BAP GHG emissions by sector from 2016 to 2050.

[1] International Energy Agency, Net Zero by 2050: A Roadmap for the Global Energy Sector (May 2021).

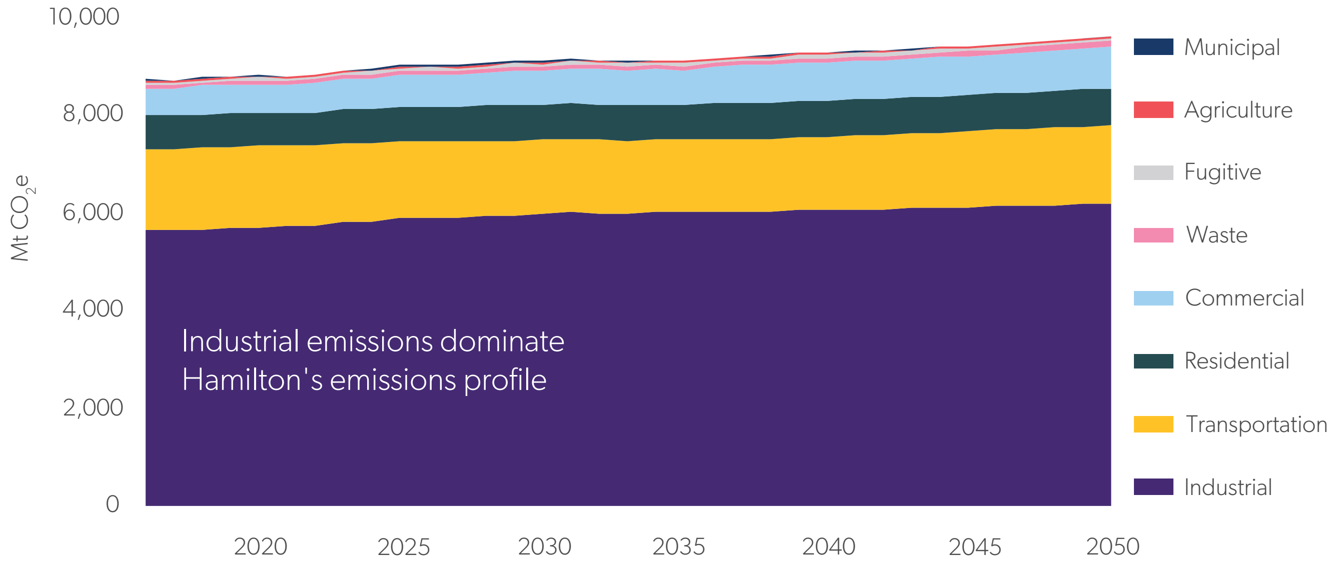


Figure ES1. Projected business-as-planned GHG emissions (Mt CO_2e) by sector, 2016-2050.

Based on best practices and community input, 30 low-carbon targets were modelled to assess how Hamilton could reach its goal of net-zero emissions by 2050. The net-zero scenario prioritizes energy efficiency in order to minimize the societal and environmental costs of the low-carbon transition. As a general rule, a unit of energy saved is less expensive than building another unit of energy production capacity, regardless of fuel source. Only after energy efficiency measures are incorporated is fuel switching to low-carbon/renewable energy sources considered. Figure ES2 shows the GHG reductions (by sector) resulting from the net-zero scenario.

The modelled low-carbon actions still result in positive GHG emissions by 2050. These are primarily from the few remaining combustion engine vehicles on the road and a small amount of industrial emissions. These remaining emissions are called 'the carbon gap.' The carbon gap will need to be addressed in future iterations of the plan using technological or policy innovations, or through carbon offsets.

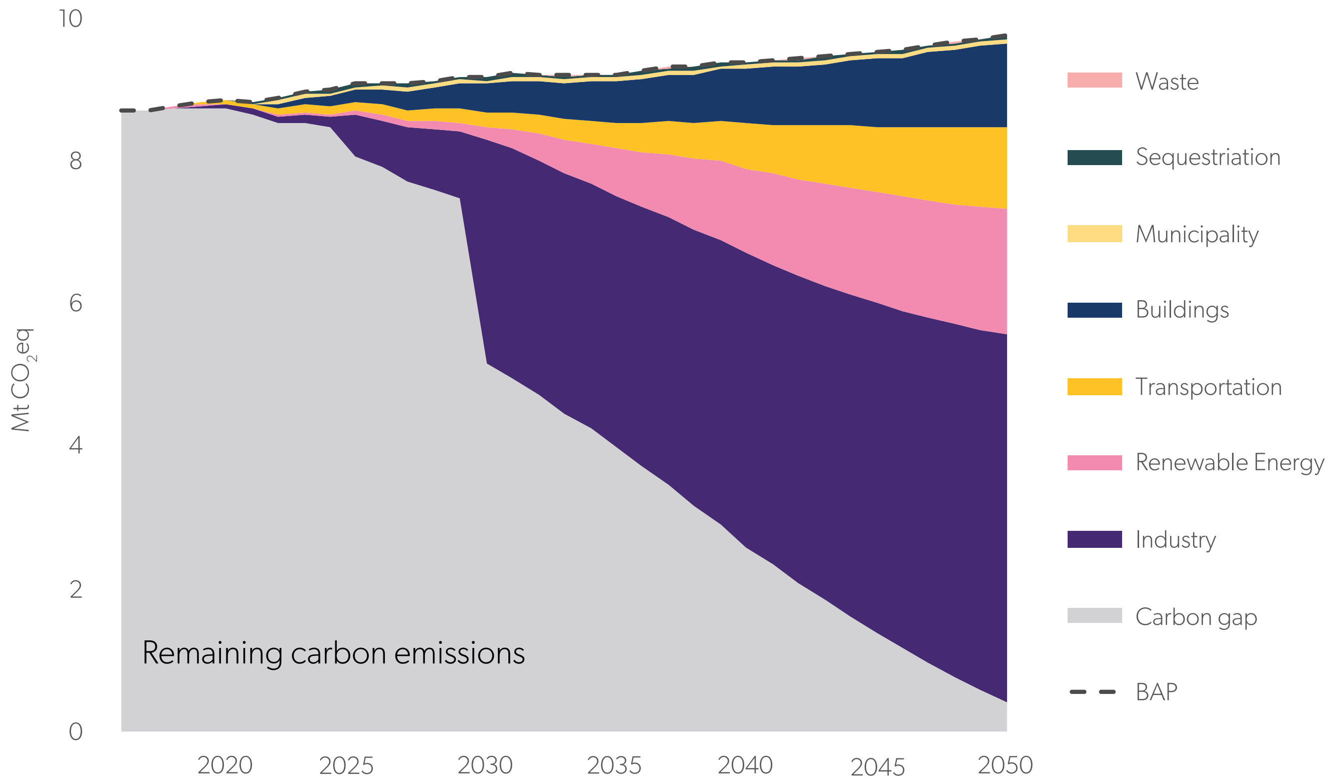


Figure ES2. GHG emissions reductions (Mt CO_2e) in the net-zero scenario. Note: For visual clarity, modelled targets are grouped by sector. A complete list of modelled targets is provided in Appendix A.

4.3 Getting to Net-Zero: Co-Benefits

In addition to reducing GHG emissions, ReCharge Hamilton has the potential to act as an economic catalyst and create about 5,500 full-time jobs within the City, primarily due to the mass industrial process efficiency and building retrofit program at its core.[2] The plan will also create a variety of other co-benefits, or benefits that go beyond greenhouse gas reductions.

Households will see energy bills drop by an average of 50% by 2050 as household comfort increases. Air quality will improve, and there will be less noise from combustion engine vehicles. Biodiversity and protection of wildlife are an additional outcome of protecting and expanding the city's natural areas. Several of the actions proposed within ReCharge Hamilton also have the co-benefit of increasing physical activity through the promotion of active transportation, transit, and e-mobility, which can contribute to an increase in positive health outcomes.

[2] The equivalent of about 161 thousand person years of employment from 2022 to 2050.

4.4 The Challenges

The pathway described in ReCharge Hamilton describes a City that by 2050 uses significantly less energy, switches nearly all of its energy to emission-free sources, and produces more renewable energy by applying practical, feasible, known solutions. Two of the major challenges for Hamilton are decarbonizing the steel industry and retrofitting the City's extensive older building stock.

The technological pathway for decarbonizing the steel industry is still emerging and there are fewer local and international examples of successfully decarbonizing the steel manufacturing process. Recent announcements by the Federal and Provincial governments to assist the Steel industry with funding to decarbonize is a promising move towards overcoming this challenge. Going forward, the City will need to work closely with the steel industry, research partners, utilities, all levels of government, and other stakeholders in order to help facilitate and implement a pathway to decarbonizing Hamilton's steel industry.

Completing mass deep energy building retrofits at scale represents a more common challenge that many municipalities across Canada and globally are trying to understand and resolve. Whereas the technologies to undertake retrofits are clear and established, a successful framework to deliver retrofits at the scale required is still being developed. The City will need to work with all levels of government, the skilled trades, educational establishments, Hamilton homeowners, other municipalities, and industry experts in order to develop a framework that works for Hamilton.

4.5 The Low-carbon Transformations

The actions proposed in this plan have been organized to focus on 5 key low-carbon transformations that will be pivotal in achieving Hamilton's low-carbon future.

TRANSFORMATION 1: Innovating Our Industry

Hamilton has long been an industrial hub for one of Canada's most carbon-intensive primary industries: steel. This industry represents over half of the City's emissions today.

Supporting and encouraging industrial efforts to decarbonize is key to achieving the City's targets. This means encouraging businesses and industry groups to adopt organizational net-zero targets, tracking progress towards those targets, connecting industry with resources, and engaging other levels of government for support. This includes establishing a net-zero working group for local industry stakeholders, and the creation of a cleantech accelerator to expedite low-carbon technology development and increase industry access to upcoming technology.

For the steel industry, it will mean switching from coal to emission-free alternatives, like sustainably sourced biochar or green hydrogen. For other industries, the focus will be on improving energy efficiency using new and emerging technologies and fuel-switching to clean energy sources.

TRANSFORMATION 2: Transforming Our Buildings

By 2050 in the BAP scenario, residential and commercial buildings are projected to represent the second largest source of emissions in Hamilton, primarily from the use of natural gas for space and water heating, particularly in older, more inefficient homes.

This plan features a comprehensive energy efficiency and fuel switching building retrofit program. This fuel switching will primarily serve to replace natural gas furnaces with electric heat pumps. The program will aim to cover most of the City of Hamilton by 2050. This plan also recommends partnering with local institutions, labour associations, and not-for-profits to ensure that appropriate education and training programs are in place to prepare the labour force for the proposed mass building retrofits.

This plan will also recommend the creation of comprehensive sustainable building and development guidelines, which will help increase the energy efficiency and decrease the GHG impact of new development. There are various examples of such guidelines throughout Ontario. This will also limit the need for new buildings to be retrofitted in the future.

TRANSFORMATION 3: Changing How We Move

Closely following buildings, fossil-fuel combustion in cars, trucks, and buses are estimated to account for about 19% of the City's GHG emissions in 2016, and decline slightly to 17% of Hamilton's emissions in a BAP scenario by 2050.

To achieve net-zero in this sector, the City will play a key role: expanding active transportation, e-mobility and transit networks, decarbonizing their fleet and transit, and by ensuring the City is designed to support electric vehicle adoption by creating a City-wide EV Strategy that will provide a comprehensive overview of how the City can support the uptake of EVs and encourage the private sector to do so as well. The City and it's partners will also work with commercial fleet owners to form a community of best practice to share information, support the setting of fleet net-zero targets, track progress towards them, and help connect businesses with resources.

TRANSFORMATION 4: Revolutionizing Renewables

ReCharge Hamilton prioritizes maximizing energy efficiency. Then, the plan relies on fuel switching away from gasoline, diesel, coal, and natural gas to renewable electricity, renewable natural gas, and green hydrogen to achieve net-zero emissions.

Where possible, the production of local renewable electricity is best, as it helps support local economic development and energy independence. Hamilton has access to a wealth of untapped energy and renewable energy resources. For example, the low-carbon model includes:

- Industrial residual heat;
- Rooftop and ground mount solar energy;
- Wind; and
- Biogas from the decomposition of household organic waste.

These combine to meet about 7% of the City's energy needs. Additional renewable energy capacity is available, for example from large-scale wind (inside or outside the City boundaries) along with agricultural and institutional organic waste.

This plan recommends a review of planning and regulatory documents to remove regulatory and policy barriers to the establishment of renewable energy projects, while also encouraging innovative, local ownership structures for these projects. ReCharge Hamilton will also recommend that the City, with its partners, further investigate renewable sources of energy, such as those originating from industrial residual heat, household organics and green hydrogen. This includes exploring the creation of a "hydrogen hub" in Hamilton.

TRANSFORMATION 5: Growing Green

Green space defines Hamilton; it is a lifeline for local wildlife, water quality, and resident well-being and health. Continuing to protect and expand these natural areas is an important part of achieving net zero, as trees and healthy soil are an important source of carbon sequestration. ReCharge Hamilton will focus on preserving and expanding the City's tree canopy cover, which helps sequester carbon, while providing significant co-benefits such as moderating micro-climates, providing stormwater storage, improving air quality, and enhancing energy efficiency.

This plan proposes to plant 50,000 trees per year across the entire community, Including efforts from the City, local Conservation Authorities, the general public and the private and not-for-profit sectors. The City will also ensure it's land use planning policies and regulations preserve the City's existing tree canopy cover wherever possible.

4.6 Plugging the Emissions Gap

The net-zero scenario modelled for ReCharge Hamilton doesn't quite achieve zero emissions. Remaining emissions come from:

- aviation, rail, and marine sources;
- some remaining natural gas use in homes and industry; and
- gasoline and diesel in the few gas-powered cars.

Much of these emissions are difficult to address and lack current policy and technological solutions. These emissions will be addressed through carbon offsets, technology developments (for aviation, rail and marine sectors), or other emerging strategies.

4.7 Equity in Action

ReCharge Hamilton sets the course for a green, equitable recovery. During the development of the City's Community Energy and Emissions Plan, the COVID-19 pandemic spread across the globe, severely impacting communities throughout Canada and the world. Hamilton was no exception. This pandemic has demonstrated the ability of individuals, communities, and leaders to quickly change and adapt their habits and behavior in a time of crisis to achieve a common goal for the greater good of society. This highlighted people's ability to adapt, change, innovate and problem solve. As we recover from COVID-19, we have the opportunity to "build back better," using this same innovative and creative spirit to address the climate crisis. At the forefront of this approach should be ensuring a just and equitable recovery for all Hamiltonians.

Decarbonization programs will be designed, first and foremost, with low-income and traditionally marginalized communities in mind. For example, home retrofit programs will prioritize residents experiencing energy poverty.[3] Job training for low-carbon industries will prioritize historically under-employed communities. Business owners from historically marginalized communities contributing to the net-zero economy will be supported by the City. Investments in tree planting, as well as cycling and walking infrastructure, will be targeted at historically underserved communities. Consultation with these communities will be a core component of implementation as this plan moves forward.

A core guiding principle in the development of ReCharge Hamilton has been to ensure that equity is a foremost consideration in its implementation, in order to maximize benefits to the City's marginalized communities.

[3] Households that spend more than 6% of their income on their energy needs. ("Energy Poverty in Canada: a CUSP Backgrounder" (CUSP, October 2019) at 2, online: www.energypoverty.ca/backgrounder.pdf; Alternatively, Homelesshub.ca defines energy poverty as those spending more than 10% of their income on energy (see: Homelesshub.ca, "Energy Poverty" (accessed May 2021) online: https://www.homelesshub.ca/povertyhub/basic-needs/energy-poverty.)

Part 1

5.0 Part I: Setting the Scene

5.1 Net Zero by 2050

On March 27th, 2019, Hamilton City Council passed a motion stating that,

> "*[T]he City of Hamilton declares a climate emergency that threatens our city, region, province, nation, civilization, humanity and the natural world.*

As part of this motion, City Council directed Staff to investigate and identify a path for the entire city to achieve net-zero carbon emissions by 2050, including a process for measuring and reporting on progress towards that goal. With support and guidance from a multi-stakeholder advisory committee and input from the broader public, ReCharge Hamilton seeks to do just that.

5.2 What is a Community Energy and Emissions Plan?

ReCharge Hamilton is a community energy and emissions plan (CEEP). A CEEP is a tool that helps municipalities understand their influence on greenhouse gas emissions (GHG), and how to plan their communities so that the goal of reducing GHGs is aligned with other community social and economic goals.[4]

Developing a CEEP enables communities to consider energy and emissions early in the land-use and infrastructure planning process, and identify opportunities to integrate local renewable energy solutions at a building or neighbourhood-scale. The impetus for developing a CEEP is summarized well in a 2015 report on local finance best practices:

Setting GHG Reduction Targets: The Science

Net zero by 2050 aligns with the goals of the United Nations Framework Convention on Climate Change (UNFCCC) Paris Agreement and the Intergovernmental Panel on Climate Change (IPCC) Special Report on Global Warming of 1.5°C.[1] This target increases the likelihood of avoiding catastrophic global climate change.

The IPCC identifies global targets of net zero by 2045 to 2055. UN treaties recognize that rich countries, such as Canada, need to reduce their emissions more quickly. This requires a steep decline in emissions starting as soon as possible.

Moving from targets decades in the future to interim targets (e.g., for 2025, 2030, etc.) and annual emissions targets that can be meaningfully operationalized is an important next step in this City's response to the climate emergency.

[1] C40 Cities, Science-Based Climate Targets, a Guide for Cities (November 2020), online at sciencebasedtargetsnetwork.org/wp-content/uploads/2020/11/SBTs-for-cities-guide-nov-2020.pdf.

[4] Community Emissions Reduction Planning: A Guide for Municipalities (Government of Ontario, December 2017) at 20.

> *"The infrastructure planning and financing decisions made today will determine the world's climate and development outcomes for the next century. Taken together, these decisions will lead to the building of either low-emission, climate-resilient infrastructure that increases economic opportunity or more of what we have already, effectively locking the world into a carbon-intensive pathway with sprawling human settlements, hazardous pollution, and heightened vulnerability to climate change.*[5]

5.3 Building on Community Climate Action

This plan covers GHG emissions from across the community. The effort builds on momentum for energy efficiency, renewable energy production, and emission reductions action already underway across the City energy sector, industry, businesses, and institutions, and within the City of Hamilton itself. Some notable examples are highlighted throughout Part II of this document.

5.4 Developing the Plan

The Plan was developed using technical models that help quantify the GHG impact of certain actions that can be implemented by the City and broader community. These technical models helped inform what actions, and to what extent, would be included within the Plan to help Hamilton reach net-zero by 2050. Equally as important, however, was the significant public and stakeholder consultation that was completed throughout the development of the Plan. This consultation helped identify what actions should be prioritized, highlight what actions represented community priorities, and inform how these actions should be implemented.

Significant public engagement, with a variety of groups and in a variety of formats, has fed into this Plan. Four multi-disciplinary groups provided their input. These included:

- The City Steering Committee (CSC), a group of representatives from relevant departments across the municipal corporation;
- The Stakeholder Advisory Committee (SAC), a group of representatives invited by the City from relevant Hamilton organizations (see the Acknowledgments section for a list of participating organizations);
- Individual experts; and
- The general public.

[5] The State of City Climate Finance (Cities Climate Finance Leadership Alliance, 2015) online: http://wedocs.unep.org/bitstream/handle/20.500.11822/7523/-The_State_of_City_Climate_Finance-2015CCFLA_State-of-City-Climate-Finance_2015.pdf.pdf?sequence=3&isAllowed=y.

The CSC and SAC participated in several workshops designed to elicit informed input into the plan. These workshops covered:

- An introduction to the project and the process;
- An overview of the base year and business-as-planned energy use and emissions;
- An overview of the net-zero scenario pathway and the associated costs and benefits; and
- An overview of the Implementation Strategy.

Through these workshops, the CSC and SAC helped shape the project's Visions and Goals and define the sectoral energy efficiency and GHG-reduction targets, as well as key short-term implementation actions. These groups also had an opportunity to provide feedback on a draft version of this Plan.

Individual experts, like those at the Natural Resources Canada's CanmetMATERIALS Lab at McMaster University and the Canadian Steel Producers Association, provided critical context on the state of knowledge and best practice relating to the low-carbon transition pathways for Hamilton's steel producers and manufacturers.

The public provided their input through a series of online surveys and a public information session. Some of the responses from these surveys are highlighted throughout this Plan.

5.5 The Pathway: A Collection of Targets

Hamilton is home to a large and growing population, a major industrial sector (most notably steel), impressive academic institutions and healthcare services, a major port, and diverse neighbourhoods—all of this, and much more, contribute to its current energy use and GHG emissions. These features are also sources of potential energy savings, renewable energy, climate innovation, and other climate solutions.

Based on a series of assumptions regarding existing plans and policies that are likely to be in place through to 2050 ('business-as-planned' or BAP scenario), overall GHG emissions for the city are projected to increase by 10% (see Figure 1). However, on a per person basis, energy use and GHG emissions will decline by 28%, as Hamilton's population is projected to increase by 53% over the period. In a BAP scenario Hamilton's 2050 GHG emissions will be far from its net-zero GHG emission target. In 2050, each Hamiltonian will represent the equivalent of 11.2 tonnes of GHGs. As a whole, the City will emit 9.6 Mt CO_2e, up from 8.7 Mt CO_2e in 2016.

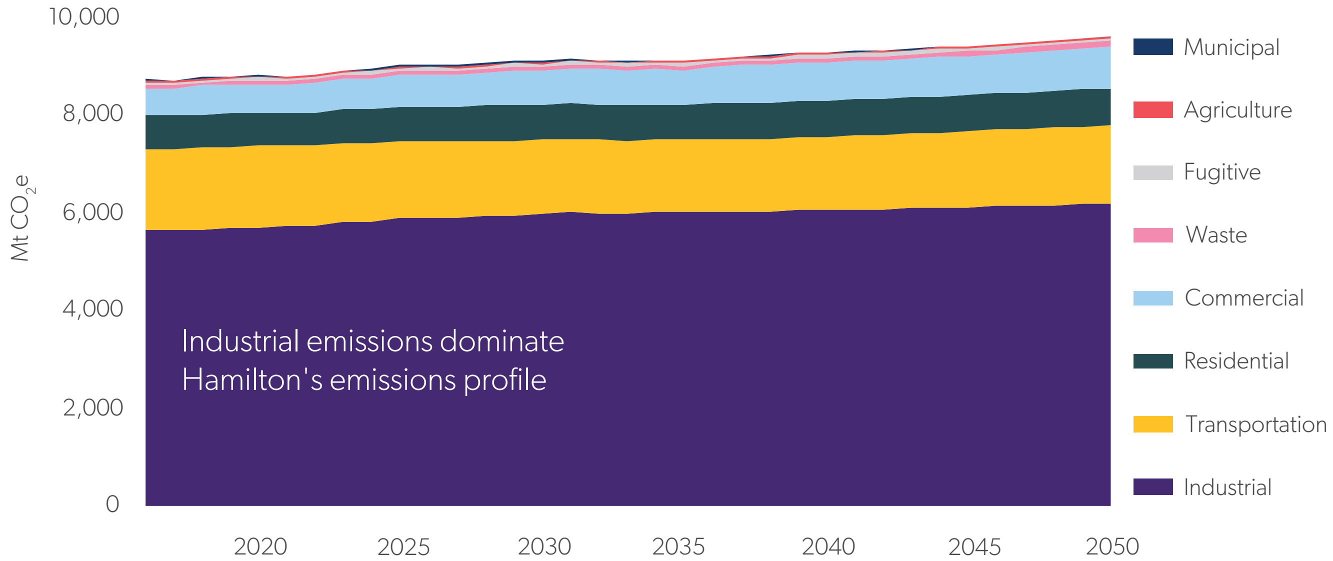


Figure 1. Projected business-as-planned GHG emissions (Mt CO_2e) for the city of Hamilton, by sector, 2016-2050.

What is unique about Hamilton's current emissions profile is the proportion of emissions that are attributed to industry (primarily steel): 64%. Transportation is a distant second at 17% of the City's emissions, followed by commercial buildings (9%) and then by residential buildings (8%). For a more detailed analysis on the City's base year (2016) and business-as-planned (2050) emissions, please refer to the Base Year and Business-As-Planned 2016-2050 Energy and Emissions Report attached hereto as Appendix D.

Based on a detailed study of the community's current and projected energy uses and emissions in a BAP scenario out to 2050, the City and stakeholders were able to develop a pathway for Hamilton to achieve net zero by 2050.

The wedges diagram in Figure 2 show the 30 low-carbon targets that were modelled to reduce the 2050 BAP emissions by 96%, bundled by sector. (A comprehensive table of modelled targets is provided in Appendix A.)

While accommodating a projected increase in the city's population of 53% by 2050, the net-zero pathway models a reduction of per capita GHG emissions from over 11 tonnes in a BAP scenario to less than 1 tonne.

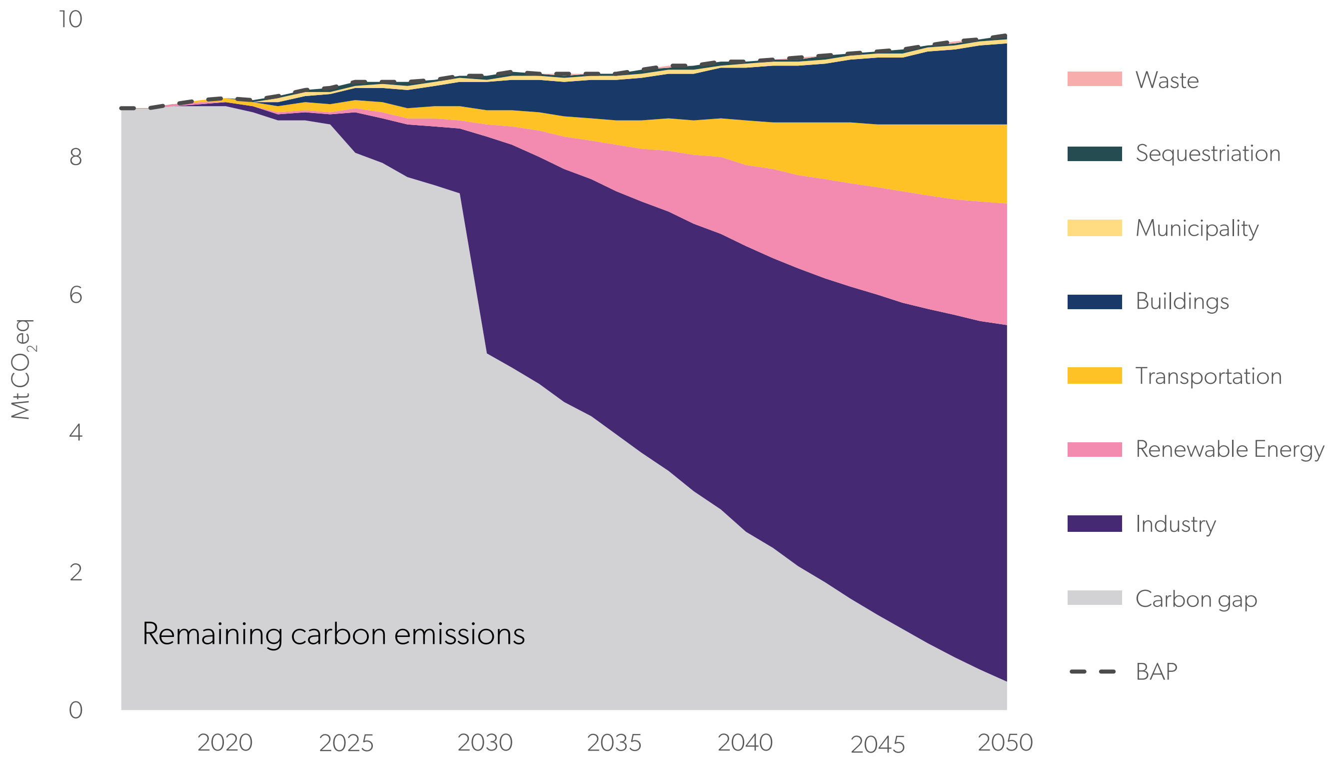


Figure 2. GHG emissions reductions (Mt CO_2e) in the net-zero scenario. Note: For visual clarity, modelled actions are grouped by sector. A complete list of modelled actions is provided in Appendix A.

In order to achieve net-zero emissions by 2050, the remaining carbon gap will need to be addressed via the purchase of offsets or in future CEEP iterations via new technological developments, regulations, or policies.

It is very important to note that the modelled pathway represents only one of many possible community-informed, evidence-based GHG-reduction pathways for the City of Hamilton. This pathway was selected based on community and stakeholder input, City advice, and consultant research on best practices. The pathway assembled and presented in this Plan is ambitious and will not be without challenges. Moreover, the pathway is dynamic and will change as new technologies, opportunities, and challenges arise over the coming decades.

» This Plan includes 30 targets, outlined in tables at the beginning of the section on each sector. Together, they are designed to achieve maximum energy efficiency, avoid waste-related GHG emissions, switch to local renewable energy sources, and maximize natural carbon sequestration.

5.6 The Cost of Action and Inaction

The net-zero scenario offers many direct financial and economic benefits to the city, including new jobs, a positive return on investment, and reduced household and business energy costs. All low-carbon actions included in the net-zero scenario with publicly-available financial data were evaluated in a financial analysis (see Appendix B).

The net-zero scenario requires an estimated $367 million/year of investment, excluding the cost of changes to the steel and marine sectors, and the expansion of active transportation infrastructure. This investment will have a marginally net-positive return for the community of $1 per tonne of GHG reduced, or $63 million dollars, over the life of the investments.[6] These annual investments, which amount to just over a third of the City's annual tax operating budget, will not be the sole responsibility of the City, but rather will be shared across the community and various levels of government in a manner that has yet to be determined. For example, a mass home energy retrofit program is contingent on the investment of homeowners to improve the efficiency of their homes; however, it is assumed that there will be low-interest financing and grants available from various levels of government to improve the business case and return on investment, while also reducing the burden of the large up-front capital cost on the homeowner.

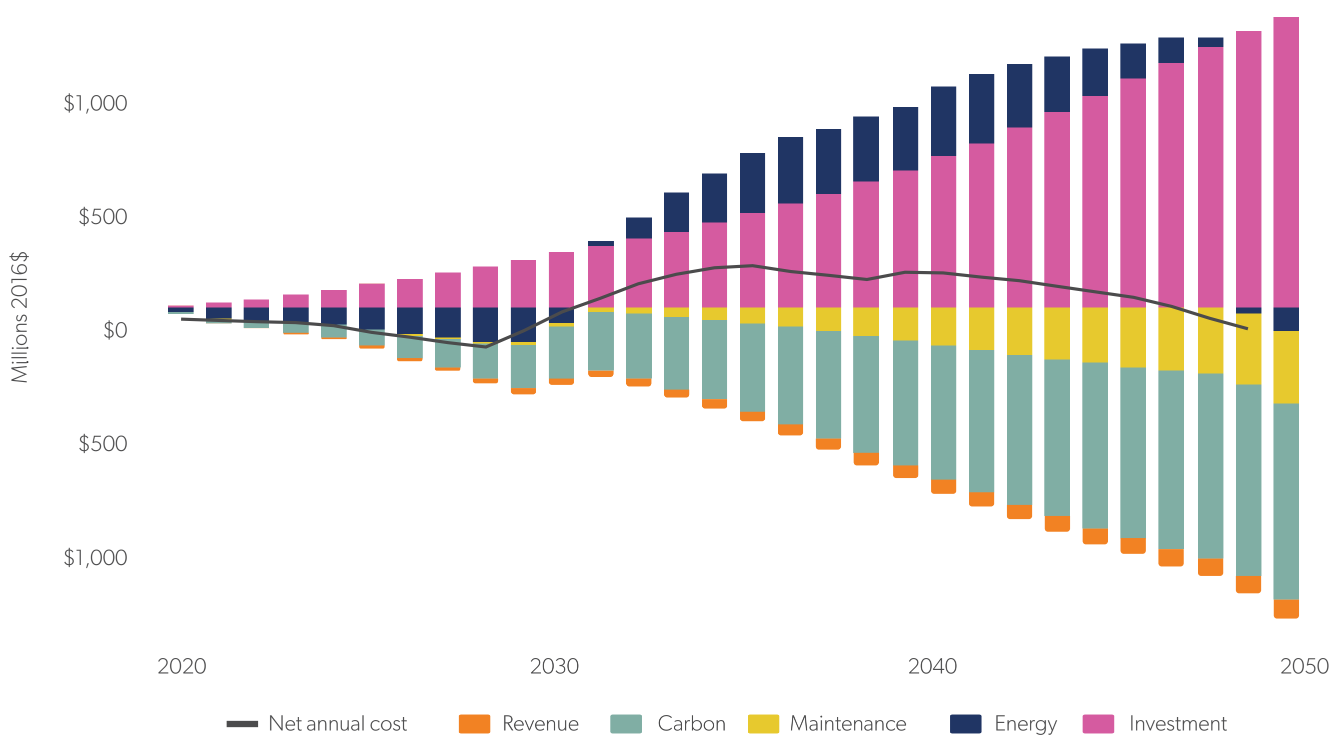


Figure 3. Capital expenditures vs. savings and revenues from the net-zero scenario, 2021-2050.

In addition, most elements of the net-zero pathway also offer co-benefits—which are benefits additional to the reduction of GHG emissions—including positive health outcomes and improvements in social wellbeing and equity.

[6] This number does not account for a few low-carbon actions where defensible cost and savings data was not available: namely steel sector decarbonization, active transportation infrastructure expansion, marine fuel efficiency improvements, and water use reduction.

A financial and economic risk facing Hamilton is failing to engage in the global transition to a low-carbon economy. Though impossible to quantify this risk, some have made valiant attempts. For example, the global re-insurer Swiss Re estimates the global GDP will drop by 18% if no climate action is taken.[7] A second risk is if the transition further entrenches social inequalities. Residents that are already marginalized face the brunt of extreme weather and other climate-related social impacts (e.g., food price shocks). If they are not financially supported in the transition to a net-zero economy, they face being left further behind, and becoming even more vulnerable to the impacts of climate change.

» The tables at the beginning of each low-carbon transformation provide the cost or savings associated with reducing each tonne of GHG emissions per action (this is referred to as the marginal abatement cost), where defensible data was available.

5.7 Co-benefits: Vision and Purpose

At the outset of the project, the community Stakeholder Advisory Committee (SAC) established the following visions and principles for Hamilton's net-zero pathway, that it:

- Supports an equitable energy transition;
- Helps improve the City's resilience to climate change;
- Is community-led;
- Involves a public education campaign;
- Promotes the development and use of clean energy;
- Protects and supports biodiversity;
- Encourages local economic development; and
- Promotes practical climate mitigation and adaptation actions.

The following is a statement that summarizes these principles:

ReCharge Hamilton identifies a pathway to net zero GHG emissions by 2050 that increases the resilience of the energy system and improves economic prosperity for all. Drawing on a history of work, policies and initiatives in this area, ReCharge Hamilton builds on Hamilton's historic and current strengths as an industrial leader in the midst of a rich natural environment, and as a caring community.

[7] "World economy set to lose up to 18% GDP from climate change if no action taken, reveals Swiss Re Institute's stress-test analysis" (Zurich, 22 Apr 2021) Swiss Re, online: www.swissre.com/media/news-releases/nr-20210422-economics-of-climate-change-risks.html.

These principles and vision helped guide the identification of actions and the design of the implementation framework to maximize co-benefits, such as enhancing equity. Opportunities for improved social equity will be realized during implementation. For example, in designing a residential retrofit program, low-income communities experiencing energy poverty would be targeted. In designing improved transit, those communities that do not have the luxury of owning a personal vehicle would be prioritized. Similarly, in designing urban tree planting projects, neighbourhoods with less access to green space and lower existing canopy cover would be targeted. Throughout the implementation of every action the equity lens will be applied in order to maximize the co-benefits of the Plan.

» Throughout this Plan, the co-benefits section for each low-carbon transformation outlines how the sectoral targets support this vision and purpose.

5.8 Turning to Action

Time is of the essence. For this reason, key short-term actions and their potential delivery partners, funding, and financing solutions have been identified throughout this plan. These were determined based on consultations across the City Corporation, the SAC and the public.

The City will play a leadership role by committing to net-zero emissions ahead of 2050 and supporting community-wide implementation with it's partners.

» Throughout this Plan, the implementation section for each sector outlines key actions that will need to be taken in the next five years in order for the GHG reduction targets to be achieved. Each action is numbered to correspond with the appropriate action in the Implementation Strategy attached as Appendix C.

Part 2

6.0 Part II: The 5 Low-carbon Transformations

It's 2050, our major industrial emitters have adopted new, low-carbon technologies to power their processes, reducing the City emissions by over 50% from business-as-planned (BAP). Most homes and businesses have been retrofitted to use less energy, many have rooftop solar, and all heating is produced by clean electricity, renewable natural gas or green hydrogen. As a result, energy bills are lower and comfort is higher. More people are taking transit and active modes of transportation and almost all cars on the road are electric, which reduces noise and air pollution and cuts our City's emissions by over 10% from BAP. The City has more trees, producing cleaner air, providing shelter and food for animals, recreational space for residents, and stormwater management capabilities. Finally, the City is producing much more of its own energy, from the sun, industrial residual heat, and from food and other organic waste. This renewable energy supports the local economy and the City's energy independence and resilience.

This future is the result of implementing the 5 Low-carbon Transformations of ReCharge Hamilton:

1. Innovating our industry;
2. Transforming our buildings;
3. Changing how we move;
4. Revolutionizing renewables; and,
5. Growing Green.

Each transformation is described below, which includes the targets modelled including their impact on BAP emissions, cost per tonne of GHG reduced (a.k.a. marginal abatement cost or MAC), their major co-benefits, and the proposed implementation actions associated with each transformation. The modelled targets represent the low-carbon scenario model that, if achieved, can reduce City-wide GHG emissions by 96% by 2050. The Taking Action section within each low-carbon transformation will discuss immediate and near-term actions that can be taken to work towards our low-carbon future. A more detailed implementation framework can be found in Appendix C, including examples of key performance indicators proposed for monitoring each proposed action.

6.1 Innovating Our Industry

The industrial sector is the main energy consumer and GHG emitter in Hamilton, representing 64% of the City's emissions in the base year and out to 2050 in the BAP scenario. The majority of these emissions are from the coal used at the steel mills. Hydrogen, biochar, and electric arc technologies, all of which are low-carbon alternatives, are likely to be able to replace coal well before 2050. Recent announcements from the Federal and Provincial governments to support decarbonization of the steel sector locally with funding is a promising development for reducing and eliminating emissions from steel production.

For the remaining industry emissions, 50% energy efficiency targets were modelled based on measures identified in the Ontario 2019 Conservation Achievable Potential Study, undertaken on behalf of the province's energy regulator.

MODELLED TARGET	GHG REDUCTION NET ZERO VS. BAP 2050	MARGINAL ABATEMENT COST $/TC$0_2$E (BRACKETS) REPRESENT SAVINGS
Increase industrial energy efficiency (other than steel mills) by 50% from 2016 levels by 2050.	8%	$268
At the steel mills, reduce GHG emissions by 50% from 2016 levels by 2035 and achieve net-zero emissions by 2050.	45%	Not modelled[8]

6.1.1 CO-BENEFITS

Reducing industrial GHG emissions vastly will improve local air quality and, as a result, local public health. Emissions reductions will support will support industry in participating in the growing global low-carbon economy, which will create the potential for Hamilton to become an industry leader and attract global clean-tech investment and avoid carbon leakage into other jurisdictions. Hamilton's industry must change to be competitive in a future economic climate where innovative climate pricing frameworks (such as the European Union's proposed Carbon Border Adjustment Mechanism) will become more prevalent and will place additional economic pressures on the low-carbon production of goods.

6.1.2 TAKING ACTION

In order to achieve the modelled reduction in industrial GHG emissions, the below short-term (0-5 year) implementation actions are recommended. For a more detailed breakdown of the industrial implementation pathway, please see Table 5 of Implementation Strategy, attached as Appendix C.

[8] This action was not financially modelled as at the time of modelling, there was no reliable financial data nor certainty on the specific net-zero pathway that will be adopted by the steel industry.

1 & 1a → Industrial Energy Efficiency and Decarbonization Working Group

The City and it's partners will convene an industrial energy efficiency and decarbonization working (or "net-zero") group. This group will share information, support business or industry groups in setting organizational net-zero targets, track progress towards them, help connect industry with resources, and lobby higher levels of government for support.

In parallel and in conjunction with existing industrial sustainability-themed groups (e.g., Hamilton Industrial Environmental Association and City-led Bayfront Industrial Strategy efforts). This working group will focus explicitly on coordinating and fast-tracking GHG reductions in alignment with the City's GHG targets.

2 → Establish a Clean-tech Accelerator

Building on the skills and expertise available at the City's multiple post-secondary institutions, the City and it's partners, with support from the Provincial and Federal governments, can support the development of a clean-tech accelerator to prioritize and accelerate the development of technologies necessary for the decarbonization of the steel and other local industries.

3 → Expand Local Industrial Energy Management Training Programs

The City and it's local partners, including the Canadian Colleges for Resilient Recovery and other institutions and not-for-profits can work to expand local industrial energy management training programs. This will help build capacity and expertise in the labour force for the decarbonization of the City's industrial sector.

What excites you about this plan?

"Hamilton can be a leader and an example of a rust belt city [embracing] climate action to enhance the local economy, environment and quality of life."

"The potential to collaborate on a plan to move to a low-carbon steel industry based in Hamilton. This is crucial to Canada's long-term competitiveness in steel production [...]."

» *From responses to an online community survey for ReCharge Hamilton.*

Community Momentum

» In 2020, Canadian Steel Producers Association set a net-zero-by-2050 target.

» In 2021, ArcelorMittal Dofasco (AMD) in Hamilton and the Federal and Provincial government announced funding for an initiative to transition AMD's Hamilton operation to electric arc furnace and direct reduced iron technologies. This could cut City-wide emissions by up to 30%.

» Stelco is planning a 65 megawatt cogeneration plant and has developed a technology to reduce coke consumption using waste railway ties. Another Stelco project plans to capture 6,300 tonnes of CO_2 to produce algae for fish feed and bioplastics.

» Hamilton Oshawa Port Authority has a goal of being carbon neutral for its own operations by 2025.

6.2 Transforming Our Buildings

In the base year (2016), commercial and residential buildings in Hamilton now account for almost a quarter of the city's energy consumption and 14% of its GHG emissions, primarily due to natural gas use for space and water heating. Hamilton's older and more inefficient homes are a particular issue. The majority of Hamilton's current building stock was built before any energy efficiency requirements existed (i.e., before 1990). Newer dwellings are built in accordance with the current Ontario Building Code which is more energy efficient. Older and typically more inefficient homes are an important target in order to reduce Hamilton's GHG emissions from residential buildings.

Energy efficiency is the main priority in tackling GHG emissions in the building sector. Significant improvements in energy efficiency can be achieved via implementing energy performance standards and guidelines for new buildings and deep energy retrofits of existing buildings. It is anticipated that through future updates to the Ontario Building code, greater energy efficiencies will be achieved in new buildings. Building retrofit programs will be necessary to accelerate emissions reductions in this sector.

MODELLED TARGET	GHG REDUCTION NET ZERO VS. BAP 2050	MARGINAL ABATEMENT COST $/TCO$_2$E (BRACKETS) REPRESENT SAVINGS
Retrofit 100% of commercial buildings, increasing energy efficiency by 50% by 2050 relative to 2016 levels.	2.7%	($257)
New commercial buildings are 60% lower in energy use intensity than 2016 levels by 2050.	1.4%	($320)
Retrofit 100% of existing homes to achieve 50% energy efficiency savings relative to 2016 by 2050.	2.8%	$139
Post-retrofits, switch buildings to heat pumps for space and water heating by 2050.	4.3%	$451
By 2031, new dwellings are 60% more energy efficient relative to 2016. Only 20% of new dwellings are single detached by 2050.	0.4%	($460)
By 2050, all new municipal buildings achieve net-zero emissions.	0.5%	($290)
By 2050, all municipal buildings are retrofitted to achieve 50% energy efficiency relative to 2016.	0.04%	$53

6.2.1 CO-BENEFITS

Hamilton's deep energy retrofit program will create an estimated 1,600 full time jobs and leverage local expertise in energy-efficient buildings. The benefit of these jobs can help redress inequities if they are targeted at historically marginalized and under-employed communities, for example by providing subsidized training and retraining programs.

Energy efficiency can also help alleviate energy poverty, which is a persistent issue in Hamilton.[9] According to the 2016 Census, about 15% of Hamilton residents (more than 1 in 6) live below the after-tax low-income cut off, and struggle to pay their energy bills.

Social equity can be improved by targeting low-income residents with the proposed home energy retrofit program, such as by prioritizing the delivery of retrofits to social housing and subsidizing retrofits for low-income residents in other types of housing. Energy efficiency retrofits have the potential to reduce household energy bills by over 80% by 2050 (see Figure 4)., thereby resulting in more discretionary income for lower income households for basic needs (e.g. food) or other household purchases.

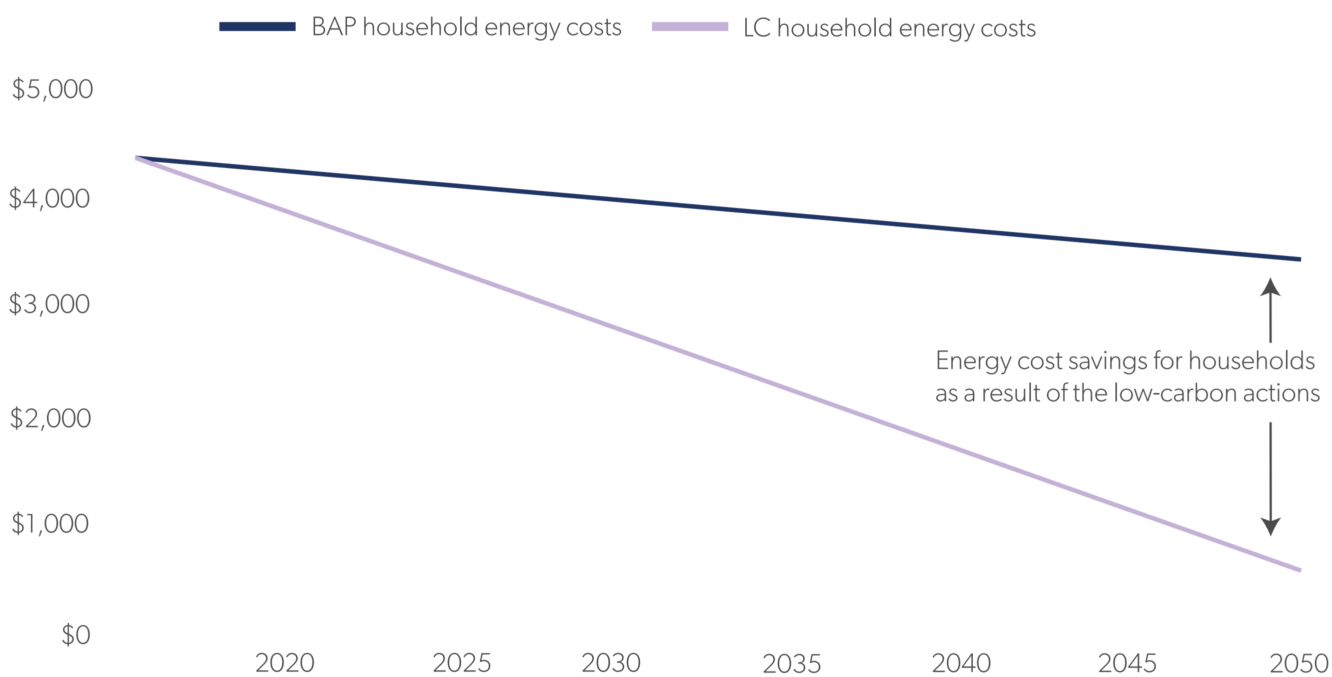


Figure 4. Average annual household energy costs (including transportation fuels) in the business-as-planned (BAP) and net-zero scenarios, 2016-2050.

6.2.2 TAKING ACTION

In order to achieve the modelled buildings GHG emissions reductions, the below short-term (0-5 year) implementation actions are recommended. For a more detailed breakdown of the buildings implementation pathway, please see Table 6 of the Implementation Strategy in Appendix C.

This plan recommends the development of a comprehensive energy retrofit program that will aim to improve energy efficiency and enable fuel switching to low-carbon sources in most of Hamilton's homes and businesses by 2050.

[9] Households that spend more than 6% of their income on their energy needs. ("Energy Poverty in Canada: a CUSP Backgrounder" (CUSP, October 2019) at 2, online: www.energypoverty.ca/backgrounder.pdf; Alternatively, Homelesshub.ca defines energy poverty as those spending more than 10% of their income on energy (see: Homelesshub.ca, "Energy Poverty" (accessed May 2021) online: https://www.homelesshub.ca/povertyhub/basic-needs/energy-poverty.)

4 → Green Standards for New Buildings/ Moving toward Net Zero Buildings

Hamilton is projected to grow by approximately 100,000 households in the 2021- 2051 time period, generally from 200,000 to 300,000 households. Although new buildings are projected to represent a relatively low share of GHG emissions in the City, new development represents long-term infrastructure that will establish patterns of energy use and GHG emissions for decades. The municipality will enact net-zero-aligned building and development standards, guidelines, or policies as soon as possible in order to avoid the need to retrofit new buildings in the future. This will involve working closely with the development community to develop and implement the guidelines. The City can also take on an advocacy role in asking the Provincial government to update the Ontario Building Code to reflect incremental changes towards net-zero construction for new buildings.

5 → Encourage Solar PV on New Buildings

In addition to the proposed Sustainable Development Guidelines, the City can review it's zoning and policy framework to remove barriers for the uptake of roof-mounted solar pv systems. This includes reviewing building height and side-yard requirements for solar PV related mechanical equipment. This also includes reviewing policies and regulations related to shadowing and solar access.

6 6a, 6b, & 6c → Retrofitting Existing Buildings

Many cities are exploring how to bring down the cost of mass deep energy retrofits, such as by revisiting the current utility-led delivery model, as well as ordering equipment (e.g., heat pumps) and undertaking retrofits in bulk. Building and business owners also have a central part to play in building retrofits.

City Council approved staff to apply for available funding through the Federation of Canadian Municipalities. If successful, the City will retain the Centre for Climate Change Management (CCCM) at Mohawk College to complete a detailed design of a Home Energy Retrofit Program to accelerate home energy retrofits across the City. This will be paired with a Home Energy Retrofit Delivery Centre to drive the uptake of retrofits.

The below four key short-term steps are recommended to prepare for a mass deep Home Energy Retrofit Program:

2022: Undertake a detailed design study for a Home Energy Retrofit Program to enable accelerated retrofitting across the City.

2022-onwards: Ensure local skilled labour is being trained or retrained to prepare the local workforce for when the program design is complete and implementation begins. Hamilton's post-secondary institutions (i.e., Mohawk College, McMaster University, and

How will you contribute to building-related GHG reductions?

"Installing solar panels on my property."

"Undertaking an energy audit at my home or work."

"Switching to electric appliances."

"Reducing my water use."

"Installing additional attic insulation."

"Establishing a work-from-home policy at my office."

» *From responses to an online community survey for ReCharge Hamilton.*

Redeemer University) will be key partners in this initiative. This will enable the program to be deployed and implemented seamlessly.

2022-2023: Undertake a small scale retrofit implementation to test the business case model and address potential kinks in the concept. Target low-income households or social housing.

2024-onwards: Expand the program, with particular attention to portions of the population that would stand to benefit the most from reduced energy costs and improved comfort and air quality (among other benefits).

What excites you about this plan?

"The possibility of creating a regulatory and financial support system to transition to renewable, net-zero homes and buildings as soon as possible."

"Buildings and houses built with self-sustaining renewable energy as the default."

"Greater efficiency, reduced heating (and potentially reduced cooling costs)[...]"

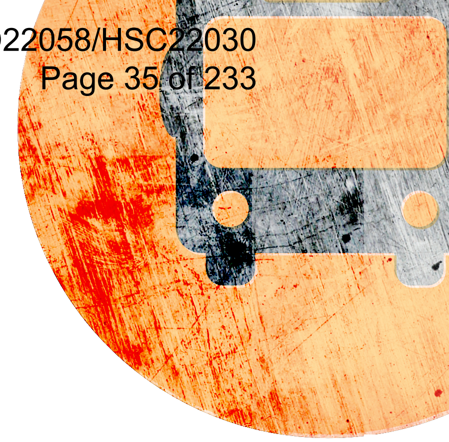
» *From responses to an online community survey for ReCharge Hamilton.*

Community Momentum

The Bay Area Climate Change Council is advising on the design and development of a building retrofit program and "delivery centre" to help the Bay Area achieve a low-carbon future.

In 2018, local architectural firm McCallumSather was recognized by the Hamilton Burlington Society of Architects for its work on the Joyce Centre for Partnership & Innovation at Mohawk College—the first institutional building in Canada to be certified as a Zero Carbon Building.

In 2020, McMaster University published a plan to reach net-zero carbon emissions by 2050 on its main campus.



6.3 Changing How We Move

In the base year (2016), gas- and diesel-powered cars, trucks, and buses account for 19% of Hamilton's emissions, which is second only to industrial emissions. A challenge to scaling up to electric vehicles is lifespan of existing internal combustion engine (ICE) vehicles (greater than 20 years). It will take a generation to retire these existing vehicles. This plan addresses these emissions by supporting alternatives to personal-use vehicles (PUV) through increased active transportation infrastructure (i.e., bike lanes and trails), expanded emissions-free transit, and decarbonizing personal and commercial vehicles.

MODELLED TARGET	GHG REDUCTION NET ZERO VS. BAP 2050	MARGINAL ABATEMENT COST $/TCO$_2$E (BRACKETS) REPRESENT SAVINGS
100% of new PUV sales are electric by 2040.	6.6%	($621)
By 2050, 100% of heavy-duty vehicles are green-hydrogen based and light-duty commercial vehicles are electric.	4.0%	($464)
Private vehicle trips decline by 9% relative to 2016 per person by 2050. Vehicular trip length declines by 6% from 2016 levels by 2050.	0.9%	($424)
Increase marine energy efficiency by 50% by 2050 relative to 2016.[10]	0.2%	Not modelled
100% of new municipal small and light-duty vehicles are electric by 2040. 100% of new municipal heavy-duty vehicles switch to clean hydrogen by 2040.	0.04%	($1,521)
Decarbonize the transit fleet by 2035.	0.1%	$268
By 2050, 10% of short trips are completed by e-mobility or EV car-share.	0.1%	$1,697
Increase transit use to 15% of trips by 2050 in the urban area.	0.02%	($3,908)
By 2050, 50% of short trips in the urban area take place through walking or cycling.	0.00%[11]	Not modelled

[10] This is an existing International Maritime Organization target.

[11] This action follows electrification of vehicles in the model, which explains why it shows no reductions of GHGs.

6.3.1 CO-BENEFITS

Research indicates that air pollution was responsible for about 90 deaths in Hamilton in 2012.[12] The exhaust emissions from cars, trucks, and buses are a leading source of poor air quality in the city.[13] Switching from internal-combustion vehicles to zero-emissions vehicles will improve health outcomes for Hamilton residents, particularly those living, going to school, or working within 100 metres of an arterial major road or 500 metres of a controlled access highway.[14] From 2013 to 2018, Hamilton recorded the highest particulate matter rating of the 10 largest cities in Ontario.[15] Zero-emission vehicles will reduce tail pipe emissions components of particulate matter, leaving non-emissions components such as dust to be addressed through other means.

Equitable outcomes are achieved when mobility (transit, active transportation, and e-mobility) is prioritized for historically marginalized communities. Mechanic training and retraining programs to service the next generation of vehicles can also target low-income and underemployed individuals, further improving social equity outcomes.

By increasing the amount of trips that are taken using an active mode of transportation, Hamilton residents will benefit from improved cardiovascular health, as well as quieter, less stressful streets and improved pedestrian safety.

6.3.2 TAKING ACTION

In order to achieve the modelled GHG emissions reductions, the below short-term (0-5 year) implementation actions related to transportation are recommended. For a more detailed breakdown of the transportation implementation pathway, please see Table 7 of the Implementation Strategy in Appendix C.

How do you see yourself contributing to transportation GHG reductions?

"Taking transit/walking/cycling to work."

"Switching to an electric vehicle."

"Setting up an EV charging station at work."

"Carpooling for my commute."

"Limiting my driving."

"Not idling."

» *From responses to an online community survey for ReCharge Hamilton.*

[12] 2018 Hamilton's Air Quality Trends Appendix "B" to Report BOH19039, at 14 of 15, online: pub-hamilton.escribemeetings.com/filestream.ashx?DocumentId=210129.

[13] Anthony Ciccone and Janya Kelly, "Hamilton Airshed Modelling System: Sub-Regional Analysis" (Golder Associates, March 30, 2021) at slide 23.

[14] Public Health Ontario, Traffic-Related Air Pollution: Avoiding the TRAP zone (n.d.) online: www.publichealthontario.ca/-/media/documents/O/2016/ohp-trap.pdf?la=en.

[15] City of Hamilton, Epidemiology and Evaluation Healthy and Safe Communities, Health Check: Assessing the local burden of disease in the City of Hamilton, 2nd edition (July 2018) at 27, online: www.hamilton.ca/sites/default/files/media/browser/2018-08-02/health-check-report-2018-edition2-v2.pdf.

The following are near-term transportation actions that are designed to first reduce vehicle kilometres traveled and then switch remaining vehicle kilometres travelled (VKTs) to low and/or zero emission vehicles.

7 ⟶ Expand Active Transportation Networks

Increasing active transportation is a priority for reducing transportation emissions; it offers many co-benefits, including improved physical health and increased social well-being. The City can expedite the roll out of its Cycling Master Plan and update future iterations of the Cycling Master Plan to align with the net-zero scenario active mode share targets.

8 ⟶ Decarbonize Transit

The City has recently committed to transitioning its buses to CNG, while also piloting an RNG powered bus; however, as the following section on renewable energy highlights, there is a limited supply of sustainable RNG.

Electrification is a preferred option, as the technology is available and emission-free buses don't emit pollutants that contribute to poor air quality.

9 ⟶ Expand Transit and E-mobility Services

Expanding transit helps reduce the need for personal-use vehicles and also offers an important means of transportation for those who are not able to drive or access personal vehicles. The City should also focus on developing higher-order transit in order to attract new transit riders.

To address those trips that are not suited to transit or active transport, the City can support the establishment of local e-mobility services, such as e-car, e-bike, and e-scooter share businesses.

10 ⟶ Establish a City-wide EV Strategy

To encourage the adoption and increase uptake of EVs, an extensive EV charging network needs to be in place. The City can continue to situate charging stations on City-owned lands through the implementation of the Parking Master Plan, as well as partner with businesses and multi-unit residential buildings to install charging stations in appropriate locations. The City can also require EV infrastructure through the development process for new development within the City. These efforts, among others, can be consolidated and integrated through the development and implementation of a City-wide Electric Vehicle Strategy.

11 ⟶ Commercial Fleet Decarbonization Working Group

The City can accelerate the transition of private fleets by convening a working group to coordinate activities and share insights from implementing the City's net-zero-aligned Green Fleet Strategy, support

What excites you about this plan?

"That we might begin to eliminate cars as a primary mode of transportation and actually become a progressive, green city."

"Less cars on roads."

"Cleaner air and more/safer bike lanes."

"The thought of breathing clean air, not polluted with carcinogenic matter."

» *From responses to an online community survey for ReCharge Hamilton.*

fleet net-zero targets, track progress towards them, and help connect businesses with resources.

12 → Support the Transition of Automotive Mechanics

The projected increase in EVs will require a new and/or retooled labour force. The City, local colleges (e.g., Mohawk College), and professional trade associations will work together to develop a plan to train and retrain the mechanic workforce using an equity lens to shift from ICE vehicles to EVs, although both share some common mechanical components.

13 → Limit Parking and Incentivize EVs

The City can continue its efforts to reduce and manage parking requirements for developments in strategic locations, such as along transit corridors and throughout the Downtown. Where parking spots are required, the City can incentivize EV access through differentiated fee structures and exploring options through legislation for enforcement. The City can also incorporate EV parking requirements into the Zoning by-law for certain types of development.

Community Momentum

In 2021, McMaster University, with support from its industry partners, announced the establishment of a green automotive, aerospace, and advanced manufacturing hub, called iHub.

The Canada Excellence Research Chair in Hybrid Powertrain Program at McMaster is pioneering sustainable energy-efficient solutions from advanced power electronic converters and electric motor drives to electric, hybrid electric, and plug-in hybrid electric vehicles, and working to alleviate the loss of performance of lithium ion batteries over time.

In May 2021, the City Council approved its Green Fleet Strategy which includes converting 89 fossil fueled cars to electric vehicles reducing GHG emissions by 18% in 3 years (not including police, fire and transit vehicles). The Strategy also includes a long-range target of achieving net zero across the municipal fleet by 2050.

In March 2021, the City partnered with Enbridge to fuel Ontario's first carbon-negative transit bus as part of the HSR's fleet.

6.4 Revolutionizing Renewables

As a final step to achieving net zero by 2050, remaining fossil fuel energy use needs to be replaced with renewable energy. Due to the expected increased reliance on fossil fuels by the provincial electricity grid, the switch to renewable energy will require directly generating renewable energy or purchasing renewable energy from outside of City boundaries to offset remaining emissions.

The City has strategic opportunities to increase production of renewable energy via wind turbines, rooftop and ground mount solar energy, renewable natural gas (RNG) from local organic waste, and capturing residual heat from the industrial sector. The low-carbon scenario modelled for the city of Hamilton included a combination of these sources that amounted to 7% of the City's energy needs by 2050.[16] There is potential to produce much more, for example via large-scale wind and solar installations inside or outside of the city limits, as well as RNG produced from the city's commercial and agricultural organic waste. Ample renewable energy will be crucial in order to produce the green hydrogen that is vital in the pathway to decarbonizing Hamilton's industrial sector, including steel production.

The City is home to extensive district energy systems, local energy generation that powers multiple buildings at a time. This is an important local resource that can be leveraged to expand local renewable energy generation.

If the Provincial grid decarbonizes by 2050, then the purchase of renewable energy certificates outlined in the table below will not be required.

MODELLED TARGET	GHG REDUCTION NET ZERO VS. BAP 2050	MARGINAL ABATEMENT COST $/TC$O_2$E (BRACKETS) REPRESENT SAVINGS
In 2050, for each MWh of central electricity demand remaining after local renewable energy production, purchase a Renewable Energy Certificate (REC).[17] (This action includes the modelled wind capacity)	6.1%	$51
In order to replace the remaining natural gas in the City, green hydrogen (produced via renewable energy) is pumped into the natural gas distribution system.	5.0%	$816

[16] As a result of approximately 830 GWh of wind, 560 GWh of rooftop solar, 400 GWh ground mount solar, 5 GWh of RNG, and 130 GWh of industrial residual heat.

[17] Renewable Energy Certificates (RECs) are a market-based instrument that certifies the bearer owns one megawatt-hour (MWh) of electricity generated from a renewable energy resource. Once the power provider has fed the energy into the grid, the REC received can then be sold on the open market as an energy commodity. RECs earned may be sold, for example, to other entities that are polluting as a carbon credit to offset their emissions.

MODELLED TARGET	GHG REDUCTION NET ZERO VS. BAP 2050	MARGINAL ABATEMENT COST $/TC$O_2$E (BRACKETS) REPRESENT SAVINGS
By 2050, Installation of 280 MW of ground mount solar PV, inside or outside the City boundary.	0.3%	($1,254)
Expansion of the downtown district energy network powered by industrial residual heat.	0.1%[18]	$192[19]
By 2050, Installation of rooftop solar PV capacity to power, on average, 50% of building electric load, before the introduction of heat pumps.	0.2%	($959)
Starting in 2031, all new homes have 30% annual load coverage by solar PV, before the introduction of heat pumps.	0.2%	($1,343)
Starting in 2026, all new commercial buildings include rooftop solar PV panels.	0.2%	($654)
By 2050, 50% of municipal buildings will add rooftop solar PV, covering 30% of the building's electrical load.	0.01%	($494)
By 2050, 95% of organic waste is sent to anaerobic digestion for local energy use. Purchase remaining RNG needed to replace all remaining natural gas demand by 2050, starting in 2025.	5.8%	$74

6.4.1 CO-BENEFITS

Local energy generation helps ensure local energy resilience and keeps energy dollars and jobs within the community. For Hamilton, increasing local renewable energy generation will also decrease energy waste. For example, the residual heat from industrial smoke stacks could be captured to heat buildings, instead of using natural gas, and organic waste decomposing in the landfill could be captured, processed, and then used instead of natural gas to power waste disposal trucks or the City's transit vehicles.

Switching away from fossil fuel-based sources of energy and towards renewable sources of energy will also contribute to a reduction in airborne particulate, and ultimately better air quality.

6.4.2 TAKING ACTION

Renewable electricity and renewable natural gas are essential to the City achieving its target of net zero by 2050. In terms of electricity, either the provincial electricity grid will have to

[18] Further work by Hamilton Community Enterprises and its partners on their industrial residual heat harvesting project has identified a potential to reduce GHG emissions by 200,000 tCO2e which translates to ±2.3% in the above table

[19] This expanded opportunity would further reduce the marginal abatement costs to $12/tCO2e

decarbonize by 2050 or the City will need to increase local sources of renewable electricity. The remaining natural gas supply will need to be replaced with renewable natural gas (one recent study shared by Enbridge suggests this represents 6% of today's natural gas consumption[20]) or green hydrogen (produced by renewable electricity). For a more detailed breakdown of the revolutionize renewables implementation pathway, please see Table 8 of the Implementation Strategy in Appendix C.

14 → Advocate for and Build an Electricity Grid for the Future

To achieve greater resilience and flexibility in the electricity grid, the City will coordinate with Alectra, Hydro One, the IESO, and the Province to streamline connections for solar PV, electric vehicles, and energy storage. Strategies can include targeted investments in the grid, streamlined application/permitting, and low-interest financing.

Furthermore, building on its November 2020 resolution calling on the Province to phase-out the use of natural gas in its electricity grid by 2030, the City can partner with other municipalities to highlight the imperative for a zero-emissions Provincial grid.

15 → Encourage Local, Alternative Renewable Energy Ownership Structures

To maximize local economic benefits, the City can support alternative renewable electricity ownership structures, such as co-operatives that maximize community benefits.

16 → Ensure Land Planning Policies Support Solar Array Installations

The City can establish land planning by-laws and policies that support the development of solar arrays in a manner that maximizes the beneficial uses of lands while protecting lands that have other values, for example, on appropriate rural lands or above parking lots, commercial and industrial buildings. These regulatory and policy changes should have the effect of making it easier to establish local solar energy generation. The City, in coordination with Alectra, Hydro One, and the IESO can identify strategic lands for the development of solar energy installations.

17 & 20 → Organic Diversion and AD Systems

In order to reach net zero, as much organic waste as possible should be diverted from the landfill and used as feedstock for anaerobic digester (AD) systems. Ideally, the City needs a centralized system for multiple local organic waste streams to achieve economies of scale.

What excites you about this plan?

"The idea of decentralized energy networks."

"[I]mproving organics recovery is very exciting to both reduce emissions and move towards the circular economy."

» *From responses to an online community survey for ReCharge Hamilton.*

[20] Torchlight Bioresources, Renewable Natural Gas (Biomethane) Feedstock Potential in Canada (2020), online: www.enbridge.com/~/media/Enb/Documents/Media%20Center/RNG-Canadian-Feedstock-Potential-2020%20(1).pdf?la=en.

AD systems produce biogas that can be used onsite or refined into renewable natural gas and used locally (e.g., in buses, dump trucks, district energy systems) or injected into the natural gas system as a source of City revenue. The City should complete a technical review and analysis of increasing organics diversion to anaerobic digesters for energy production.

18 → Technical Analysis of Green Hydrogen

Green hydrogen is key in the pathway to decarbonizing the City's industrial sector, including primary steel production. Green hydrogen also has enormous potential when it comes to other applications such as transportation, energy generation and storage, and building heating.

Building on the Hydrogen Strategy for Canada released in December of 2020, Hamilton needs to explore the creation of a hydrogen hub. This may include a technical analysis of the potential opportunities and challenges for green hydrogen in Hamilton, along with potential costs of green hydrogen and actions to increase green hydrogen deployment throughout the City.

19 → Decarbonize and Expand District Energy

With its partners, the City can work towards decarbonizing and expanding the downtown district energy system, drawing on RNG and industrial residual heat. Over time, this project would represent at least a thirty-two fold increase of building space served by net-zero carbon district energy, as well as many co-benefits including local revenue, jobs and energy cost-savings. This project would represent a powerful way to leverage the planned urban intensification of the downtown.

The Hamilton Chamber of Commerce along with several local partner organizations, recently released its report on the industrial waste heat recovery project in Hamilton. This report began the assessment of the feasibility of industrial waste heat in Hamilton and identified 11 project recommendations for advancing waste heat and smart energy systems in Hamilton. Based on this work, HCE has initiated an Energy Harvesting Project to use industrial residual heat as a low-carbon energy source for district energy. The City of Hamilton should work closely with the Hamilton Chamber of Commerce and HCE & its partners to implement the recommendations of this report.

Please refer to the Large-Scale Renewable Energy Planning Practices Memo for more details on renewable energy technologies, policies, and best practices attached as Appendix F.

Community Momentum

» Hamilton Community Enterprises (HCE) is working with the Hamilton Chamber of Commerce and other partners to harness industrial residual heat – an ample local source of low cost, emissions-free energy to modernize and expand its downtown district energy systems.

» Since 2010, HCE and McMaster Innovation Park have been developing and implementing an innovative low-carbon district energy system at their research and innovation campus.

» McMaster's Mechanical Engineering Department has been undertaking research on Integrated Community Energy and Harvesting (ICE-Harvest) systems, that embed integrated thermal and electrical generation, as well as storage, within communities, so they can be powered, heated and cooled in a way that's cost effective and carbon-reduced.

6.5 Growing Green

Growing 'green' requires the protection and expansion of the City's green infrastructure (natural areas and urban forest) to maintain and increase carbon sequestration. Growing green also requires a focus on land use planning patterns and policies to ensure that future growth patterns support and enable related low carbon actions and behaviours such as promoting transit and active transportation, and achieving low carbon development.

In December 2021, Hamilton City Council adopted a 'no urban boundary expansion' pattern for future growth to 2051. While the final approval of Council's decision has yet to be received from the Provincial government, the City is already on its way to strengthening its land use planning policy framework to support the significant increase in intensification development required to accommodate projected growth. Continuous review and revision of the City's Urban Hamilton Official Plan and Rural Hamilton Official Plan to ensure the city is 'growing green' will need to occur to support the pathway to a net zero City.

6.5.1 TREE PLANTING

The Niagara Escarpment and its associated features that run through the City defines Hamilton; it is a lifeline for local wildlife, water quality, and resident well-being and health. Continuing to protect and expand these green spaces is an important part of achieving net-zero emissions, as trees and healthy soil are an important source of carbon sequestration.

MODELLED TARGET	GHG REDUCTION NET ZERO VS. BAP 2050	MARGINAL ABATEMENT COST $/TC$O_2$E (BRACKETS) REPRESENT SAVINGS
Planting 50,000 trees a year through to 2050	0.75%	($2)

6.5.2 CO-BENEFITS

Land-use patterns can enable people to adopt low-carbon behaviours such as walking or cycling. Many of the factors that facilitate active transportation and reduce GHG emissions also contribute to positive equity outcomes. These changes tend to reduce household transportation costs and utility bills, which can increase affordability.

Increased sequestration from tree planting results in a relatively small reduction in GHG emissions; however, trees offer co-benefits including reduced air pollution, improved well-being, regulated temperature, shade, reduced stormwater runoff, and more.

6.5.3 TAKING ACTION

In order to achieve the modelled GHG emissions reductions, the below short-term (0-5 year) implementation actions related to land use are recommended. For a more detailed breakdown of the growing green implementation pathway, please see Table 9 of the Implementation Strategy in Appendix C.

21 → Review and Update Official Plan(s)

The City has committed to applying a climate change lens to population and employment intensification targets, which will align GHG targets with future land-use policies. The City is already reviewing it's Official Plans to ensure supportive climate change and energy policies, which includes policies that support the acceleration of the development of low carbon buildings and communities, the reusing and retrofitting of existing buildings and the circular economy, enhancing the City's natural environment as a carbon sink, building community resilience, and accelerating the adoption of low-carbon transportation options.

22 → Community Energy/Climate Action Policy Into Secondary Plans

The City can require the integration of community energy/climate action policy directions into secondary plans. New greenfield areas that might be added to the City's boundary in future or redeveloped areas, should require their own community energy system planning process. Relevant considerations, such as design for passive heating and cooling, shadow studies for solar PV, embodied carbon in materials, dwelling size, connectivity of roads, proximity to and mix of destinations, consideration of district or community energy systems, and others, can be addressed at the level of the secondary plan.

23 → Carbon Sequestration and Tree Planting

The City can create an ambitious tree planting program that builds on existing City efforts, including the draft Urban Forest Strategy, as well the efforts of the local Conservation Authorities' and other institutional and not-for-profit organizations. The goal of the program will be to plant a total of 50,000 trees annually throughout the City.

Improved agricultural soil management practices is another opportunity for carbon sequestration that can be examined in future CEEP updates.

Best Climate Practices For Greenfield Development

In order to minimize environmental impacts, it is best to avoid greenfield development where possible and maximize urban intensification. At the same time, intensification can increase well-being and social equity if it is undertaken in a way that maximizes resident access to green space, improves air quality, lowers noise levels, and ensures widespread access to municipal and community services.

Intensification will help improve the City's energy-use profile by reducing reliance on personal-use vehicles and lowering building square footage per person. Improved energy efficiency is critical to enabling the net-zero target, as it reduces overall costs to the energy system. Furthermore, increased intensification can help reduce embodied carbon emissions, as well as the loss of ecosystem services associated with greenfield development.

How do you see yourself contributing to natural carbon sequestration?

"Supporting the planting of native trees."

"Carbon sequestration by rebuilding a deep, rich humus layer on degraded suburban soil."

"Moving away from wood heating to cleaner methods."

"Supporting the establishment of treed pedestrian malls."

"Selecting trees and vegetation that are appropriate for our area and goals and gardening to provide some of our own food to reduce the need to transport."

» *From responses to an online community survey for ReCharge Hamilton.*

What excites you about this plan?

"I really like the idea about greening the urban core with tree planting/rewilding."

» *From responses to an online community survey for ReCharge Hamilton.*

Community Momentum

- » The Just Recovery Hamilton Coalition was created, which is a coalition of Hamilton community member organizations with a focus on policy development to address a more equitable COVID-19 recovery.
- » The Centre for Climate Change Management at Mohawk College is a regional hub for collaboration on climate action. As an applied research arm of the College, the Centre is a model for how colleges can support their region's transition to a low-carbon economy by partnering with municipal, industry, and community partners to catalyze climate change interventions.
- » As a result of the City's Corporate Energy Policy, the City has reduced its GHG emissions at City-owned facilities by 42% (as of 2018) when compared to the base year (2005).

Part 3

7.0 Part III: Towards Implementation

7.1 Monitoring, Oversight, and Adaptive Management

In order for Hamilton to get on track to meet its net-zero carbon emissions target by 2050 and respond to its climate emergency declaration, the City must implement this plan as soon as possible.

Effective implementation will require oversight and coordination. This effort will be led by the City and a properly resourced and skilled non-governmental organization working hand-in-hand with the City. Key components of the coordinating framework would be:

ANNUALLY REPORTING GHGs: the primary data to track progress towards the net-zero target. It should include community-wide and sector-specific energy and emissions reporting on established key performance indicators.

COORDINATING ADAPTIVE MANAGEMENT: regular reviews (for example, every 5 years) of ReCharge Hamilton programs based on predetermined metrics, as well as trends in overall energy use and GHG emissions, updates in policy best practice, and technological innovation.

MAINTAINING TRANSPARENCY: by ensuring that all reporting and reviews are made easily accessible to the public.

COMMUNITY ENGAGEMENT AND OVERSIGHT: via a formal body representing a cross-section of the community.

This plan recommends a three-pronged implementation framework that consists of:

1. City of Hamilton Centralized Climate Office

A centralized entity within the City Corporation should act as a hub for coordinating the implementation of the City-led CEEP actions across the municipal corporation, as well as reporting on corporate and community-wide progress on the implementation of CEEP actions of GHG reductions. The proposed Climate Office would also be the stewards of the proposed Climate Change Impact Adaptation Plan, currently under development , and would be responsible for leading updates to the City's climate change related documents such as the Community Energy and Emissions Plan and the Climate Change Impact Adaptation Plan. The Climate Office will also partner with the Community Climate Advisory Committee to design and undertake community engagement throughout the implementation of the plan.

2. Community Climate Advisory Committee

The Community Climate Advisory Committee is an independent external committee of community stakeholders that operates as an independent body to review the City's corporate and community wide targets, actions, and progress on same. The Community Climate Advisory Committee will also serve as a liaison between the broader community and the proposed City Climate Office and coordinate the implementation of community-led actions, data collection, education and awareness, and reporting.

3. Multi-Departmental Climate Change Working Group

This plan also proposes the creation of a City Multi-departmental Climate Change Working Group, which may be adapted from the existing Corporate Climate Change Task Force, with Staff resources available from each City department. The Multi-departmental Climate Change Working Group will play an important role in monitoring and reporting on targets for City-led actions. These departmental representatives will serve as a liaison to the centralized Climate Office and will be part of a Multi-Departmental Climate Change Working Group to report on actions, progress and monitor implementation and targets associated with their respective departments.

7.2 Municipal Role

Although the Municipal Corporation's GHG emissions account for less than 1% of the total City emissions, it plays a leadership role in the community. From its fleet to its buildings, the municipality can and should be a leader in reaching net zero.

In the short-term, to ensure public tax dollars are not working at cross-purposes to this Plan, the City will implement a climate lens on all budget decisions and investigate the establishment of an annual carbon budget—an emerging best practice—to ensure Council decisions align with GHG targets. The City will also develop a procurement strategy that accounts for embodied carbon emissions.

In addition, the municipality will also support broader community implementation in partnership with the proposed Community Climate Advisory Committee, as outlined in the implementation sections within each key low-carbon transformation, above.

When it comes to its fleet and buildings, the City is already on a net-zero trajectory based on its most recent Green Fleet Strategy. The City has also recently updated its Corporate Energy and Sustainability Policy (formerly Corporate Energy Policy) to ensure its buildings are on the same path. Implementation and compliance with these corporate policies will be important.

Finally, the City can mobilize financial resources using tools, such as the issuance of green bonds, an expanded revolving fund that is administered by the City's Office of Energy Initiatives, and allocating a sustainable source of funding to the City's existing Climate Change Reserve fund in support of this plan.

Setting a Carbon Budget

Point-in-time carbon emissions reduction targets, like this CEEP's target of net-zero emissions by 2050, are only aligned with the Paris Agreement target of limiting global warming to well below 2.0°C and preferably 1.5°C, if they also limit cumulative emissions. Remaining within the threshold for global cumulative emissions, or rather the global carbon budget, is what will significantly reduce the risk of catastrophic climate change.[1]

City-level carbon budgets are an emerging best practice that involve setting annual caps on how much communities can emit leading up to their target year(s).[2] Staying within the world's carbon budget generally requires a steep decline in emissions starting as soon as possible.

In setting its carbon budget, the City needs to determine its fair share of the global carbon budget. This question requires the City to consider its current per capita wealth and emissions as compared to those of other local and global jurisdictions. For example, C40 recommends that cities set their interim targets based on an average per capita emissions target.[3] Per this method, Hamilton would have to limit emissions to 3.2 tCO_2e per capita by 2030, assuming a goal of keeping global warming below 2°C; to remain below 1.5°C, the budget would be even lower.

[1] Ibid.

[2] IPCC, 2018: Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. World Meteorological Organization, Geneva, Switzerland, 32 pp.

[3] C40, Deadline 2020, How Cities Will get the Job Done (n.d.) at 102, online at: resourcecentre.c40.org/resources/deadline-2020#:~:text=Deadline%202020%20identifies%20C40%20cities,tCO2e%20per%20capita%20by%202030.

7.3 Community Role

7.3.1 ENGAGING THE COMMUNITY

Going forward, there will be many ways for individuals and businesses to participate in Hamilton's path to net zero, from participating in policy and program development, to partnering in program implementation, to participating in community programs. This is why developing and delivering a public education and engagement campaign is one of the main features of the CEEP's near-term Implementation Strategy (Appendix C). As specific community based programs are developed and implemented, opportunities for further public involvement will be highlighted. This may include home energy retrofit opportunities, tree planting initiatives and participating in renewable energy project cooperatives, among many others.

How do you see yourself contributing to GHG reductions?

"I would like to join a committee or board to support this plan."

"Calling for collaboration on low-carbon steel production."

"Calling for closing compact business districts to vehicle traffic."

» *From responses to an online community survey for ReCharge Hamilton.*

What excites you about this plan?

"It is a bold vision for reductions, and has concrete ideas to achieve them."

"That it exists!"

"I think climate change is the most important issue we face and it's very good to see the City taking action on it."

"It will have very tangible effects on life in the city, not just reducing emissions but also making the city healthier, safer, and more human-friendly."

"It seems to be very comprehensive and full of great ideas that hopefully will be implemented."

"The opportunity to tackle our problems together for a better future, and for me to have a channel to provide input."

» *From responses to an online community survey for ReCharge Hamilton.*

8.0 Acronyms

AD	Anaerobic digester
BAP	Business-as-planned scenario
CEEP	Community Energy and Emissions Plan
GHG	Greenhouse Gas
EV	Electric vehicle
IPCC	Intergovernmental Panel on Climate Change
PUV	Personal-use vehicle
PV	Solar photovoltaic
RE	Renewable energy
RNG	Renewable natural gas
UNFCCC	United Nations Framework Convention on Climate Change
VKT	Vehicle kilometres travelled

9.0 Glossary

Base year: The starting year for energy or emissions projections.

Biogas: Methane captured from bacterial decomposition of sewage, manure, waste, plant crops, or other organic waste products. If refined, it can be used as a natural gas replacement.

Business-as-planned (BAP): A scenario illustrating expected energy use and greenhouse gas emissions if no additional plans, policies, programs, and projects are implemented between the present and 2050.

Carbon dioxide equivalent (CO_2e): A measure for describing the global warming potential of a greenhouse gas using the equivalent amount or concentration of carbon dioxide (CO_2) as a reference. CO_2e is commonly expressed as million metric tonnes of carbon dioxide equivalent ($MtCO_2e$).

Co-benefits: Benefits that are additional to the primary objective of the CEEP (i.e., to energy efficiency and emissions reductions).

Deep energy retrofit: A whole-building analysis and construction process minimizing building energy use by 50% or more compared to base year energy use.

District energy system: A centralized system that heats and/or cools multiple buildings.

Emissions: In this report, the term "emissions" refers exclusively to greenhouse gas emissions, measured in metric tonnes (CO_2e), unless otherwise indicated.

Emissions intensity: The ratio of emissions released per unit of electricity generated, measured in gCO_2e/kWh.

Energy efficiency improvement: An improvement in the ratio of energy consumed to the output produced or service performed. This improvement results in the delivery of more services for the same energy inputs or the same level of services from less energy input.

Electric vehicles (EVs): An umbrella term describing a variety of vehicle types that use electricity as their primary fuel source for propulsion or as a means to improve the efficiency of a conventional internal combustion engine.

Green bonds: Bonds whose proceeds are issued to climate-related projects, such as public transit expansions or low carbon infrastructure

Green revolving funds: Pools of money used to finance emissions reductions projects, whereby resulting savings are paid back and re-loaned for other emissions reductions projects

Greenhouse gases (GHG): Gases that trap heat in the atmosphere by absorbing and emitting solar radiation, causing a greenhouse effect that unnaturally warms the atmosphere. The main GHGs are water vapour, carbon dioxide, methane, nitrous oxide, and ozone.

Heat pump: A device that transfers heat energy from a source of heat to a target area using mechanical energy.

Low-carbon action: An action or policy to reduce emissions.

Marginal abatement cost (MAC): The cost of an action or policy compared to its potential GHG reduction, measured in tonnes CO_2e per dollar spent/saved. A negative MAC indicates an action results in a positive net return (i.e., savings or revenue).

Renewable energy: Energy that comes from resources that are naturally replenished on a human timescale, such as sunlight, wind, moving water, and geothermal heat.

Solar photovoltaic (PV): Also known as solar electric systems or solar panels, these are systems that convert sunlight into electricity. Any excess electricity produced that a building does not use can be sold to the utility through a process called net-metering.

Vehicle kilometres travelled (VKT): Distance travelled by vehicles within a defined region over a specified time period.

GHG emissions

1 ktCO_2e =	1,000 tCO_2e
1 tCO_2e =	1,000 kgCO_2e
1 kgCO_2e =	1,000 gCO_2e

Energy

1 MWh =	1,000 kWh
1 MWh =	3.6 GJ
1 GJ =	278 kWh
1 GJ =	1,000,000 J
1 MJ =	0.001 GJ
1 TJ =	1,000 GJ
1 PJ =	1,000,000 GJ

ReCharge Hamilton

A Propsperous, Equitable, Post-Carbon City

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SSG

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Disclaimer

Greenhouse gas emissions modelling for the Baseline, Business-as-planned and Low-carbon Scenarios was completed between the fall of 2020 and the summer of 2021 and does not reflect low-carbon initiatives within the community that have been announced since the modelling was completed.

APPENDIX A: Table of Business-as-Planned and Low-Carbon Actions

June 2021

Purpose

This document provides a table of low-carbon actions designed to address all sources of greenhouse gas emissions identified in the base year and business-as-planned (BAP) report prepared by the Consultant. The table also provides a summary of some of the key criteria that informed each action.

These low-carbon actions form the basis of the energy and emissions modelling undertaken for Hamilton's Community Energy and Emissions Plan (CEEP) to achieve net-zero carbon emissions by 2050.

The process for designing low-carbon actions

The primary criteria for designing the following table of low-carbon actions is that they enable Hamilton to achieve its target of net-zero carbon emissions by 2050 and reflect an adequate response to the City's climate emergency declaration. These actions are based on the consultants' research of best practices and experience modelling net-zero energy and emissions pathways for dozens of other communities, and less ambitious pathways for dozens more. These actions were further refined by the Stakeholder Advisory Committee's (SAC) feedback and community input.

SAC feedback was gathered during a June 2020 BAP webinar and workshop as well as through dozens of individual stakeholder meetings undertaken from June through to October 2020.

Community input was received via two online surveys, one discussing what actions residents thought should be prioritized (124 unique respondents as of October 20, 2020) and the other highlighting the criteria they felt should be prioritized in designing the net-zero pathway (67 unique respondents as of October 20, 2020).

Please note:

- Wherever the term 'efficiency' is used, it is always occurring pre-electrification.
- The energy and emissions base year is 2016 for all actions, unless noted otherwise.
- BAP actions were developed throughout 2020, and the low-carbon actions were developed throughout 2020-2021, and therefore do not include policy or other developments that took place subsequently.

ACTION	BAP	LOW-CARBON	NOTES ON LOW-CARBON ACTION
LAND-USE			
1. Spatial distribution	• Population and employment per zone, as per City projections through to 2041. • 2041-2050: population and employment trends per zone are projected linearly (based on 2031-2041 data from City).	• Population and employment distribution by zone to be consistent with the most recent projections provided by the City through to 2041. • Projections from 2031-2041 are draft not yet Council approved. • Trends provided by the City for 2031-2041 are linearly extrapolated through to 2051.	Stakeholder input: Based on data and feedback from the City planning department

ACTION	BAP	LOW-CARBON	NOTES ON LOW-CARBON ACTION
BUILDINGS			
New buildings - buildings codes & standards			
2. Building use energy intensity	• Starting in 2017: 15% energy improvement from the 2016 base year for residential, and 13% for MURBs, C&I. • As of 2019: new construction is 10% more efficient every 5 years.	• Only 20% of new dwellings to be single-detached by 2050 (a steady decline from rates in 2016). • Average floor space stays constant from the base year.	**Note:** 50% of dwellings were single-detached in 2016, compared to 71% in 1951. Historical analysis indicates that average floorspace per Hamilton dwelling has increased slightly from 1990 to 2016. **Research:** According to US research, average home sizes have almost doubled since 1950, and family sizes have decreased (see 2012 *Oregon Department of Environmental Quality's presentation on the environmental benefits of smaller housing and related policies to achieve smaller housing*; See also *best practice advice on Encouraging Development of Smaller Homes from USDN*, municipal experts from across the US & Canada)
3. New residential housing targets	• Starting in 2017: 15% energy improvement from the 2016 base year for residential, and 13% for MURBs, C&I. • As of 2019: new construction is 10% more efficient every 5 years.	• In 2026, new buildings are 30% more efficient, with similar efficiency improvements in 2031, resulting in new buildings being a total of 60% more efficient. • As of 2031, all new homes have 30% annual load coverage by solar PV (not including additional electricity demand due to fuel switching in space and water heating).	**Energy efficiency standards:** Applying Toronto Green Standard-equivalent (i.e. Passive House/ Net Zero) energy efficiency improvements -- though starting 5 years later. This is despite the fact that the City of Hamilton does not have the legislative authority to supersede the Ontario Building Code with building requirements. As such, innovation in policy design and/or lobbying higher levels of government would be required to achieve this. • Stakeholder feedback: this level of ambition was just right • Survey response: 74% felt this should be a priority action **Solar PV:** Internal analysis, as well as Google Environmental Insights Explorer, indicates that about 15% of current Hamilton building load could be provided by rooftop solar PV; the 30% in this action reflects the reduced electricity demand of more efficient new buildings (this share does not include additional electricity demand due to fuel switching in space and water heating).

ACTION	BAP	LOW-CARBON	NOTES ON LOW-CARBON ACTION
4. Commercial - New commercial development targets	• Starting in 2017: 15% energy improvement from the 2016 base year for residential, and 13% for MURBs, C&I. • As of 2019: new construction is 10% more efficient every 5 years.	• In 2026, new buildings are 30% more efficient, with similar efficiency improvements in 2031, resulting in new buildings being a total of 60% more efficient. • including roof-top PV	**Best Practice:** Applying Toronto Green Standard-equivalent (i.e. Passive House/ Net Zero) energy efficiency improvements--though starting 5 years later. This is despite the fact that the City of Hamilton does not have the legislative authority to supersede the Ontario Building Code with building requirements. As such, innovation in policy design and/or lobbying higher levels of government would be required to achieve this. **Stakeholder feedback:** this level of ambition is just right. **Solar PV:** see Action 3
Existing buildings - retrofitting			
5. Retrofit homes built prior to 1980	• Starting in 2020, retrofit existing building stock exponentially until in 2050 a total of 6% achieve 10% electricity and 10% heating savings	• Starting in 2022, by 2050, on average, all existing dwellings built before 1980 achieve thermal savings of 50%; electrical savings of 50% (not including electrification of space and water heating) • Applied exponentially to homes. • 90% of all pre-1980 dwellings switch to heat pumps	**Research:** Windsor, Ontario had a business case presented to Council in February 2020 for a City-sponsored retrofit program to cover 80% of Windsor's 60,000 homes by 2041. **Stakeholder feedback:** Retrofit 90% of homes, built before 1980, by 2050 is just the right level of ambition, but will be tough. **Survey:** 70% of respondents felt retrofitting existing homes should be a priority action **Note:** The intensity of this action was increased from initial stakeholder consultation due to the limitations on green hydrogen and RNG supply available to replace remaining natural gas demand in the City. In the model, we have defaulted to ASHPs over ground source heat pumps (GSHPs) (due to lower capital costs and ease of installation, however, GSHPs are more efficient). In implementation efforts, the selection of ASHPs vs GSHPs should be assessed on a case-by-case basis, and future model revisions should be reconsidered as technology and experience evolve.

ACTION	BAP	LOW-CARBON	NOTES ON LOW-CARBON ACTION
5a. Retrofit homes post 1980	• Starting in 2020, retrofit existing building stock exponentially until in 2050 a total of 6% achieve 10% electricity and 10% heating savings	• Starting in 2035, retrofit 100% of all dwellings built between 1980 and 2016, exponentially, by 2050 (following pre-1980 dwellings) • Achieve on average thermal savings of 50%; electrical savings of 50% (not including electrification of space and water heating) • 100% for all post-1980 dwellings switch to heat pumps	See notes for Action 5 above.
6. Retrofits of commercial	• Starting in 2020, retrofit existing building stock exponentially until in 2050 a total of 6% achieve 10% electricity and 10% heating savings	• Starting in 2022, increase efficiency for 100% of commercial buildings by 50% by 2050 (linearly)	**Stakeholder feedback** (Re: Retrofit 90% of institutional, commercial, and industrial (ICI) buildings, greater than 50,000 ft2 by 2050): is just the right level of ambition. **Surveys:** almost 70% of survey respondents felt that retrofitting commercial buildings should be a priority action for the community. **Note:** The intensity of this action was increased from initial stakeholder consultation due to the limitations on green hydrogen and RNG supply available to replace remaining natural gas demand in the City.

ACTION	BAP	LOW-CARBON	NOTES ON LOW-CARBON ACTION
7. Industry - (processes, motive, lighting, space cooling, plug load) other than coal use in primary steel	• Assume energy use intensity and emissions profile stays constant from 2016-2050.	• Starting in 2022, increase efficiency by 50% by 2050 (linear)	**Surveys:** Industry is a major source of community GHG emissions and air quality issues, which are a top community criteria for action design. **Research:** According to the *2019 Achievable Potential Study* (for natural gas and electricity conservation) undertaken by the IESO and Ontario Energy Board, the difference between the reference case and technically achievable efficiency potential for the industrial sector is nearly 30 GWh to just over 100 GWh (over 230% increase in efficiency). **Stakeholder feedback:** May be challenging
7b. Industry - Primary steel	• Assume energy use intensity and emissions profile stays constant.	• 50% reduction in emissions by 2035, net zero emissions by 2050 • Steel industry commitment to using newly developing technologies of biochar, carbon capture and/or alternative renewable energy sources to reduce and replace coal	**Research:** Based on *July 2020 Hamilton AMD community environmental liaison ppt*; *Arcelor Europe's May 2020 climate action plan (p.4)*; *Sept. 30, 2020 Globe and Mail article* confirms the company's net-zero by 2050 target and the technological pathway and timeline selected. **Stakeholder:** emphasized the importance of mitigating primary steel industry emissions. Meetings with the Canadian Steel Producers Association and NRCan also helped inform this action.

ACTION	BAP	LOW-CARBON	NOTES ON LOW-CARBON ACTION
ENERGY GENERATION			
Renewable energy generation (on-site, building scale)			
8. Solar PV - rooftop	• 0 MW	• Starting in 2022, install solar PV on pre-2016 buildings, achieving on average 30% of building electric load (not including any potential increased electricity load from fuel switching to electric space and water heating) • Solar PV scales up to 50% of these buildings by 2050.	**Research:** According to our internal analysis, solar PV has the potential to supply just over 15% of existing building electricity load. Google Environmental Insight Explorer indicates 14%. In both cases, this is before undertaking our building retrofit action outlined above, which calls for reducing electrical load by 50%.
Low- or zero-carbon energy generation (community scale)			
9. Solar PV - ground mount	• 0 MW	• Install a total of 280 MW, 10 MW/yr from 2022 to 2050, inside or outside city boundary (prioritizing inside)	**Stakeholder feedback (re: 5MW/ yr 2022-2050):** behind-the-meter/net meter has less red tape than grid supply/ export permitting, but technology is there. **Note:** The community will need to use 100% clean electricity in order to achieve net zero. **Research:** 4 ha / 1 MW = 1,120 ha (11.2 km^2) (Kirby Calvert, Mapping opportunities for land-based renewable energy generation in Ontario, 2019)
10. Expand downtown district energy system- decarbonize	• 15 MW of natural gas hot water and reciprocating natural gas engine for heating capacity • -3.1 MW of absorption and electric chillers for cooling capacity • Serves ~ 232,000 m^2 of residential and ICI space	Downtown DE system: • Additional 25.4 MW of industrial waste heat for heating • Additional of 7.1 MW of industrial waste heat for cooling • Corresponding expansion of the downtown DE network to service an additional 232,000 m^2 of commercial floor space	**Stakeholder feedback (re: by 2050 all district energy systems are fuelled by renewable energy sources):** could be more impactful if there were an expansion plan **Stakeholder meetings:** with HCE Inc. and Chamber of Commerce Research: Based on data provided by HCE Inc. and Chamber of Commerce, as well as internal analysis.

ACTION	BAP	LOW-CARBON	NOTES ON LOW-CARBON ACTION
11. Wind	• 0 MW	• Install 250 MW by 2050 inside or outside the city, starting in 2022 (50 MW installed every 4 years, starting in 2030)	**Stakeholder Feedback (re: 300 MW of wind by 2050):** level of ambition is too low, but there is a real issue with NIMBYism and cost of land in the GTHA is high **Note:** The community will need to use 100% clean electricity in order to achieve net zero. **Research:** 1ha/ 3MW = 83 ha (Kirby Calvert, Mapping opportunities for land-based renewable energy generation in Ontario, 2019).
12. Renewable Natural Gas	• 50,000 GJ	• Replace remaining NG in the system post-retrofits and heat pumps with available supply of RNG (maximizing local RNG feedstock) (see Action 23)	**Research:** The Ontario Energy Board and Enbridge are actively exploring increased RNG integration; A *2019 Ontario Biogas and RNG Market Potential study* conservatively projects the potential for 5x growth in RNG energy production in the province by 2029, the most important source of supply being organic waste diverted from landfill; communities in Ontario are increasingly diverting their organic waste to anaerobic digestion facilities (e.g. Toronto and Peel, and Stratford is finalizing its AD plans). **City input:** Income generating opportunity is of interest.
13. Hydrogen	• 0 MW	• In order to replace remaining natural gas in the city (post action 12), starting in 2030, hydrogen (produced via renewable energy) is pumped into the natural gas distribution system	**Research:** A major UK project (*"H21"*) is working on transitioning Northern UK's natural gas system to 100% hydrogen; Enbridge is running a *pilot project in Markham*, Ontario involving hydrogen storage **Note:** 2030 start date for this action is in order to allow time for the technology to evolve. All green hydrogen is produced from local renewable energy in excess of what is needed to replace electricity grid demand.

ACTION	BAP	LOW-CARBON	NOTES ON LOW-CARBON ACTION
TRANSPORTATION			
Transit			
14. Increase transit mode share	• Incremental increase in bus service from 2016 transit service to keep up with population growth through to 2050. Mode share assumed to stay constant to 2016-2050.	• Increase transit mode share from 7% in 2019 linearly to 12% by 2031, then linearly increase to 15% by 2050 (reflects installing BRT or LRT for the urban area).	**City input:** The City's Transportation Master Plan sets a transit mode share target of 12% for 2031 based on the adoption of a BRT or LRT system along the major East-West transit corridor (from McMaster to EastGate), though transit expansion will only occur in urban areas, that is also where the majority of population growth will be. A small increase in modeshare through to 2050 is possible. **Stakeholder feedback:** improving modeshare in rural areas will be challenging **Note:** The impacts of Covid-19 during the modelling process cannot be understated. Transit ridership saw a steep decline, and as a result, stakeholders felt plans for future expansion were more difficult to justify.
15. Electrify transit system	• Fleet turnover reflects increasing transition to CNG and electric. 50% electric and 50% CNG by 2050 (diesel stock completely phased out by 2050)	• Existing CNG fleet transitioned to RNG by 2025 • All other buses to be electric by 2035	**Notes:** Because an average bus life span is about 12 years, if starting in 2022 all new buses that are purchased can be emissions free. Emission free buses have major public health benefits, and cities globally are showing that this transition is possible. **Research:** Many places in Canada are targeting 100% electrification of their transit fleets (Montreal: by 2040; Toronto: by 2040; BC: by 2040), internationally we are seeing even more ambitious targets (Oslo: by 2020; Amsterdam: by 2025; Antelope Valley, Cal: by 2025; Los Angeles: by 2030) **Stakeholder feedback:** Even by 2050, this action is too ambitious, the City is currently on track to transition fleet to CNG, infrastructure would need to be put in place now **City input:** 100% electrification by 2050 is reasonable per City Transit Department. Bus fleet expansion numbers provided by the City for 2014-2024.

ACTION	BAP	LOW-CARBON	NOTES ON LOW-CARBON ACTION
Active Transportation and Car Sharing			
16. Home Based Work/ Transportation marketing & individual planning	• Held constant	• Private vehicle trips decline by 9% per person and vehicular trip lengths declined 6%. • All areas of Hamilton are affected. Implement smart commute / home-based work	**Research:** A 2010 UK study of 3 towns over a 5-year period, found that travel planning, increasing active transportation, and transportation marketing reduced individual car trips by 9%, and trip length by 6% (Sloman L, *et.al*. The Effects of Smarter Choice Programmes in the Sustainable Travel Towns: Summary Report, UK Department of Transport, 2010). COVID-19 has also led to the acceleration of home based work. Many large employers are now switching to hybrid or full-time remote work for employees.
17. Increase/ improve cycling & walking infrastructure	• Active transportation mode share is held constant to 2050.	• By 2050, mode shift 50% of up to 2km trips to walking and up to 5km to cycling in the urban and whitebelt zones	**Research:** *City of Vancouver cycling trips increased by 32% between 2014 and 2015 following investments in cycling infrastructure* (May 2016, presentation to Vancouver City Council). This shows the potential for the scale of short-term changes possible when the right infrastructure is put in place.
18. E-bikes & EV car-share	• Active transportation mode share is held constant to 2050.	• By 2050, 10% of trips up to 10km are complete by E-Bike or EV Car-Share in the urban zones	**Research:** (Re: e-bikes) A 2015 Norwegian study indicates more is feasible (Fyhri, et al. Effects of e-bikes on bicycle use and mode share, **Transportation Research Part D:** Transport and Environment, 36: 2015) where participants have access, 28% of all trips up to 10.5 KM are taken by E-Bike, 18% reduction in transit and 10% in vehicle use (low estimate from the study).
Private/personal use			
19. Zero-emissions municipal fleet	• 25% of new vehicle sales are electric by 2030.	• 100% of new small and light-duty vehicles are electric by 2040 • 100% of new heavy-duty vehicles switch to clean hydrogen (or similar emissions-free technology) in 2040	**Research:** this is 10 years more ambitious than the City's current plan (per March 13, 2020, Information Update to Council); *Seattle has a target of a 100% electric fleet by 2030*. **Stakeholder feedback:** electrifying the municipal fleet by 2030 was too ambitious/ just right; suggest acting immediately on light duty and support/ monitor heavy-duty (or pilot) for options in coming years.

ACTION	BAP	LOW-CARBON	NOTES ON LOW-CARBON ACTION
20. Electrify personal vehicles	• Starting in 2020, 14% new sales by 2030; share holds constant to 2050	• Zero-emission vehicles targets of 10% of light-duty vehicles sales per year by 2025, 30% by 2030 and 100% by 2040	**Stakeholder feedback (re: 90% of sales are EV by 2040):** "Need to be more specific on the technology to identify feasibility; High impact and tough; battery range and infrastructure need to be improved; need for advocacy to higher level of government to provide clear direction (e.g. Sweden and Norway identifying no imports and/or manufacturing of combustible vehicles)" **Research:** The federal government set a target of 100% new passenger vehicles sales being electric by 2040 (per. IEA, Global EV Outlook 2019, p. 67.) **Note:** average lifespan of an EV is about 13 years (per CanESS model).

ACTION	BAP	LOW-CARBON	NOTES ON LOW-CARBON ACTION
21. Low-Carbon Commercial Transport Activities	• 25% of new commercial vehicle sales are electric by 2050.	By 2050, • all heavy-duty vehicles are green-hydrogen based • Light-duty commercial vehicles are 100% electric	**Stakeholder feedback (re: 50% of commercial vehicles are EV by 2050):** In between just right & too low; Vehicles will likely electrify more quickly/ or introduce hydrogen; The challenge could be the distribution system; the Hamilton Port Authority has a net zero by 2050 target; the International Maritime Organization has a 50% GHG reduction by 2050, by exploring fuels such as bio LNG. **Research:** Global EV Outlook 2019 pg 67.; Hydrogen is seen as being the most viable fuel source for heavy haul trucks (see: *CBC How Ottawa hopes to supercharge Canada's hydrogen fuel sector, Sep.9, 2020*); for a review of the state of the international, Canadian, and Ontario fuel cell markets, see this *Electric Autonomy May 28, 2020 article; BNEF (2020) Hydrogen Economy Outlook* predicts that green hydrogen could meet 24% of energy world demand by 2050; EC, *A hydrogen strategy for a climate-neutral Europe* (8 July 2020) "this Communication sets out a vision of how the EU can turn clean hydrogen into a viable solution to decarbonise different sectors over time, installing at least 6 GW of renewable hydrogen electrolysers in the EU by 2024 and 40 GW of renewable hydrogen electrolysers by 2030." (This would focus first on industrial processes, then heavy duty transport.) 1)
22. Marine	• Held constant	• Reduce GHGs by 50% by 2050	The International Maritime Organization has set a goal of 50% GHG reductions by 2050.

ACTION	BAP	LOW-CARBON	NOTES ON LOW-CARBON ACTION
WATER AND WASTE			
23. Water and Waste	• Held constant, growing proportionate to population	• (1) By 2050, 95% organic waste sent to anaerobic digestion - Reroute from compost to AD • (1a) Maintain existing waste diversion target (55% by 2021), then increase to 70% in 2025, 85% by 2030, 95% by 2040 • (2) By 2050, 25% reduction in water / wastewater consumption (behaviour change, leak detection system, greywater reuse) (modelled as the following step changes: 15% improvement in 2030, another 10% improvement in 2035)	**Stakeholder feedback (re: 95% organic waste diversion):** The level of ambition is too low; scale it up by including human/sewage as well as organic waste; (re: 25% reduction of water consumption) the level of ambition is just right **Research:** Ontario is considering a ban on organic waste from landfills as well as associated resource recovery (see: *Food and Organic Waste Framework*); An expanded wastewater anaerobic digestion facility (to accept food waste, is being considered in Stratford Ont.); see generally ECO's Every Drop Counts 2016/2017 (chap. 5: water conservation; chap. 8: energy from sewage); see also *A Handbook for Co-digestion Projects at Municipal Wastewater Treatment Facilities* (revised March 2020) **Note:** 95% (vs. 100%) is based on assumed contamination rates
24. Wastewater Process Efficiency	• Held constant	• Increase efficiency by 30% by 2050 (modelled as the following step changes: 10% in 2025, 10% in 2035, 10% in 2045)	**Research:** see generally chap 2 of ECO's *Every Drop Counts* 2016/2017 for a description of the significant process efficiency opportunities that exist in most wastewater processes.
25. Decarbonize pelletizer	• In 2030 introduce natural gas powered pelletizer	• In 2030, switch fuel source to RNG	**Research:** City has advised of this new contract for a natural gas pelletizer, in order to avoid sunk costs, recommend switching fuel source to locally produced RNG

ACTION	BAP	LOW-CARBON	NOTES ON LOW-CARBON ACTION
Municipal Buildings			
25. Municipal buildings	• Starting in 2020, reduce energy intensity in all corporate facilities by 60% by 2050, with an interim goal of 45% by 2030 (against a 2005 base year, retrofits assumed to be implemented linearly)	• In addition to the EUI improvements modeled for the residential and commercial buildings, 50% of municipal building square footage achieves (on average) net-zero emissions by 2030 -- of this, solar PV is added to 50% of rooftop area, covering 30% the related building area's electrical load • Applied linearly, starting in 2024, though to 2030 • From 2030, linearly to 2050, this action is applied to the remaining 50% of municipal building square footage	**Stakeholder feedback:** The level of ambition of this action is just right. City input: Reflects current City plans to assess and install solar PV on municipal building rooftops. **Note:** Corporate Energy measures its energy and emissions against a 2005 base year (see Appendix to the Nov. 2020 BAP report for the conversion process).
Sequestration and Land Accounting			
26. Tree Planting	• Held constant	• Add 50,000 trees in Hamilton by year, by 2050 (total 30 years x 50, 1.5 million)	**Research:** Wellington, NZ Has been planting a tree every five minutes, on average, for the past 15 years–more than 1.5m in total. Wellington is New Zealand's greenest city, and one of the few cities in the world where biodiversity is increasing. About 40% of the city's emissions are now mitigated by so-called land use, land use change and forestry (LULUCF) activities. **Context:** the City of Hamilton planted 10,000 trees per year between 2013 and 2018.

ACTION	BAP	LOW-CARBON	NOTES ON LOW-CARBON ACTION
Renewable Energy Procurement			
27. Purchases of Renewable Energy Certificates	• None	• In 2050, for each MWh of central electricity demand remaining after local renewable energy production, purchase a Renewable Energy Certificate (REC).	**Note:** Each REC represents the environmental benefits of 1MWh of renewable energy generation. When you purchase RECs, renewable energy is generated on your behalf. When you purchase RECs it is guaranteed that renewable energy has been generated on your behalf and sent to the electrical grid, which is the network that delivers electricity from suppliers to consumers. However, once it enters the grid, it is impossible to distinguish where or how that electricity is being delivered. (per *RenewableEnergyWorld.com (8.24.15)*, and *US EPA*)
28. Purchases of Renewable Natural Gas	• None	• First, switch to local RNG (from wastewater and organic waste, see Action 22), undertake analysis of other sustainable local sources, then purchase remaining → starting in 2025, ramp up exponentially to 2050 in order to replace all natural gas demand	**Stakeholder meeting:** Enbridge explained that it is currently enabling transactions between its clients where one buys RNG that is produced and consumed outside of its borders, but is able to account for the reductions in their emissions.

APPENDIX B: Economic and Financial Analysis

July 2021

Purpose of this Document

This document provides a summary of the projected costs, revenues, and savings represented by the net-zero pathway modelled for Hamilton's Community Energy and Emissions Plan. The pathway's financial impacts are assessed as a whole and on an action-by-action basis.

A detailed analysis of the net-zero scenario modelled as the basis of the CEEP is provided in Appendix E.

Contents

Disclaimer

Reasonable skill, care and diligence have been exercised to assess the information acquired during the preparation of this analysis, but no guarantees or warranties are made regarding the accuracy or completeness of this information. This document, the information it contains, the information and basis on which it relies, and the associated factors are subject to changes that are beyond the control of the author. The information provided by others is believed to be accurate but has not been verified.

This analysis includes strategic-level estimates of capital investments and related revenues, energy savings, and avoided costs of carbon represented by the proposed Community Energy and Emissions Plan (CEEP). The intent of this analysis is to help inform project stakeholders about the potential costs and savings represented by the CEEP in relation to the modelled business-as-planned scenario. It should not be relied upon for other purposes without verification. The authors do not accept responsibility for the use of this analysis for any purpose other than that stated above and do not accept responsibility to any third party for the use, in whole or in part, of the contents of this document.

This analysis applies to the City of Hamilton and cannot be applied to other jurisdictions without further analysis. Any use by the City of Hamilton, its sub-consultants or any third party, or any reliance on or decisions based on this document, is the responsibility of the user or third party.

Acronyms

AD	anaerobic digester
BAP	business-as-planned
CEEP	community energy and emissions plan
EUI	energy use intensity
GHG	greenhouse gas
NPV	net present value
MAC	marginal abatement cost
MACC	marginal abatement cost curve
PUV	personal use vehicles
PV	photovoltaic
RNG	renewable natural gas

Overview

The following table highlights the key findings from the financial analysis of the net-zero scenario modelled for Hamilton's Community Energy and Emissions Plan (CEEP). When reviewing the results, it is useful to put them in context of the City's current annual:

- GDP ($34.7 billion);[1]
- expenditures on fuel and electricity ($2.1-2.4 billion, $1.7 billion if the heavy industry is excluded);[2] and
- investment in buildings alone in Hamilton ($3.6 billion).[3]

Details about what is captured in each financial estimate are provided in the report's body, as indicated in the right-hand column.

The following modelled actions were not included in this financial analysis due to limited financial data:

- Primary industry (i.e. steel sector transition),
- Marine sector greenhouse gas reductions,
- Active transportation, and
- Water efficiency.

Table 1. Summary of high-level financial analysis of Hamilton's CEEP.

FINANCIAL ESTIMATE	KEY RESULTS (PRESENTED IN TODAY'S DOLLARS, ASSUMING A 3% DISCOUNT RATE, A.K.A. 'NET PRESENT VALUE')	WHERE TO FIND FURTHER DETAILS
Net benefit of the CEEP investments, 2021-2089	≈ $63 million (≈ $7 million without avoided carbon costs)	Part 2, Table 3
Total incremental capital investment, 2021-2050	≈ $11.4 billion ≈ $370 million/year	Part 2, NPV and MAC Values
Total savings, 2021-2089 (incl. avoided maintenance, carbon, and energy costs,)	≈ $10.6 billion (≈ $3.7 billion without avoided carbon costs)	Part 2, Cash Flow Analysis
Total revenue, 2021-2089	≈ $840 million	Part 2, Cash Flow Analysis
Average cost to reduce each tonne of GHG	≈ $1 in savings	Part 2, Table 3

[1] Statistics Canada, Table 36-10-0468-01, Gross domestic product (GDP) at basic prices, by census metropolitan area (CMA) (x 1,000,000), online: www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3610046801.

[2] Consultant calculation, multiplying base year numbers for energy by NRCan's posted energy prices by fuel and sector.

[3] Statistics Canada, Table 34-10-0175-01, Investment in Building Construction, 2019 data, including new buildings and renovations for residential and commercial buildings, online: www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=3410017501.

FINANCIAL ESTIMATE	KEY RESULTS (PRESENTED IN TODAY'S DOLLARS, ASSUMING A 3% DISCOUNT RATE, A.K.A. 'NET PRESENT VALUE')	WHERE TO FIND FURTHER DETAILS
Most cost-effective GHG-reduction action ($/ tonne CO_2e)	1. Transit Expansion: ≈ $4,000 in savings 2. Electrify municipal fleet: ≈ $1,500 in savings 3. Ground mount solar and new residential roof solar PV: ≈$1,300 in savings 4. Personal use vehicle electrification: ≈ $600 in savings 5. Commercial fleet electrification: ≈$500 in savings	Part 2, Table 3
Household savings on energy	$2,900 avg/year in 2050	Part 2, Cost Savings for Households

Part 1. Key Financial Analysis Concepts

The direct financial impacts of Hamilton's Community Energy and Emissions Plan (CEEP) provide important context for local decision-makers. However, it is important to note that the direct financial impacts are a secondary motivation for undertaking actions that reduce greenhouse gas (GHG) emissions. First and foremost, GHG reductions are a critical response to the global climate emergency. In addition, most measures included in the CEEP also provide social goods to the community, such as net job creation and positive health outcomes, which are only marginally captured in this financial analysis via the cost of carbon. Similarly, the cost of inaction is not captured. Quantifying the financial costs of each tonne of GHG emissions produced is extremely complicated, they include the impacts of tailpipe emissions in individual health and economic productivity, as well as the infrastructure costs associated with extreme weather events, to name just two.

The following are key concepts that are used to analyze the financial impacts of the CEEP.

COSTS ARE RELATIVE TO THE BUSINESS AS PLANNED SCENARIO (BAP)

This financial analysis tracks projected costs and savings associated with net-zero measures that are above and beyond the assumed 'business-as-planned' costs.

DISCOUNT RATE

The discount rate is the investor's baseline growth value on their investment dollar. A project is considered financially beneficial by an investor if it generates a real rate of return equal to or greater than their discount rate.

An investor's discount rate varies with the type of project, duration of the investment, risk and the scarcity of capital. The social discount rate is the discount rate applied for comparing the value to society of investments made for the common good and as such it is inherently uncertain and difficult to determine. Some argue that in the evaluation of climate change mitigation investments a very low or even zero discount rate should be applied. In this analysis, investments are valued based on a 3% future discount rate. This is the social discount rate used by the Federal Treasury Board. Governments typically use more conservative discount rates than the private sector, especially when the value of a public good is being assessed.

NET PRESENT VALUE (NPV)

The NPV of an investment is the difference between the present value of the capital investment and the present value of the future stream of savings and revenue generated by the capital investment. This means that if an investment is made in 2049, the benefits associated with that investment's expected life would be included in the NPV of the measure and the overall plan.

Five aggregate categories are used to track the financial performance of the net-zero actions in this analysis: capital expenditures, energy savings (or additional costs), carbon cost savings (assuming the carbon price reaches $170/tonne CO_2e in 2030 and is held constant thereafter), operation and maintenance savings, and revenue generation (associated with renewable energy production facilities and some transit actions). Administrative costs associated with implementing programs, as well as any energy system infrastructure upgrades that may be required (e.g., transmission line upgrades) are not included.

ABATEMENT COST

The abatement cost of an action is the estimated cost for that action to reduce one tonne of greenhouse gas emissions ('GHG') and is calculated by dividing the action's NPV by the total GHG emissions it reduces (tCO_2e) over its lifetime. For example, if a project has a net present value of $1,000 and generates 10 t$CO_2$e of savings, its abatement cost is $100 per t$CO_2$e reduced.

AMORTIZATION

The costs of major capital investments are typically spread over time (e.g. a mortgage on a house commonly has a 25-year mortgage period). Amortization refers to the process of paying off capital expenditures (debt) through regular principal and interest payments over time. In this analysis, we have applied a 25-year amortization rate to all investments (no interest cost was associated with future payments).

INDUSTRIAL EMISSIONS

Financial analysis of the industrial sector includes only the low carbon investments for secondary manufacturing. Primary industry (e.g., steel manufacturing) comprises about 80% of industrial gas and electricity sales in Hamilton and emission reduction costs for that sector have not been estimated in this analysis. As the technological pathway for reaching net-zero is uncertain and specific to the individual steel manufacturing plants in Hamilton, the associated costs cannot be determined.

ENERGY AND CARBON COST PROJECTIONS

The energy cost projections displayed in Figure 1 underlie the financial analysis. These projections were derived from:

- the Independent Electricity System Operator's Long-Term Energy Plan (electricity),
- the US Energy Information Administration (propane), and
- the National Energy Board (all other fuels).

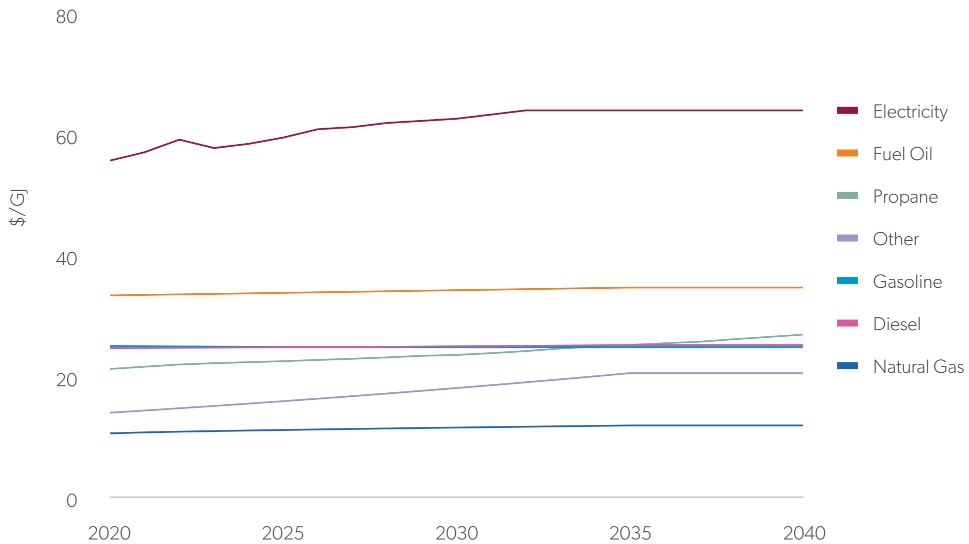


Figure 1. Projected energy costs.

The financial analysis is sensitive to electricity and natural gas costs. Electricity costs are projected to increase more rapidly than natural gas; if natural gas costs increase more rapidly, then the financial benefit of many of the actions increases.

An escalating cost of carbon, based on federal regulation, was applied out to 2030, then held constant.

Part 2. Hamilton's CEEP Financial Analysis Results

ABATEMENT COSTS

As outlined in Table 2, the investments included in the net-zero pathway yield a positive return for each tonne of carbon reduced; that is, the net savings and revenues the reductions generate yield a positive financial return that translates to a weighted average benefit of $1/tonne of CO_2e reduced.[4] The values for the individual measures are also included in Table 2.

Measures with a positive net present value are highlighted in green (i.e. where the investment has a positive return of at least 3%) will therefore have a negative abatement cost, which is also highlighted in green (i.e. they would be worth doing even without consideration of the carbon benefits). Whereas measures with a negative net present value are highlighted in red and have a positive abatement cost (i.e., these are measures with returns less than the discount rate of 3%).

Reviewing the following table action-by-action requires understanding the action's sequencing in the model (i.e., what is it offsetting), and what is bundled in each action. For example, "Waste diversion and Renewable Natural Gas with Anaerobic Digester (RNG with AD)" includes not only organic waste diversions and RNG production at an anaerobic digestion facility, but it also includes all RNG procurement in the CEEP. If RNG procurement was not included in this action, the waste diversion and AD action would have likely had negative abatement costs (meaning each tonne reduced would save money). On the other hand, heat pumps are assessed

[4] The net present value of the measures includes credit for the avoided costs of carbon ($170/tonne CO_2e); if that credit were excluded, the net savings per tonne of GHG mitigated would be correspondingly lower.

individually and have a positive marginal abatement cost (meaning each tonne reduced costs money), but if they were bundled with the new building and retrofit actions, as would be the case in implementation, the outcome may be more favourable

These interdependencies mean that the most important lens is the abatement cost for the entire plan.

Table 2. Net present value and abatement costs by action.

	CUMULATIVE EMISSIONS REDUCTION (KT CO_2EQ)	NET PRESENT VALUE	MARGINAL ABATEMENT COST ($ / T CO_2 EQ)
New dwelling EUI	578	$266,175,503	-$460
New res solar PV	257	$345,652,988	-$1,343
New non-res EUI	3,196	$1,022,701,898	-$320
New municipal EUI	1,430	$414,230,877	-$290
New non-res solar PV	218	$142,798,467	-$654
Retrofit dwellings	1,829	-$253,658,148	$139
Retrofit non-res	4,578	$1,176,624,425	-$257
Retrofit municipal	70	-$3,740,479	$53
Existing buildings solar PV	292	$280,551,392	-$959
Existing municipal buildings solar PV	22	$10,920,507	-$494
Heat pump	6,619	-$2,985,962,167	$451
Industrial efficiency	12,438	-$3,332,733,052	$268
Ground mount solar PV	473	$592,878,707	-$1,254
District energy expansion	372	-$71,505,124	$192
Transit expansion	19	$73,627,043	-$3,908
Electrify transit	263	-$70,569,449	$268
Trip reduction	1,361	$577,082,595	-$424
Electric shared mobility	80	-$136,119,997	$1,697
Electrify municipal fleet	43	$65,878,667	-$1,521
PUV electrification	6,494	$4,030,231,161	-$621
Commercial fleet electrification	6,224	$2,887,986,366	-$464
Waste diversion and RNG with AD	9,629	-$715,191,054	$74
Wastewater efficiency	50	$16,317,070	-$326
Green electricity procurement (i.e., renewable energy certificates)[5]	8,655	-$438,330,924	$51
Tree planting	1,126	-$2,500,054	$2
Hydrogen	4,692	-$3,829,930,585	$816
TOTAL	70,631	$63,416,635	AVERAGE: -$1

[5] The wind action modelled in the net-zero scenario was included in this category.

MARGINAL ABATEMENT COST CURVE

Figure 2 shows the marginal abatement cost curve (MACC) for measures included in Hamilton's CEEP.

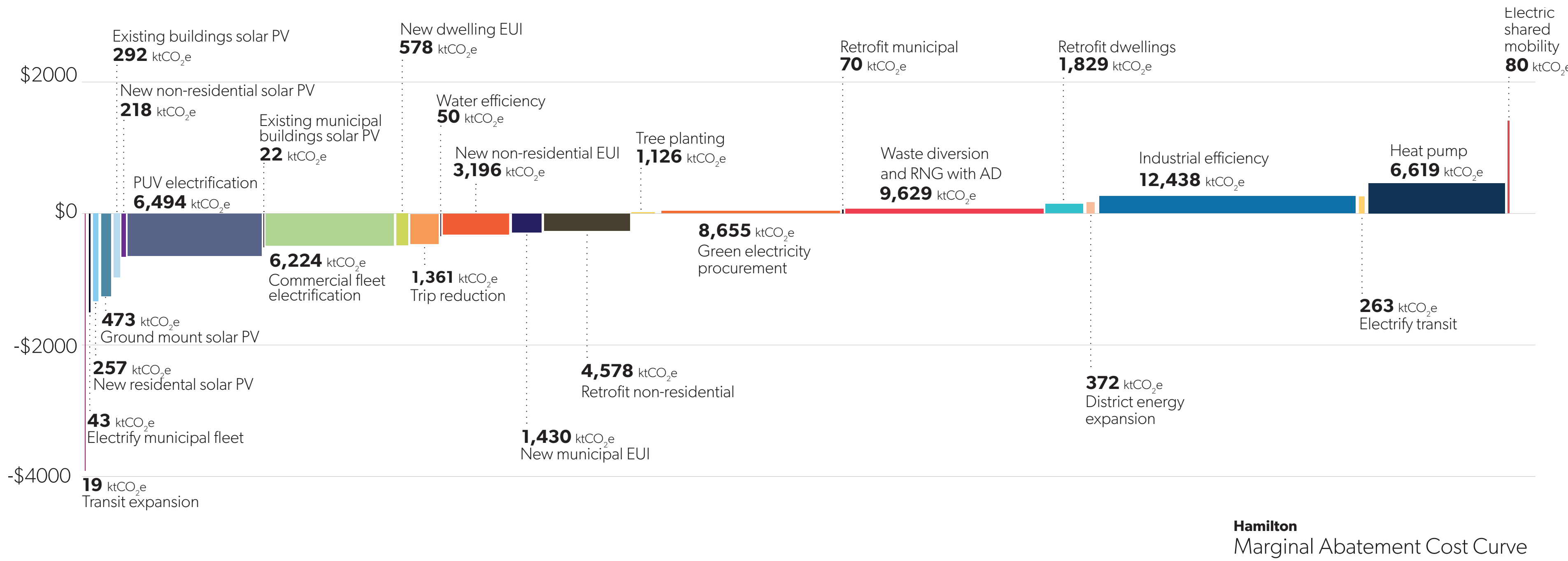


Figure 2. The marginal abatement cost curves for key actions in Hamilton's CEEP.

While a MACC illustrates the financial profile of the suite of actions, it is an imperfect indicator. The presentation of the MACC implies that the actions are a menu from which individual actions can be selected. Many of the actions are dependent on each other, for example, the district energy cost increases without retrofits. Another important message is that to achieve the City's target all the actions need to be undertaken, as soon as possible. While there can be a tendency to wait for technological improvements, this has the effect of reducing the value of the savings that can be achieved for households and businesses, and the new employment opportunities that can be created.

In Figure 2, the wider the action is, the greater the GHG emissions reduction. The higher above the middle horizontal axis the more costly the action, while the lower below the line, the more cost effective it is.

The MACC provides useful insights that guide implementation planning, for example:

- Can high cost and high savings actions be bundled to achieve greater GHG emissions reductions?
- How can the City help reduce the costs of the high-cost actions by supporting innovation or by providing subsidies?
- Which actions both save money and reduce the most GHG emissions? These can be considered the big moves.
- Which actions are likely to be of interest to the private sector, assuming barriers can be removed or supporting policies introduced?

These are exemplified in a sample Figure 3 MACC.

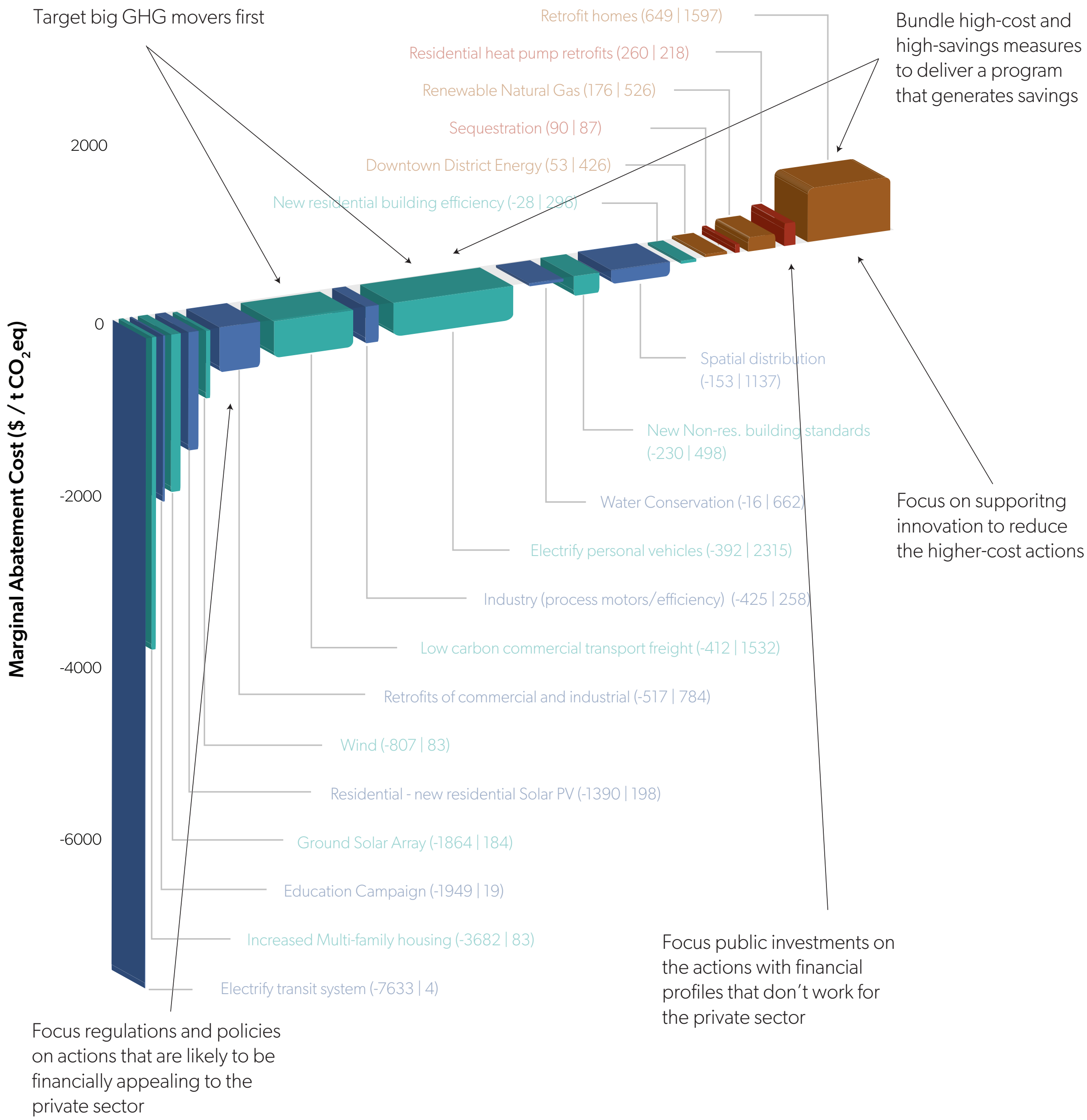


Figure 3. Examples of the strategic uses of a marginal abatement cost curve analysis.

Present and Net Present Values

As noted in the previous section, most of the actions in the net-zero scenario have positive net present values, as does the program of investments taken as a whole. Figure 4 shows the present value of the major components of CEEP: investments, operations and maintenance savings, fuel and electricity savings, avoided costs of carbon, and revenue from transit and local energy generation. After discounting at 3%, the investments in the program have a present value of $11.4 billion and the savings and revenue have a present value of $10.6 billion, for an NPV of the whole scenario of $63 million.

It is important to highlight the fact that capital investment for the plan ends in 2050, however, the NPV includes the energy, maintenance, and carbon costs savings as well as revenue projected over the full life of the measure, which in some cases extend as far as 2089 (for example a building built in 2050).

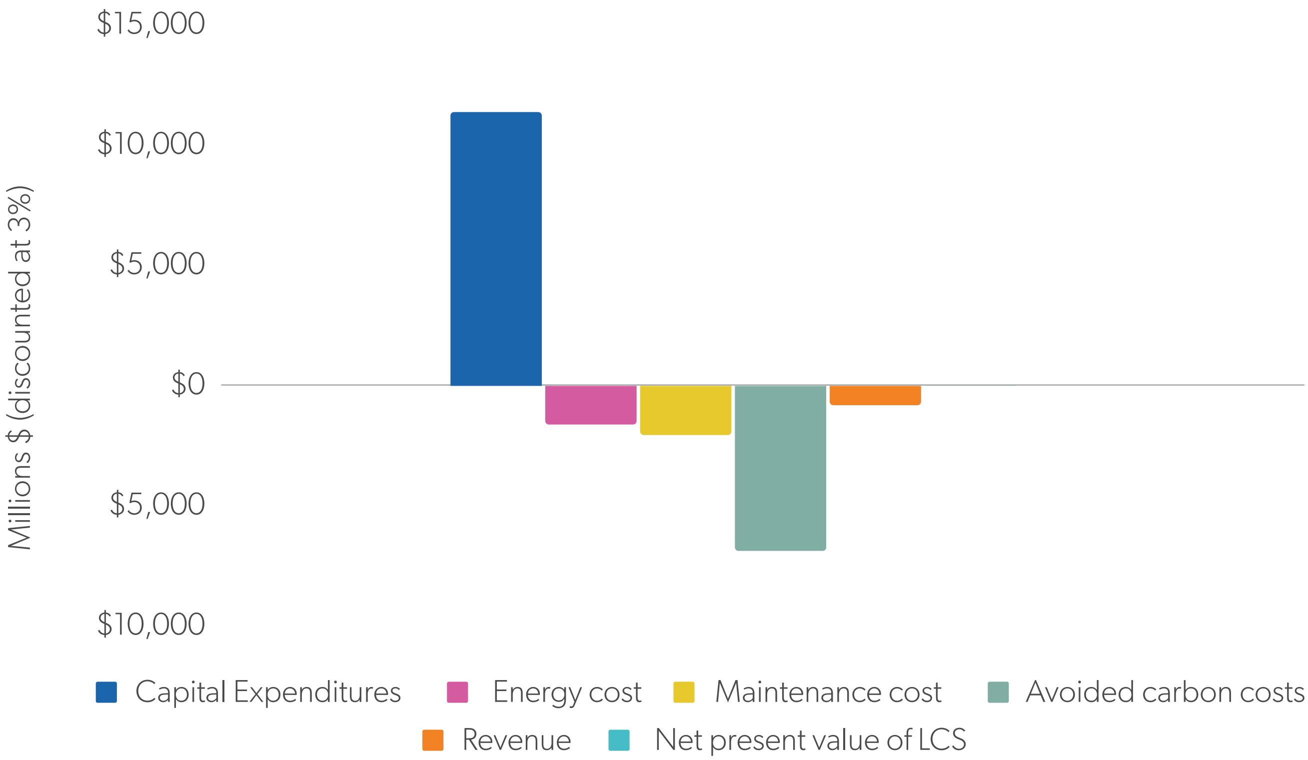


Figure 4. Present values of net-zero scenario costs, savings, and the net present value of the scenario (costs are positive, revenue and savings are negative).

Cash Flow Analysis

The annual costs, savings and revenue associated with fully implementing the actions in the CEEP are shown in detail in Figures 5, with capital expenditures shown in full in the years in which they are incurred. As is characteristic of net-zero transitions, the capital expenditures in the early years of the transition are significantly greater than the savings and revenues generated, but by the mid-2030s the annual benefits increase steadily until they nearly match the annual investments by 2050.

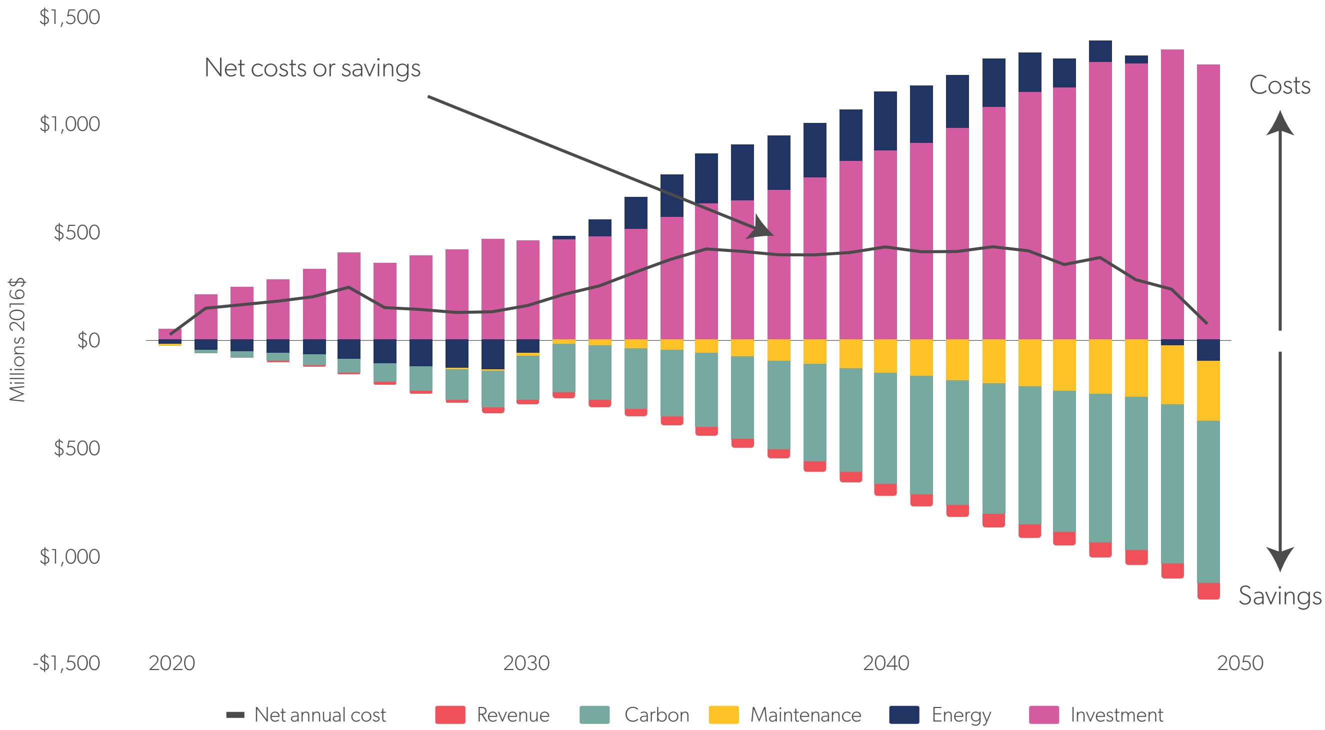


Figure 5. Capital expenditures vs. savings and revenues from the net-zero scenario, 2021-2050.

Figure 6 presents the same costs and benefits, but with the capital expenditures amortized over 25 years at 3% (no additional interest rate was applied). With this approach, which presumably would reflect actual approaches for financing the transition, the annualized capital payments are about equal to the savings and revenue generation, right from the beginning of the program. On an annual basis, the program never has a significant annual deficit. By 2050, the annual net benefit is over $63 million. After 2050, the amortized investment payments continue to taper off, reaching zero by 2075, while the benefits and revenues continue, resulting in continuous growth in the net annual benefit in the post-2050 period.

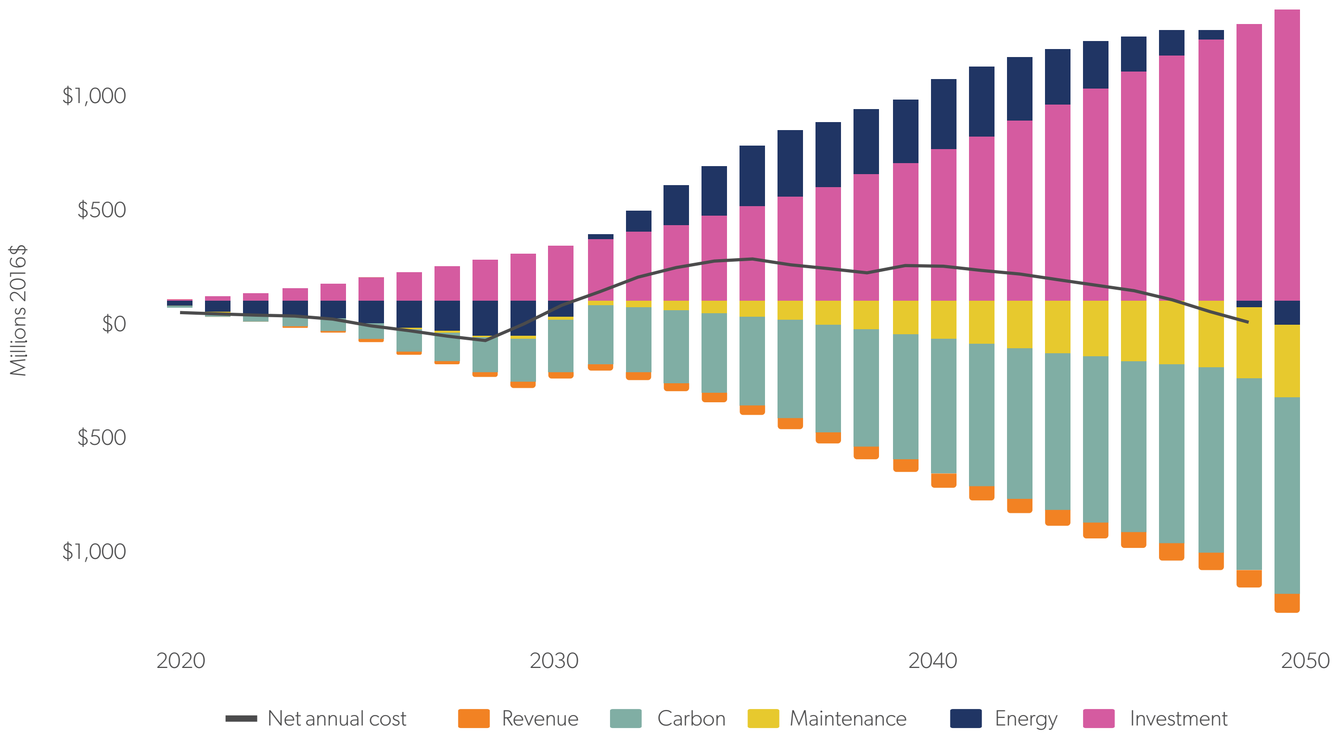


Figure 6. Annualized capital expenditures vs. savings and revenue from the net-zero scenario, 2021-2050.

Cost Savings for Households

Household expenditures on energy—natural gas, electricity, gasoline and diesel—are projected to increase in the BAP and decline in the net-zero scenario. In the BAP, household energy expenditures are relatively flat because vehicles become more efficient due to national fuel efficiency standards and because of decreased heating requirements as the climate becomes milder due to climate change. The net-zero scenario involves shifting away from natural gas and gasoline to electricity, a more costly energy source. The increased cost of electricity is partially offset by the increased efficiency of homes and electric vehicle motors. The carbon price also adds to the cost of using fossil fuels for heating and transport.

In the net-zero scenario, an average Hamilton household in 2050 spends $2,873 less on fuel and electricity (household energy and transportation expenditures) than they would have in a BAP scenario, over 84% less than what people will spend in the 2050 BAP scenario (see Figure 7). Between 2021 and 2050, the net-zero scenario saves the average Hamilton household about $37 thousand on fuel and electricity expenditures (this does not include any capital costs of energy efficiency improvements). Depending on the business, policy and financing strategies used in the implementation of the actions, these savings will be partly offset by the incremental capital expenditures required.

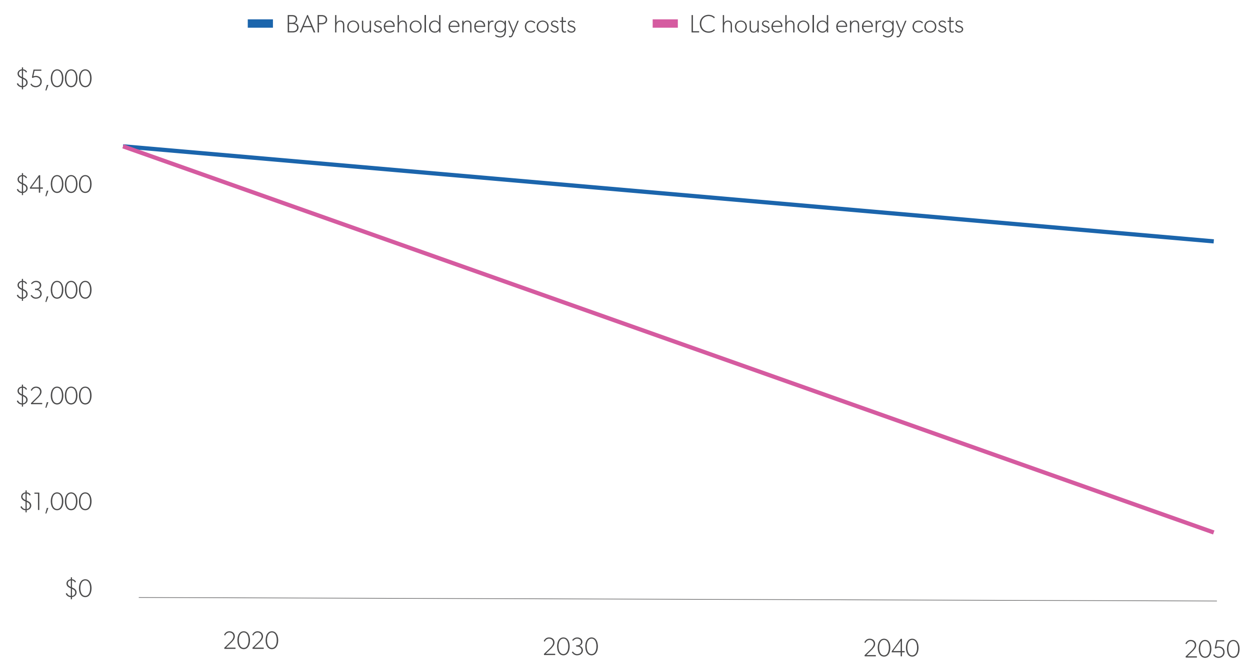


Figure 7. Average annual household energy costs in the net-zero and business-as-planned scenarios, 2021-2050.

New Job Opportunities

Transitioning to a low- or zero-carbon economy is expected to have four categories of impacts on labour markets: additional jobs will be created in emerging sectors, some employees will be shifted (e.g., from fossil fuels to renewables), certain jobs will be reduced and transitioned (e.g., combustion engine vehicle mechanics), and many existing jobs will be transformed and redefined.

From 2022 to 2050, the investments associated with the NZS are estimated to produce a total of about 160 thousand person years of employment. If these job hours were equated to full time jobs, they would total an average of 5,500 full time jobs a year (not cumulative). Implementation planning will help ensure these are local jobs.

What is evident in Figure 8 is the significant number of jobs that are expected from the industrial process efficiency action, as well as the residential and commercial retrofit actions modelled in the CEEP. Some job losses are also expected from vehicle electrification (personal and commercial) due to the reduced maintenance associated with these vehicles.

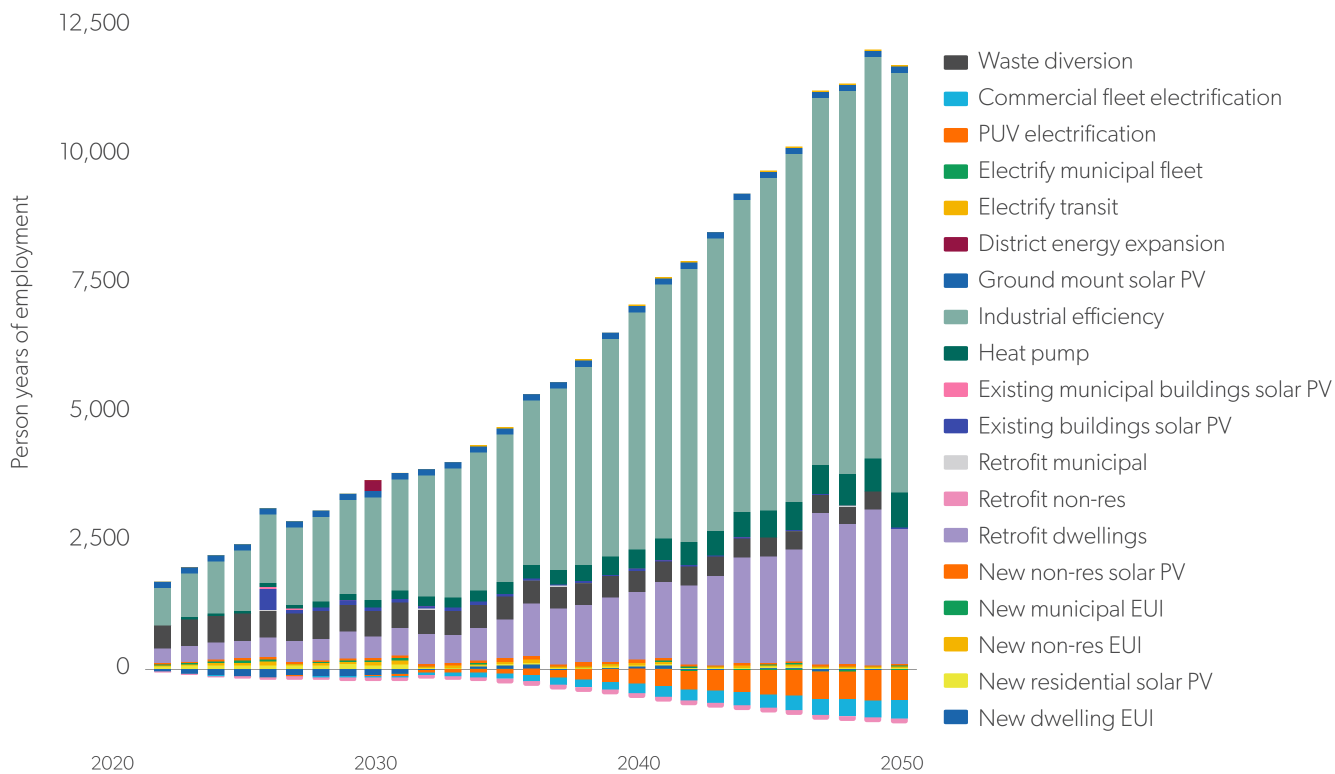


Figure 8. Additional person-years of employment associated with the net-zero scenario actions.

Conclusion

This financial analysis summarizes the overall financial and economic impacts of the CEEP in contrast to the business-as-planned scenario. Despite the fact that some actions on their own may not be cost-effective, overall the plan has a positive net present value and impact on jobs.

This analysis is based on the best available assumptions of projected costs and economic indicators out to 2050; many of these are highlighted in the table at the end of this document. It is important to note that this financial analysis is comprehensive, but incomplete. It misses many indirect benefits (e.g., on public health, resilience to extreme weather, and resilience to fuel cost fluctuations) as well as costs (e.g., the costs of inaction) that are difficult to quantify. Nonetheless, this financial and economic analysis remains an important tool to support decision-makers in their analysis of the CEEP.

Key Financial Assumptions

	CAPITAL INVESTMENT ASSUMPTION
LAND USE	
Land-use intensification Reduce avg. dwelling size Decrease share of single-detached housing	• Capital costs associated with land use intensification encompass standard investment in the community such as new housing developments; therefore they are considered to be $0. • Generally speaking with more infill development new infrastructure spending decreases.
NEW BUILDINGS	
New res. buildings w/ heat pumps New res. buildings w/ solar PV New commercial building efficiency Commercial buildings w/ solar PV	• The cost for new construction of buildings on a $/m² is estimated to be: • Single-detached: $1,776 / m² • Double: $1,426 / m² • Apt 1-4 storey: $2,341 / m² • Apt 5-14 storey: $2,556 / m² • Apt > 15 storey: $2,610 / m² • The premium associated with meeting high-efficiency building standards is assumed to average 10%. • Energy savings associated with high-efficiency buildings is calculated to be 80-90% over existing building stock. • A residential heat pump has a capital cost of approximately $6,000 (non-res is ~$10,000 and scaled to the heating requirement), with approximately $160 annually to maintain (~$400 annually for non-res)
EXISTING BUILDINGS	
Retrofit homes/energy efficiency Residential electric water heaters Heat pump as part of residential retrofits Retrofits industrial buildings Retrofits of commercial and industrial	• 100% of residential buildings built before 2017 are retrofitted; all non-residential buildings are retrofitted. • The average cost of retrofits was assumed to be (per GJ of energy saved): » Residential: $600-$2,500 (depending on the age of the building and baseline energy use intensity) » Non-Res: $500-$1,500 (depending on the age of the building and baseline energy use intensity) • A residential heat pump has a capital cost of approximately $6,000 (non-residential is ~$10,000), with approximately $160 annually to operate (~$400 annually for non-residential)

	CAPITAL INVESTMENT ASSUMPTION
RENEWABLE ENERGY	
Solar PV- net metering old and new buildings 280 MW Ground Solar Farm Renewable Energy Certificates (RECs) Organic Waste to RNG Hydrogen introduced to natural gas networks	• Solar PV has a capital cost of approximately $2,000 per kW. The capital cost is expected to decrease towards 2050. • RECs are assumed to cost $10/MW. • The lithium-ion battery for energy storage is anticipated to decrease by as much as %50 by 2050. • RNG upgrading costs via Canadian Biogas Association RNG Financial Tool. • Hydrogen is assumed to start at $75/GJ, decreasing to $52.50/GJ by 2050.
INDUSTRY	
Industrial upgrades	See table below

Industrial upgrades	$/GJ 2025	$/GJ 2038
Lighting upgrades (avg.)	$115	$59
Space heating upgrades (avg.)	$27	$34
Water heating upgrades (avg.)	$33	$49
Motive upgrades (avg.)	$107	$176
Process heat upgrades (avg.)	$28	$43

	CAPITAL INVESTMENT ASSUMPTION
PROGRAM 5: TRANSPORT	
Expand bus service Electrify transit system Increase/improve cycling & walking infrastructure E-Bikes Electrify municipal fleets Electrify personal vehicles Low carbon commercial transport activity	• The cost of an electric vehicle is approximately $55,000 in 2016 and below $34,000 by 2050. 100% of personal car sales are electric by 2040. • Fuel cost of gasoline per litre goes up to 26% with the carbon tax and market factors added by 2040. • Transit electric bus capital costs assumed to decrease to traditional engine costs by 2050.
WASTE & WASTEWATER	
25% less water use (technology & behaviour change) Wastewater process efficiency	• Behaviour change programs are a cost of staff and communications from the city • Wastewater process efficiency included under industrial efficiency
MUNICIPAL BUILDINGS	
Retrofit municipal buildings Solar PV on municipal buildings	• See retrofit and solar PV figures in Programs 1 & 3
NATURAL ENVIRONMENT & SEQUESTRATION	
Tree planting	• Cost of tree planting is valued over $2.5 million ($2.5/tree)

APPENDIX C: Implementation Strategy

November 2021

Purpose of this document

Once Council approves the CEEP ('ReCharge Hamilton'), the City will need to turn to implementation immediately. To support the CEEP's implementation, this Strategy proposes a short-term, high-level implementation plan (0-5 years) to help the City pivot efficiently from planning to doing.

This plan also includes guidance for setting up a long-term monitoring framework to ensure progress, continuous improvement, accountability, and transparency.

Contents

Acronyms

AD	anaerobic digester
CEEP	Community Energy and Emissions Plan
CIPEC	Canadian Industry Program for Energy Conservation
CHP	combined heat and power
DE	district energy
EV	electric vehicle
FCM	Federation of Canadian Municipalities
FTE	full-time equivalent
GHG	greenhouse gas
IESO	Independent Electricity System Operator
HIEA	Hamilton Industrial Environmental Association
HRAI	Heating, Refrigeration, and Air Conditioning Institute of Canada
MOU	memorandum of understanding
NGO	non-governmental organization
NRCan	Natural Resources Canada
PACE	property assessed clean energy
PV	photovoltaic
RE	renewable energy
RNG	renewable natural gas
TBD	to be determined
VKT	vehicle kilometres travelled

UNITS

CO_2e	carbon dioxide equivalent
GJ	gigajoule
Km	kilometre
Kt	kilotonne
MW	megawatt
t	tonne

Context

The following near-term (0-5 year) Implementation Strategy aims to guide progress on the pathway laid out in the CEEP. The direction of the pathway is driven by the target of net-zero carbon emissions by 2050, however the shape of the pathway is influenced by:

- input from the CEEP Stakeholder Advisory Committee;
- survey responses from the general public;
- input from City Staff;
- research on best practices; and,
- consultant experience from other projects.

As a result of this input, this Strategy is designed to enable the GHG reduction measures identified in the CEEP and to maximize co-benefits including economic development, improved equity and public health outcomes.

This Strategy includes some key City-led initiatives, but the majority of CEEP implementation will require resources and leadership from various actors in the community, including utilities, industry, businesses, and institutions (e.g., colleges and universities). Partnerships are critical to achieving the target of net-zero emissions by 2050.

Partnerships mobilize diverse skills, expertise, and capacity to support the implementation of the CEEP, and they have an opportunity to improve inclusion and social equity.

Funding, resources, and enabling policies from higher levels of government will also be critical to achieving the CEEP targets. Coordinated and early outreach and liaison will need to be prioritized.

Key to the Co-benefits Indicators

This Implementation Strategy focuses on the first steps in enabling and implementing key actions that are projected to have significant societal benefits. In addition to varying levels of greenhouse gas (GHG) reductions, actions included in this strategy result in various associated co-benefits. These include: equity improvements, employment increases, and return on investment. For simplicity we have created a code for each potential co-benefit—enabler, low, medium, and high— based on their relative impact in the net-zero scenario model undertaken for the City (see Appendix E: Net-Zero Pathway, Technical Analysis and Appendix B: Detailed Economic and Financial Analysis). These categories, and their definitions are described in the table below.

Table 1. Co-benefits indicators and their capacity to reduce emissions and improve lives.

INDICATOR	ENABLER	LOW	MEDIUM	HIGH
Greenhouse gas emissions	Enables GHG emission reductions	<20 $ktCO_2e$ reduction by 2050	21 to 1,000 $ktCO_2e$ reduction by 2050	>1,000 $ktCO_2e$ reduction by 2050
Equity	No discernible effect	Without intervention, this action may favor certain groups or create a greater disparity between higher and lower income groups	This action is more likely to be implemented in the community fairly, but existing powerful groups may still be at an advantage	This action contributes to enhanced equity
Employment ('Emp.')	Enables employment	0-2 person years of employment per $million invested	3-5 person years of employment per $million invested	>6 person years of employment per $million invested
Cost-effectiveness ('CE')	No cost associated with supporting action	This program will need incentives, loans, or grants in order to be completed	This action has the ability to break even, in particular, if paired with a more attractive investment vehicle	This action will be a driver of total cost-effectiveness of the entire program

CEEP Coordination and Oversight

The CEEP requires an entity that helps oversee and coordinate its implementation. Its role would include:

- coordinating, collecting, and reviewing targets;
- monitoring GHG emissions;
- evaluating the effectiveness of programs and progress towards sectoral targets; and,
- reporting transparently.

The following table describes the functions required to support implementation.

Table 2. Functions to support CEEP implementation.

FUNCTION	ENTITY	ROLE	EXAMPLE
Accountability	• Community Climate Advisory Committee	The Community Climate Advisory Committee is an independent external committee of community stakeholders that operates as an independent body to review the City's corporate and community wide targets, actions, and progress on the same. The Community Climate Advisory Committee will also serve as a liaison between the broader community and the City Climate Office and coordinate the implementation of community-led actions, data collection, education and awareness, and reporting.	City of Edmonton Environmental Advisory Committee; Region of Durham Roundtable on Climate Change.

FUNCTION	ENTITY	ROLE	EXAMPLE
Coordination	• City of Hamilton Centralized Climate Office	The City needs a centralized entity within the City Corporation that will act as a hub for coordinating the implementation of the City-led CEEP actions across the municipal corporation, as well as reporting on corporate and community-wide progress on the implementation of CEEP actions of GHG reductions. The proposed Climate Office would also be the stewards of the proposed climate Climate Impact Adaptation Plan, currently under development, and would be responsible for leading updates to the City's climate change related documents such as the Community Energy and Emissions Plan and the Community Impact Adaptation Plan. The Climate Office will also partner with the Community Climate Advisory Committee to design and undertake community engagement throughout the implementation of the plan. The Community Climate Advisory Committee will also play a role, in coordination with the City's Climate Office, in coordinating and supporting community-led actions. To ensure this office is effectively coordinating climate actions across the municipal organization, there needs to be commitment about exactly what actions, targets, and metrics each City department should be responsible for reporting on.	Region of Peel Office of Climate Change; Town of Halton Hills, Climate and Asset Management, CAO Office; Durham Region, Strategic Initiatives Division, CAO Office; Town of Whitby, Strategic Initiatives Division, CAO Office See also: David Miller's book "Solved: How the World's Great Cities are Fixing the Climate Crisis" (2020)
Implementation	• City Climate Office • Multi-Departmental Climate Change Working Group • External Stakeholders across the City • Community Climate Advisory Committee	The City's centralized Climate Office will coordinate municipal actions with the various City departments. Each City department will also need to have resources dedicated to the implementation and monitoring/reporting of the CEEP actions. These departmental representatives will serve as a liaison to the centralized Climate Office and will be part of a Multi-Departmental Climate Change Working Group to report on actions, progress and monitor implementation and targets associated with their respective departments. External stakeholders across the City will also be required to take action for community-based actions. This will be implemented with assistance and support from the City's Climate Office, as well as the established Community Climate Advisory Committee.	Region of Durham's Carbon Accounting Framework; Example of a third party: Our Energy Guelph; Example of contracting out for various climate change programs (see Bristol, UK); Example of procurement practices that maximize community wealth building (see Preston, UK).

The process will ensure accountability, coordination of implementation, monitoring, and reporting of implementation activities.

ANNUALLY REPORTING GHGs and **METRICS:** This provides the primary data to track progress towards the net-zero target. It should include community-wide and sector-specific energy and emissions reporting.

ADAPTIVE MANAGEMENT: regular reviews (for example, every 5 years) of CEEP programs based on established metrics, as well as trends in overall energy use and GHG emissions, updates in policy best practice, and technological innovation.

TRANSPARENCY: by ensuring that all reporting and reviews are made easily accessible to the public.

COMMUNITY ENGAGEMENT AND OVERSIGHT: via a formal body representing a cross-sector of the community.

Such a program is proposed to be led by a newly created City Climate Office and Community Climate Advisory Committee.

FUNCTION	ENTITY	ROLE	EXAMPLE
Monitoring and reporting	• Energy and Climate Office • Multi-Departmental Climate Change Working Group • Community Climate Advisory Committee	The Multi-departmental Climate Change Working Group will monitor and report on targets for actions assigned to their respective departments. The Working Group will report these targets to the City's Climate Office, who will compile a comprehensive report on the City's corporate and community GHG emissions and progress towards reductions and action implementation. The Community Climate Advisory Committee will also monitor and report on community-based progress on actions, including emission reductions and other indicators and report the data to the City's Climate Office for input into the comprehensive report. The City's Climate Office will compile this data from both the City's corporate and community GHG emissions and progress on actions and provide a comprehensive report to the Senior Leadership Team and Council annually or as often as directed.	Toronto's Energy and Environment Division is responsible for tracking emissions annually. The Bay Area Restoration Council is an example of a local organization in Hamilton that the Bay Area Climate Change Council was modelled after that provides education and awareness and annual reporting of community-wide initiatives.

Table 3. Actions, partners, and resources required for CEEP implementation.

ACTION + TIMELINE	RESOURCES REQUIRED	KEY PARTNERS	GHG REDUCTIONS BY 2050 & CO-BENEFITS	PRIMARY FUNDING SOURCE(S)	METRICS (FOR MONITORING PROGRAM)
CEEP Administration					
Creation of and dedication of staff to lead and coordinate corporate and community-wide energy and climate change work through the creation of the City Climate Office.	FTE and budget TBD	• City	Enabler	City	Annual reporting to Community Advisory Committee and Council on: Community energy and emissions; and the state of all Corporate and Community CEEP actions and their KPIs
Climate action coordinators across all major City departments and a Multi-Departmental Climate Change Working Group	FTE and budget TBD	• City	Enabler	City	Departmental reporting on progress of associated CEEP actions Departmental annual and long-term budgeting to implement CEEP actions
Ensure longevity and dedicated long-term funding for Community Climate Advisory Committee 2022-onwards	Ensure ongoing funding to support the Community Climate Change Advisory Committee.	• City and members of proposed Community Climate Advisory Committee	Enabler	City	Annual reporting to the Centralized Climate Office: State of all Community-led CEEP actions and their KPIs in coordination with City Climate Office
Establish and deliver a public engagement program to support CEEP implementation 2022-onwards	To be completed through the resources in the City's Climate Office in partnership with the Community Climate Advisory Committee and other community partners.	• City, Community Climate Advisory Committee, and other community partners	Enabler	City	Design and delivery of an educational and awareness campaign

The City of Hamilton (Corporate)

When it comes to its fleet and buildings, the City is already on a net-zero trajectory based on its most recent Corporate Energy and Sustainability Policy, and Green Fleet Strategy. The next generation approach is to ensure that all Council decisions align with community GHG targets by establishing an annual carbon budget and developing a sustainable procurement strategy that also takes into account embodied carbon emissions.

In addition, the City will need to mobilize financial resources using tools such as green bonds, investigating revenue tools, and the expansion of the existing revolving energy fund.

Municipal and Community Carbon Budget

Establishing an annual emissions cap, allocating targets to departments or sectors similar to annual financial budgets (with surpluses and deficits allotted to the following year), is currently best practice in municipal climate emergency responses. Edmonton and Ottawa are implementing this approach in Canada, drawing on an example from the City of Oslo. Carbon budgets can be established at the corporate and community-wide scale, the latter was applied in Oslo.

Climate Lens

A carbon budget requires that a climate lens be applied to all strategic and budget decisions to highlight their GHG impacts. Adaptation considerations can also be integrated into the climate lens.

Procurement

When procuring goods and services, the City has an opportunity to be a leader in supporting sustainable goods and service providers. It can do so by updating its procurement guidance to prioritize goods and service providers that are aligned with the city's net-zero target, and goods with lower embodied emissions in their products.

New and Expanding Climate Change/Corporate Energy Revolving Fund

The City has a successful revolving fund program for corporate energy efficiency programs. This successful program has the potential to be expanded to fund a broad range of low-carbon actions across the corporation. The City also has established a Climate Change Reserve and policy that guides corporate and community spending of climate actions; a clear long-term sustainable funding source for this reserve still needs to be developed.

Green Bonds

The City of Hamilton can issue green bonds to raise the capital to finance corporate and community GHG-reduction initiatives, such as deep home or business retrofits, which result in energy savings that can be used to repay the loan. The scope of eligible projects will need to be determined through the development of the bond framework (e.g., see the Climate Bonds Standard).

Community Bonds

In addition to green bonds, which are issued to large corporate investors, community bonds can be issued to community members as a source of finance for low-carbon actions. Community bonds can be issued in denominations as low as $1,000 and can be a mechanism to enable the community to invest in its own projects.

Table 4. Actions, partners, and resources required for the Corporate plan.

ACTION + TIMELINE	RESOURCES REQUIRED	KEY PARTNERS	GHG REDUCTIONS BY 2050 & CO-BENEFITS	PRIMARY FUNDING SOURCE(S)	METRICS (FOR MONITORING PROGRAM)
Municipal decision-making					
Investigate and design a carbon accounting framework (including a climate lens, carbon budget, and sustainable procurement policy) to align municipal decision-making 2022-onwards	• Dedicated staff time • Staff training	• City Council • Municipal departments • Potential expert consultant	Enabler	• City (staff time + operating expenses TBD)	• Corporate emissions • Feedback from Council and staff • Annual corporate and community CO_2e surplus/deficit
Municipal funding mechanism					
Corporate Energy Reserve (revolving fund) expansion assessment (including the addition of climate-aligned funding criteria) and implementation 2022-onwards	• Dedicated staff time to develop a business case for the expanded fund, and a funding source.	• City (Corporate Energy Office)	Enabler	• City (initially) and future revenue streams • Potentially Provincial and Federal government climate action funding	• $ loans/ annually • $ loans/ $tC0_2e$ & /GJ of energy reduced from the baseline • $ loans/ $ energy costs & /social cost of carbon saved
Municipal and community green bond assessment 2022-2023	• Dedicated staff and potentially consultant time to develop a green bond program. This analysis can also evaluate the role of community bonds.	• Corporate Services Department	Enabler	• City	• $ value of green bonds issued • $ value of community bonds issued

ACTION + TIMELINE	RESOURCES REQUIRED	KEY PARTNERS	GHG REDUCTIONS BY 2050 & CO-BENEFITS	PRIMARY FUNDING SOURCE(S)	METRICS (FOR MONITORING PROGRAM)
Climate Change Reserve and long-term sustainable funding sources 2022-onwards	• City Corporate Services Division. • City Climate Office	• Multi-departmental climate change working group • may need external expertise	Enabler	• City	• $ loans/ annually • $ loans/tCO_2e/GJ (if applicable) • Estimated climate impacts (if focusing on climate adaptation)

Innovating Our Industry

Industry, particularly the steel sector, is both a major part of the City's economy and a main source of emissions. Some segments of the sector are already hard at work reducing their energy use in order to increase their competitiveness.

Increasing industrial efficiency and Industrial decarbonization

⟶ Industrial energy efficiency and decarbonization working group

The City and it's partners will convene an industrial energy efficiency and decarbonization working (or 'net-zero') group.

In parallel to existing industrial sustainability-themed groups (e.g., HIEA and City-led Bayfront Industrial Strategy efforts), this working group will focus explicitly on coordination of and fast tracking short and long-term GHG reductions in alignment with the City's targets, including advocacy, funding opportunities and project development.

⟶ Industrial energy efficiency and fuel switching pathways

In addition to encouraging the industrial sector to adopt net-zero targets, as the steel sector has done, most industries require support in developing a pathway for deep energy process efficiency improvements and fuel switching. These pathways could be developed with support from Provincial and Federal government agencies, the working group, post-secondary institutions, and utilities.

⟶ Establish a clean-tech accelerator

Building on the skills and expertise available at McMaster University, Mohawk College, and Redeemer University; the City and it's partners, with support from the Provincial and Federal governments, can support the development of a clean-tech accelerator (potentially associated with or as an expansion of the existing McMaster Innovation Park). Not only would this help develop the technologies necessary for the sector's decarbonization, it also increases the local skilled workforce.

⟶ Financing for industrial decarbonization

In order to support the sector's transition, the City may explore the potential for creative financing tools.

⟶ Training Local Industrial Energy Managers

In order to support the sector's transition, the City and it's partners will need to work with local post- secondary institutions and trade unions to support their delivery of training and retraining industrial energy managers.

Table 5. Actions, partners, and resources required for changes to industry.

ACTION + TIMELINE	RESOURCES REQUIRED	KEY PARTNERS	GHG REDUCTIONS BY 2050 & CO-BENEFITS	PRIMARY FUNDING + FINANCING SOURCE(S)	METRICS (FOR MONITORING PROGRAM)
Industry: Energy Efficiency and Decarbonization Working Group					
1. Establish net-zero industrial working group *2022- onwards*	• Staff time from the Community Climate Advisory Committee • City staff time as an observer, City liaison (20 hours/month) • Industry staff time (as needed) • Local utility staff time (ongoing) • Post-secondary institution staff time (ongoing)	• Led by the Community Climate Advisory Committee • City (build on the eco-industrial park recommended as part of the City's Bayfront Strategy) • Industry (potentially via HIEA + Chamber of Commerce) • Local utilities • Post-secondary institutions	Enabler	• In-kind funding (City, industry, HIEA, utilities, post-secondary institutions)	• Annual reporting on industry GHGs and energy use • Number of industrial partners with corporate sustainability plans that are harmonized with the community-wide net-zero target
Industry: Process Efficiency Improvements					
1a) Development and deployment of a zero emissions industry program (a joint public and private sector initiative) *2022-2024*	• Net-Zero Industry Working Group (see above) • Industrial energy management expertise (from a consultant or utility)	• Led by the Community Climate Advisory Committee • Local utilities • Industry (potentially via HIEA + Chamber of Commerce) • City • Provincial/federal governments • Post-secondary institutions	GHG: High Equity: Low Emp: High Cost-effectiveness: TBD	• Provincial/ federal governments (e.g., NRCan CIPEC funding) • Utility ratepayers (via existing energy conservation programs) • Property Assessed Clean Energy (PACE) financing	• Program design • GJ of energy saved and $tC0_2e$ reduced against a baseline

ACTION + TIMELINE	RESOURCES REQUIRED	KEY PARTNERS	GHG REDUCTIONS BY 2050 & CO-BENEFITS	PRIMARY FUNDING + FINANCING SOURCE(S)	METRICS (FOR MONITORING PROGRAM)
Industry: Establish a cleantech accelerator					
2. Establish a cleantech accelerator *2022-2026*	• City/ Community Climate Advisory Committee coordinate with post-secondary institutions to design an accelerator, and identify funding sources	• Led by the Community Climate Advisory Committee • City • Post-secondary institutions • Federal government (likely via NRCan) • Provincial government • HIEA	Enabler	Provincial and Federal government (e.g., NRCan CIPEC funding)	• Establishment of a cleantech accelerator
Industrial Energy Management Training					
3. Expand local industrial energy management training programs (incl. subsidized opportunities for marginalized populations) *2022-onwards*	• Canadian Colleges for Resilient Recovery • City to help coordinate with post-secondary institutions and HIEA	• Led by the Community Climate Advisory Committee • Canadian Colleges for Resilient Recovery • City • Post-secondary institutions • Federal government (likely via NRCan) • Provincial government • HIEA • -BACCO	Enabler	Provincial and Federal government (e.g., NRCan CIPEC funding)	• Number of trained/ retrained industrial energy management professionals

Transforming Our Buildings

New Buildings

Although new buildings are projected to represent a relatively low share of GHG emissions in the City, new development represents long-term infrastructure that will establish patterns of energy use and GHG emissions for decades. Despite the limitations of municipal power to set building requirements that are more stringent than the Ontario Building Code, the municipality needs to create net-zero-aligned building standards or policy solutions as soon as possible, in order to avoid the need to retrofit new buildings in the near future. Action on this front should include lobbying the provincial government to strengthen the Ontario Building Code to align with net-zero construction standards by 2050.

Existing Buildings

In order to achieve net zero by 2050, the existing building stock in Hamilton will need to be decarbonized. This is a major undertaking because most buildings in the city are heated with natural gas and are energy inefficient (as compared to current best practices). Please note that the modelling contained within this plan only includes operational carbon; however, it is recognized that embodied carbon will also need to be considered when evaluating the carbon costs of individual building retrofits.

In order to decarbonize buildings in the most cost-effective manner with the smallest environmental impact, it is necessary to first maximize energy efficiency.

Many cities are exploring how to bring down the cost of mass deep energy retrofits, for example by revisiting the current utility-led delivery model as well as ordering equipment and undertaking retrofits in bulk. The City's proposed updates to the Commercial District Revitalization Grant Program offers 50% of the cost for commercial building owners in certain commercial districts to install EV chargers, some forms of renewable energy, or green walls or roofs.

The Bay Area Climate Change Council (BACCC) is currently working on advocacy and implementation recommendations to accelerate retrofits of privately-owned buildings via a Home Energy Retrofit Program. This also includes working with the Centre for Climate Change Management at Mohawk College towards the development of a sustainable business plan for a Home Energy Retrofit Delivery Centre to act as a 'one stop shop' and drive the uptake of renovations.

Improving equity in this sector involves targeting retrofits to social housing and delivering programs for low-income residents. In addition, equitable outcomes in employment can be increased by providing subsidized training and retraining programs for underemployed and historically marginalized community members.

The timeline of the retrofit strategy is as follows:

2022: Undertake a detailed design study for a residential energy efficiency program to enable deep mass retrofits.

2022-onwards: Ensure local skilled labour is being trained or retrained so that when the program is designed there is a local workforce ready to hit the ground running.

2023-2024: Undertake a small-scale version of the project to test the business case model and address potential flaws in the concept. Target low-income or social housing.

2025: Expand the program, with particular attention to portions of the population that would stand to benefit the most from reduced energy costs and improved comfort and air quality (among other benefits).

Table 6. Actions, partners, and resources required for changes to buildings.

ACTION + TIMELINE	RESOURCES REQUIRED	KEY PARTNERS	GHG REDUCTIONS BY 2050 & CO-BENEFITS	PRIMARY FUNDING +FINANCING SOURCE(S)	METRICS (FOR MONITORING PROGRAM)
New Building Standards					
4. Develop and integrate new green development standards (i.e., a stepped approach to net-zero, and DE-ready in appropriate zones) 2022-2023	• Dedicated staff time • City advocacy to higher levels of government related to standards of construction (OBC) • Funding for annual recognition/awards event for industry leaders	• Led by the City of Hamilton • Consultant • Canada Green Building Council • Urban Development Institute • Higher levels of government • Technical support from cities with experience • Clean Air Partnership • Development community	GHG: Medium Equity: Enabler Emp.: High Cost-effectiveness: High	• City • Potential for the future development of financial incentives for implementation. • Expand tax-incremental financing program provided to the downtown core	• Energy and emissions intensity of new buildings (per sq/ft or m^2) • # of buildings achieving higher tiered standards or energy efficiency certification.
5. Install solar PV on new buildings *2022- onwards*	• Zoning regulation updates to minimize barriers to solar PV • Funding for incentive programs (potentially through the building retrofit program)	• Led by the City of Hamilton • Canada Renewable Energy Association • Local electricity utility • Development community	GHG: Medium Equity: Enabler Emp.: High Cost-effectiveness: High	• Potential incentive programs for implementation • Property Assessed Clean Energy (PACE) financing program for new construction	• MW installed of solar PV on new buildings

ACTION + TIMELINE	RESOURCES REQUIRED	KEY PARTNERS	GHG REDUCTIONS BY 2050 & CO-BENEFITS	PRIMARY FUNDING +FINANCING SOURCE(S)	METRICS (FOR MONITORING PROGRAM)
Existing Building Retrofits					
6. Design and plan for a mass deep energy retrofit program (may include retrofit delivery centre) *2022-2023*	• City staff oversight • Technical analysis: Consultant (up to $200,000) • Municipalities and organizations working on this same challenge	• Led by the Community Climate Advisory Committee • FCM • Clean Air Partnership • City • Local energy efficiency organizations (e.g., Green Venture) • Local utilities	Enabler	• FCM • City	• A completed detailed plan and business case analysis
6a) Training and retraining programs *2022- onwards*	• Canadian Colleges for Resilient Recovery • Community Climate Advisory Committee • Meeting with local training centres to ensure they are preparing for the coming jobs market	• Led by the Community Climate Advisory Committee • Local colleges, universities, and training centres • Building industry • City • Labour and trade unions (e.g., HRAI) • City • Canadian Colleges for Resilient Recovery	Enabler	• Colleges, universities • Provincial, federal government • Trade associations, construction industry	• Skilled graduates and workforce trends.

ACTION + TIMELINE	RESOURCES REQUIRED	KEY PARTNERS	GHG REDUCTIONS BY 2050 & CO-BENEFITS	PRIMARY FUNDING +FINANCING SOURCE(S)	METRICS (FOR MONITORING PROGRAM)
6b) Launch small-scale neighbourhood deep energy and emissions retrofit projects in the residential sector *2022-2023*	• Program delivery organization • Dwelling owners willing to participate in pilot • Example funding for program: $4 million ($50k * 80 homes) • Rezoning approval (potentially) • Architects / designers • Supply chain analysis of heat pumps and solar PV	• City • Construction / renovation/ energy efficiency industry • Canada Green Building Council / Passive House Institute Canada • Local utilities • Potentially a 3rd party, non-profit organization	GHG: Low Equity: Medium - High Emp.: High Cost-effectiveness: TBD	• FCM funding for program start-up • Grant program from City budget • IESO + utility incentive programs • Funding from other levels of government • Suppliers of low-carbon technology (heat pumps, solar PV, electric hot water heater)	• Small-scale program completion and public reporting • Energy use and emissions intensity over subsequent years, by sector
6c) Finance and deliver mass deep energy retrofit program for the residential sector, scaling up to a city-wide program Consider the development of a commercial retrofit program *2023 - onwards*	• Program delivery organization • City	• City • Construction / renovation industry • Businesses / banks • Utility companies	GHG: High Equity: Medium - High Emp.: High Cost-effectiveness: TBD	• Incentive programs from City • FCM funding • Property Assessed Clean Energy (PACE) financing • IESO + utility support via incentives • Provincal + Federal governments	• Program completion and public reporting • Energy use and emissions intensity over subsequent years by sector • # of building retrofits completed through program.

Changing How We Move

The following are near-term transportation actions that are designed to first reduce vehicle kilometres traveled and then switch remaining VKTs to low and/or zero emissions energy sources.

Equitable outcomes are amplified when mobility (transit, active transportation, and e-mobility) is prioritized for historically marginalized communities. Mechanic training and retraining programs can also target low-income and under-employed individuals, further improving social equity.

Reducing vehicle kilometres traveled

⟶ Expand active transportation networks

Increasing active transportation is a priority for reducing transportation emissions; it offers many co-benefits, including improved physical health and increased social well-being. The City can expedite the roll out of its Cycling Master Plan and update future iterations of the Cycling Master Plan and other City-wide transportation planning documents to align with the CEEP active mode share targets.

⟶ Expand transit

Expanding transit helps reduce the need for personal use vehicles and also offers an important means of transportation for those who are not able to drive or access personal vehicles. This includes the development and expansion of higher-order transit modes within the City. The City has also been examining options to offer innovative transit solutions to its low-density rural areas via an on-demand pilot.

⟶ Develop e-mobility services

To address those trips that are not suited to transit or active transport, the City can support establishment and expansion of local e-mobility services such as e-car, e-bike, and e-scooter share businesses.

⟶ Limit parking and incentivize EVs.

The City can continue its efforts to reduce parking requirements for developments. Where parking spots are required, establish guidelines, requirements, and incentivize EV access. This includes through parking regulations for new development.

Switching to zero-emissions vehicles

⟶ Decarbonize transit

The City has recently committed to transitioning its buses to RNG; however, as the following section on renewable energy highlights, there is a limited supply of sustainable RNG, and many potential end uses in the City that have limited low-carbon alternatives. Electric or green hydrogen-powered busses may be a more sustainable solution to decarbonizing transit.

⟶ Expand EV charging network

To encourage the adoption of EVs, an extensive EV charging network needs to be in place. The City can continue to situate charging stations on City-owned land, and partner with businesses and owners of multi-unit residential buildings to install charging stations in appropriate locations. A city-wide EV strategy will help to consolidate and coordinate all of these efforts.

⟶ Commercial fleet decarbonization working group

The City can accelerate the transition of private fleets by convening a working group to coordinate activities and share insights from implementing the City's net-zero-aligned Green Fleet Strategy. This also includes working with and supporting private fleet owners across the City to establish net-zero targets and identify obstacles and pathways to achieving those targets.

In doing so, the City can apply best practices from other jurisdictions, such as Michigan's Green Air Alliance Green Fleet Strategy, as well as the 2020 Multi-State MOU about low- and zero-emissions medium and heavy-duty vehicles, which has 15 state signatories.

⟶ Support the transition of automotive mechanics

The projected increase in EVs will require a new and/or retooled labour force. The City, local colleges, and professional trade associations should work together to develop a plan to train and retrain the mechanic workforce using an equity lens.

Table 7. Actions, partners, and resources required for transportation changes.

ACTION + TIMELINE	ACTION DETAILS + RESOURCES REQUIRED	KEY PARTNERS	GHG REDUCTIONS BY 2050 & CO-BENEFITS	PRIMARY FUNDING SOURCE(S)	METRICS (FOR MONITORING PROGRAM)
Transportation: Active Transportation					
7. Expand and connect active transportation networks *2022-onwards*	• Complete long-range transportation modelling requirements to align with CEEP targets • Update active transportation planning documents based on updated modelling requirements and CEEP targets.	• Led by the City of Hamilton • Third party active transportation providers	GHG: Low- Medium Equity: High Emp: High Cost-effectiveness: TBD	• Development Fees • City Infrastructure Budget • Third party active transportation providers	• Km's of active transport links connected • Km's of total cycling infrastructure and breakdown of type (e.g., new, upgrades, separated, etc.)
Transportation: transit					
8. Decarbonize the bus fleet *2022-onwards*	• Technical analysis of bus charging or fuelling infrastructure required for fleet decarbonizationLed by the City of Hamilton	• Led by the City of Hamilton • EV or green hydrogen bus manufacturers • Neighbouring cities interested in bulk purchasing • Provincial/ federal government	GHG: Medium Equity: Potentially High Empl.: High Cost-effectiveness: High	• City • Provincial/ Federal government	• Number of decarbonized buses in use • Percentage of decarbonized vs. fossil-fueled buses • Completion of infrastructure requirement technical study
9. Plan for and develop expanded urban and rural transit service and e-mobility services *2022 - onwards*	• Update Transportation Master Plan and other City-wide transportation documents with CEEP modal split targets. • Support the establishment and expansion of higher-order transit	• Led by the City of Hamilton • HSR • Metrolinx • Third party e-mobility service provider	Enabler	• City • Provincial/ federal government • Third party e-mobility service provider	• Transit ridership and modal split • Establishment of e-mobility service and user statistics

ACTION + TIMELINE	ACTION DETAILS + RESOURCES REQUIRED	KEY PARTNERS	GHG REDUCTIONS BY 2050 & CO-BENEFITS	PRIMARY FUNDING SOURCE(S)	METRICS (FOR MONITORING PROGRAM)
Transportation: Personal and Commercial Vehicles					
10. Establish then implement a city-wide EV Strategy (residential, commercial, and municipal) *2022-2025*	• Consultant or City staff to develop the EV Strategy • Technical analysis and program design (incl. budget)	• Led by the City of Hamilton • Local electricity utility • Local institutions • Consultant	GHG: Enabler Equity: Depends on charging fees Empl.: Medium Cost-effectiveness: TBD	• City (initial EV Strategy development) • Local utilities • Businesses and building owners • Incentive program from City • Provincial / Federal governments • Developers	• Charging station per km^2 • Kwh/day/month/yr at each station • # of networked station
11. Commercial fleet decarbonization working group *2022-onwards*	• Commercial and industry networking group to establish fleet decarbonization pathways and targets (for both large freight and smaller and medium-sized fleets) • Development of a barrier analysis and action plan.	• Led by the Community Climate Advisory Committee • A network of businesses with significant large vehicle fleets • Auto sector • Chamber of Commerce • City	Enabler	• In-kind from participating businesses	• # of fleet decarbonization targets established • GHG reductions from decarbonization of member private fleets

ACTION + TIMELINE	ACTION DETAILS + RESOURCES REQUIRED	KEY PARTNERS	GHG REDUCTIONS BY 2050 & CO-BENEFITS	PRIMARY FUNDING SOURCE(S)	METRICS (FOR MONITORING PROGRAM)
12. EV mechanic training and retraining program *2022-onwards*	• Ensure college programs provide the necessary mechanic/electrician training/ retraining or upgrading • Canadian Colleges for Resilient Recovery	• Led by the Community Climate Advisory Committee • Local colleges and association groups • Auto sector • Canadian Colleges for Resilient Recovery	GHG: Enabler Equity: Depends on subsidies Empl.: Enabler Cost-effectiveness: Enabler	• College / Universities • Canada Homebuilders Association • Trade associations	• Number of trained/ retrained low-carbon transportation mechanics
13. Limit parking in the downtown core and promote EV parking *2022-2025*	• Continue to decrease parking maximums to encourage less parking near downtowns/ eliminate the requirement for parking, and encourage the redevelopment of large parking lots • Set requirements in the Zoning By-Law for EV priority parking with charging stations / differentiated parking fees	• Led by the City of Hamilton	Enabler	• City Budget	Number of EV parking space created

Revolutionizing Renewables

Renewable electricity and renewable natural gas are essential to the City achieving its target of net-zero by 2050. In terms of electricity, either the Provincial electricity grid will have to decarbonize by 2050 or the City will need to increase local sources of renewable electricity. The remaining natural gas supply will need to be replaced with renewable natural gas (one recent study shared by Enbridge suggests this represents 6% of today's natural gas consumption[1]) or green hydrogen (produced by renewable electricity).

Renewable Electricity

⟶Build an electricity grid for the future

To achieve greater resilience and flexibility in the electricity grid the City will coordinate with Alectra, Hydro One, the IESO and the Province to streamline connections for solar PV, electric vehicles, and storage. Strategies can include targeted investments in the grid, streamlined application/permitting, and low-interest financing.

⟶ Land planning that supports solar array installations

The City can establish land planning by-laws that support the development of solar arrays in a manner that maximizes the beneficial uses of lands, for example appropriate rural lands, above parking lots, commercial and industrial buildings, while protecting lands that have other values such as agriculture and natural or cultural heritage value. This would also include completing an analysis of the electrical grid's transmission capacity to support these types of large scale projects.

⟶ Encourage local, alternative RE ownership structures

To maximize local economic benefits the City can support alternative renewable electricity ownership structures, such as cooperatives that maximize community benefits.

⟶ Advocate for a net-zero grid

The City can partner with other municipalities and community organizations to highlight the imperative for a zero-emissions provincial grid. For example, after 26 municipalities advocated for the Province to phase out natural gas by 2030 the IESO is proposing to complete a feasibility study, showing that many municipal voices can lead to action.

Decarbonize + Expand District Energy

The CEEP includes a proposal to decarbonize and expand the downtown district energy system, via renewable natural gas (RNG) as well as industrial waste heat. This project represents a doubling of building space served by district energy as well as many co-benefits, including: local revenue, jobs, and energy cost-savings.

The Hamilton Chamber of Commerce has assessed the feasibility of using industrial waste heat and has identified 11 enabling policies that the City can implement.

Important research on integrated community energy is also being undertaken at McMaster university (e.g., see research by Dr. Cotton), and should be leveraged. the Hamilton Chamber of Commerce (HCC) and Hamilton Community Enterprises (HCE) have signed a Memorandum of Understanding to collaborate on a multi-year initiative to modernize and expand Hamilton's downtown district energy system.

A carbon-cutting priority is to unlock known opportunities to utilize industrial residual heat readily available across Hamilton's Bayfront Industrial Area as an energy source for heating and cooling buildings linked to new and existing thermal networks.

An initial stage in the gated process is to engage specialized third-party consultants to conduct a study. The study would help determine the technical feasibility and commercial viability of one or more community-facing district energy concepts selected in consultation with stakeholders.

Results would help inform whether to proceed with detailed engineering work that could begin as early as 2023.

The vision of decarbonizing space heating by expanding the footprint of Hamilton's district energy system, utilizing industrial waste heat as a low carbon fuel source is seen as a transformational project on the path to net zero.

[1] Torchlight Bioresources, Renewable Natural Gas (Biomethane) Feedstock Potential in Canada (2020), online: www.enbridge.com/~/media/Enb/Documents/Media%20Center/RNG-Canadian-Feedstock-Potential-2020%20(1).pdf?la=en.

Local Biogas + RNG

Organic matter decomposition produces methane, a potent greenhouse gas. If captured, this gas can become a local source of energy and a sustainable alternative to natural gas. The City already has experience in biogas upgrading and renewable natural gas through projects at the Woodward Avenue Water Treatment Plant and the Glanbrook Landfill. The City can build on this success and experience to expand its biogas and RNG capacity.

⟶ Organic diversion + AD

In order to reach net-zero, as much organic waste as possible should be diverted from the landfill and used as feedstock for anaerobic digester (AD) systems, ideally a centralized system for multiple organic waste streams (to achieve economies of scale).

AD systems produce biogas that can be used onsite or refined into renewable natural gas and used locally (e.g. in buses, dump trucks, district energy systems), or injected into the natural gas system as a source of City revenue.

Table 8. Actions, partners, and resources required for renewable energy implementation.

ACTION + TIMELINE	ACTION DETAILS + RESOURCES REQUIRED	KEY PARTNERS	GHG REDUCTIONS BY 2050 & CO-BENEFITS	PRIMARY FUNDING SOURCE(S)	METRICS (FOR MONITORING PROGRAM)
Renewable Energy: Solar and Wind					
14. Develop a next generation electrical grid *2022- onwards*	• Coordinate a working group with Alectra, Hydro One, IESO, the Province, post-secondary institutions. • City Staff Participation in working group.	• Led by the City of Hamilton • City Council • Alectra + Hydro One • IESO • Provincial government • Post-secondary institutions	Enabler	Utilities FCM	• Long-term electricity plan aligned with a net-zero future and significant local electrification (e.g., the LRT, commercial and personal EVs, increased solar PV, fuel switching from natural gas furnaces to electric heat pumps, etc.) • A simple and easy program for new connections to the electricity grid for solar PV and EV charging stations. • Investment by Alectra, Hydro One, IESO, and/or the Province

ACTION + TIMELINE	ACTION DETAILS + RESOURCES REQUIRED	KEY PARTNERS	GHG REDUCTIONS BY 2050 & CO-BENEFITS	PRIMARY FUNDING SOURCE(S)	METRICS (FOR MONITORING PROGRAM)
15. Encourage development of local renewable energy cooperatives *2022-onwards*	• Including additional points in local renewable energy development RFPs for local renewable energy cooperatives • Setting up workshops featuring renewable energy cooperatives from other Ontario cities (e.g., Toronto and Ottawa) • Supporting the establishment of renewable energy cooperatives throughout the City	• Led by the City of Hamilton • Local nonprofits committed to renewable energy • Renewable energy cooperatives from other municipalities	Enabler	n/a	• Establishment of cooperatives • MW installed by cooperatives • Annual return on investment for cooperatives
16. Implement strategic renewable solar energy installations *2022-2025*	• Develop criteria for strategic solar development sites (in partnership with local utilities and renewable energy developers) and identify lands that meet these criteria • Focus on strategic sites (e.g., sites where land can be used for more than one purpose) • RFPs for these strategic sites	• Led by the City of Hamilton • Alectra + Hydro One • IESO • Developers • Canada Renewable Energy Association • Hamilton Chamber of Commerce	GHG: Medium Equity: Low Emp.: High Cost-effectiveness: High	• Community bond program • Utility companies • Infrastructure Canada • Renewable Energy Developers	• MW of RE capacity installed • kWh of RE supplied

ACTION + TIMELINE	ACTION DETAILS + RESOURCES REQUIRED	KEY PARTNERS	GHG REDUCTIONS BY 2050 & CO-BENEFITS	PRIMARY FUNDING SOURCE(S)	METRICS (FOR MONITORING PROGRAM)
Renewable Energy: Biomass and Green Hydrogen					
17. Technical feasibility study of expanded anaerobic digestion facilities *2023-2025*	• Technical analysis: amount of wet organic waste supply in the City (building on work undertaken through the Renewable Energy From Organics Study) • Centralized site for digester	• Led by the City of Hamilton • Ontario Clean Water Association • City (incl. Glanbrook Landfill) • Enbridge • Private waste collection and disposal companies	GHG: Low - Medium Equity: Enabler Emp.: TBD Cost-effectiveness: TBD	• FCM • City • Enbridge	• Completion of feasibility study
18. Technical analysis of green hydrogen potential, costs, as well as actions to increase green hydrogen deployment in the City through the creation of a "hydrogen hub" *2024-2025*	• Potential technical consultant • Community Climate Advisory Committee • City and or utility staff time	• Led by the Community Climate Advisory Committee • Local utilities • City • Clean Tech Accelerator	GHG: High Equity: TBD Emp.: TBD Cost-effectiveness: TBD	• Local utilities • City • Industrial partners • NRCan • FCM	• Evaluation of a pilot project and strategy (e.g., cost-effectiveness, efficiency)

ACTION + TIMELINE	ACTION DETAILS + RESOURCES REQUIRED	KEY PARTNERS	GHG REDUCTIONS BY 2050 & CO-BENEFITS	PRIMARY FUNDING SOURCE(S)	METRICS (FOR MONITORING PROGRAM)
Decarbonize and Expand Downtown District Energy System					
19. Decarbonize and expand HCE downtown district energy system *2023-2025*	• Existing CHP facility • Support ongoing work being undertaken by the Chamber of Commerce and Hamilton Community Enterprises related to modernizing and expanding the downtown district energy system	• Led by the City of Hamilton • Hamilton Community Enterprises • Hamilton Chamber of Commerce • Local utilities • Industry (potentially via HIEA) • City	GHG: Medium Equity: Enabler Emp.: High Cost-effectiveness: Low	• City • Hamilton Community Enterprises • Hamilton Chamber of Commerce • Industrial partners • Utilities • FCM • Provincial &/ or federal government	• GJ of residual heat • GJ of RNG • $tC0_2e$ avoided
Organics Diversion + Anaerobic Digestion					
20. Technical + financial analysis for expanded organics collection and diversion *2022-onwards*	• City staff time (potential for consultant support)	• Led by the City of Hamilton • Waste management companies	GHG: Medium Equity: Enabler Emp.: High Cost-effectiveness: TBD	• City	• Tonnes of organics diverted from landfill

Growing Green

Aligning Planning Policy

Land-use patterns can either enable people to adopt low carbon behaviours such as walking or cycling, or limit their ability to adopt such behaviours. In December 2021, Hamilton City Council adopted a 'no urban boundary expansion' pattern for future growth to 2051. While the final approval of Council's decision has yet to be received from the Provincial government, the City is already on its way to strengthening its land use planning policy framework to support the significant increase in intensification development required to accommodate projected growth.

In addition to evaluating the GHG impact of intensification targets, the City can also require the integration of community energy/climate action policy directions into secondary plans. For new greenfield areas added to the City's boundary in the future, community energy systems could also be considered as part of a separate component of planning. Considerations such as design for passive heating and cooling, shadow studies for solar PV, embodied carbon in materials, dwelling size, connectivity of roads, proximity to and mix of destinations and others can be addressed at the level of the secondary plan.

Many of the factors which facilitate active transportation and reduced GHG emissions also contribute to equity outcomes, by reducing household "operational" costs such as transportation costs and utility bills, and therefore increasing affordability.

Carbon Sequestration

Increased sequestration from tree planting results in a relatively small reduction in GHG emissions but trees offer many co-benefits including reduced air pollution, improved wellbeing and enhanced ecological services such as water runoff management, amongst others. An ambitious tree planting program would build on existing City efforts, including the draft Urban Forest Strategy, as well as the efforts of the various conservation authorities and community organizations.

Improved agricultural soil management practices is another opportunity for carbon sequestration which can be examined in future CEEP updates.

Table 9. Actions, partners, and resources required for land use and carbon sequestration implementation.

ACTION + TIMELINE	RESOURCES REQUIRED	KEY PARTNERS	GHG REDUCTIONS BY 2050 & CO-BENEFITS	PRIMARY FUNDING SOURCE(S)	METRICS (FOR MONITORING PROGRAM)
Equitable, smart, and compact communities					
21. Review + update Official Plan to address climate change and energy policies (incl. enabling renewable energy policies, and other enabling policies for retrofits, new construction, etc) *2022 - onwards*	• Dedicated staff time	• Led by the City of Hamilton • City • Land developers • Renewable energy companies	Enabler	• City	• Completion of an Official Plan review and update to apply a robust climate lens. • % of new dwelling units within walking access (to be defined based on local transportation planning expertise) to transit, active transportation routes, green space.

ACTION + TIMELINE	RESOURCES REQUIRED	KEY PARTNERS	GHG REDUCTIONS BY 2050 & CO-BENEFITS	PRIMARY FUNDING SOURCE(S)	METRICS (FOR MONITORING PROGRAM)
22. Integrate community energy/climate action policy directions into secondary plans *2022 - onwards*	• Dedicated staff time	• Led by the City of Hamilton	Enabler	• City	• Completion of Official Plan review related to secondary plan requirements • Number of secondary plans integrating energy/climate action policy direction
Tree Planting					
23. Set community-wide tree planting target of 50,000 trees per year and expand existing tree planting programs *2022 - onwards*	• Implement the recommendations of the Urban Forest Strategy • A 5-year tree planting work plan • Establish robust database and tracking mechanisms for both corporately- owned and privately-owned trees • Partner with various external governmental and community organizations on tree planting initiatives	• Led by the City of Hamilton • Conservation Authorities • Temporary workforce • Community Organizations	GHG: High Equity: High potential Emp.: High Cost-effectiveness: Low	• City, province, or federal governments • Community Organizations • Land Developers • Conservation Authorities	• Number of trees planted

APPENDIX D: Base Year and Business-As-Planned 2016-2050 Energy and Emissions Report

December 2020

Contents

Glossary

Baseline Year: the starting year for energy or emissions projections.

Business-as-planned (BAP): a scenario illustrating energy use and greenhouse gas emissions which aims to reflect current and planned policies and actions that are likely to be implemented.

Carbon dioxide equivalent (CO_2e): a measure for describing the global warming potential of a greenhouse gas using the equivalent amount or concentration of carbon dioxide (CO_2) as a reference. CO_2e is commonly expressed as million metric tonnes of carbon dioxide equivalent ($MtCO_2e$).

Cooling degree days (CDD): the number of degrees that a day's average temperature is above 18°C, requiring cooling.

District energy: Energy generation within the municipal boundary that serves more than one building.

Emissions: In this report, the term 'emissions' refers exclusively to greenhouse gas emissions, measured in metric tonnes (tCO_2e), unless otherwise indicated.

Electric vehicles (EVs): an umbrella term describing a variety of vehicle types that use electricity as their primary fuel source for propulsion or as a means to improve the efficiency of a conventional internal combustion engine.

Greenhouse gases (GHG): gases that trap heat in the atmosphere by absorbing and emitting solar radiation, causing a greenhouse effect that unnaturally warms the atmosphere. The main GHGs are water vapor, carbon dioxide, methane, nitrous oxide, and ozone.

Heating Degrees Days (HDD): number of degrees that a day's average temperature is below 18°C, requiring heating.

Local electricity: Electricity produced within the municipal boundary and sold to the electricity system operator or used behind the meter.

Renewable Natural Gas (RNG): Biogas resulting from the decomposition of organic matter under anaerobic conditions that has been upgraded for use in place of fossil natural gas.

Sankey: a diagram illustrating the flow of energy through a system, from its initial sources to points of consumption.

Vehicle kilometres travelled (VKT): distance traveled by vehicles within a defined region over a specified time period.

GHG emissions

1 $mtCO_2$ = 1,000,000 tCO_2e

1 $ktCO_2e$ = 1,000 tCO_2e

1 tCO_2e = 1,000 $kgCO_2e$

1 $kgCO_2e$ = 1,000 gCO_2e

Energy

1 PJ = 1,000,000,000 J

1 GJ = 1,000,000 J

1 MJ = 0.001 GJ

1 TJ = 1,000 GJ

1 PJ = 1,000,000 GJ

Units of Measurement:

To compare fuels on an equivalent basis, all energy is reported primarily as petajoules (PJ) or sometimes as gigajoules (GJ) (a PJ is a million GJ). Greenhouse gas emissions are primarily characterized as Kilotonnes or megatonnes of carbon dioxide equivalents ($ktCO_2e$ or $MtCO_2e$) (a Mt is a thousand kt).

- An average house uses about 100GJ of energy in a year
- 100 liters of gasoline produces about 3.5 GJ
- A kilowatt-hour is .0036 GJ
- A terawatt-hour is 3.6 PJ
- Burning 50,000 tonnes of wood produces 1 PJ
- A typical passenger vehicle emits about 4.7 metric tons of carbon dioxide per year.*

*Data provided by United States Environmental Protection Agency

Introduction

In 2019, Hamilton City Council declared a Climate Change Emergency with a target to have net-zero carbon emissions by 2050. The Community Energy and Emissions Plan is a critical part of the City's emergency response—it sets the path for getting to net-zero by 2050.

To support and inform the development of the plan, SSG and whatIf? Technologies have been contracted by the City of Hamilton to undertake energy and emissions modelling. This modelling has 2 stages:

1. The baseline and business-as-planned (BAP) scenario

   A spatial energy use and greenhouse gas (GHG) emissions baseline (2016) profile for the City of Hamilton and the reference (or business-as-planned) projection for the community out to 2050.

2. The low-carbon scenario

   A spatial energy and emissions reduction model that examines the impact of implementing low-carbon actions to reduce energy consumption and emissions in the city, including through improved efficiencies, local energy generation and fuel switching.

This report summarizes the technical modelling results for the first stage: Baseline and BAP. The BAP scenario aims to reflect current and planned policies and actions that are likely to be implemented.

The energy and emissions baseline and BAP scenario were developed using CityInSight; this tool will also be used in the second stage of modelling.

The GHG accounting framework in CityInSight applies the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC Protocol). The geographic boundary of Hamilton is the inventory boundary. The model's scope is outlined in Appendix 2.

The remainder of this report is divided into three parts:

1. **BAP Energy and Emissions, 2016-2050,** includes the results and analysis of the baseline energy use and GHG emissions inventory for the year 2016 and the business-as-planned (BAP) scenario to the year 2050. (All energy use and emissions are described on a per year basis unless specified otherwise.)
2. **The Data, Methods and Assumptions Manual** outlines the CityInSight modelling methodology and the key assumptions driving the energy use and GHG emissions in the BAP scenario.
3. **Appendices** include all the relevant energy use and emissions data tables referred to throughout the report, a list of detailed assumptions applied in the BAP, and a table outlining the scope emissions captured in the model.

MAIN FINDINGS

Based on a series of assumptions regarding existing plans and policies that are likely to be in place through to 2050 ('business-as-planned' or BAP scenario), overall GHG emissions for the city are projected to increase by 10%.[1] However, on a per person basis, energy use and GHG emissions will decline by 28%, as Hamilton's population is projected to increase by 53% over the period.

In a BAP scenario Hamilton's 2050 GHG emissions will be far from its net-zero GHG emission target. If the total GHG emissions are divided by the projected population in 2050, each Hamiltonian will represent the equivalent of 11.2 tonnes of GHGs. As a whole, the City will emit 9.6 Mt CO_2e, up from 8.7 Mt CO_2e in 2016.

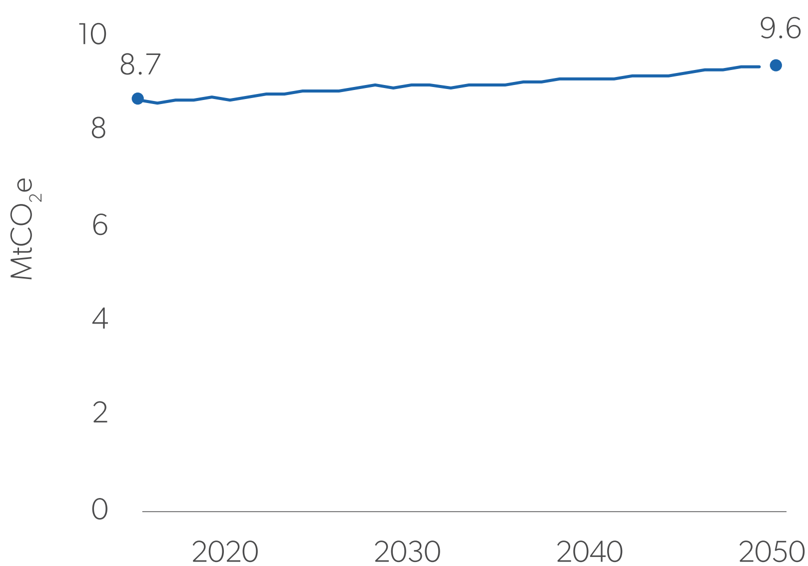


Figure 1. GHG emissions in Hamilton, 2016-2050.

[1] A comprehensive Table of BAP Assumptions is provided in Appendix 2.

By examining the city's energy use and GHG emissions in 2016 and then analyzing trends through to 2050 in the BAP scenario, it is possible to gain some insights about what is driving the city's energy use and GHG emissions. This modelling and analysis provides a basis upon which the community can develop the policies and programs needed to work towards net zero.

As with most jurisdictions, energy use is the main driver of the city's emissions, representing 98% of total GHG emissions. The remaining fraction is generated by organic waste, animal husbandry and fugitive emissions (i.e. methane leaks from the natural gas distribution system).

What is unique about Hamilton's energy profile is the percentage of that energy which is used to power the industry (primarily steel): 60%. In terms of energy use, transportation is a distant second at 17%, followed by homes (13%) and then by the commercial sector (10%).

Analysis of the city's carbon sequestration was also undertaken and it was found that a projected 314 ktCO_2e will be sequestered in 2050, mostly through urban and rural trees.

The major factors driving changes in energy use and GHG emissions in Hamilton through to 2050 in the BAP include:

- the city's projected population and employment growth;
- growth in Hamilton's fossil fuel-intensive industrial sector;
- An expected increase in electric vehicle ownership paired with increased vehicle fuel efficiency standards;
- A decrease in heating degree days due to a generally warming climate; and
- A marginal increase in fossil fuel use in the provincial electricity grid towards 2050.

Part I: BAP Energy and Emissions, 2016-2050

Demographics

POPULATION, HOUSEHOLDS, VEHICLES, AND EMPLOYMENT

Population and employment underlie many aspects of the modelling, including building and transportation needs, as well as waste production.

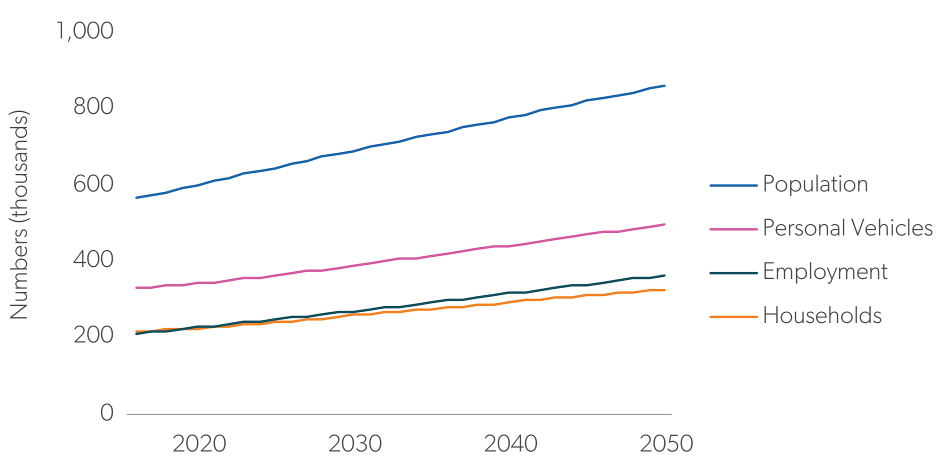


Figure 2. Projected population, personal vehicles, households, and employment 2016-2050.

A 53% population increase through to 2050 is projected in the BAP scenario, increasing from 561,918 in 2016 to 857,932 in 2050. This population growth is based on the City's projections (see Appendix 2) and a linear extrapolation of the City's projected population from 2041 to 2050 as population projection data out to 2050 was not available at the time of modeling.

This population growth is expected to result in a similar increase in households and personal vehicles (see Figure 2).

The City foresees a higher rate of employment growth, a 74% increase from 207,273 in 2016 to 361,502 in 2050. This drives increased commercial and industrial energy and emissions in the city.

Understanding how people and jobs are distributed within the city helps evaluate potential actions to decrease related emissions from transportation and buildings. For example, through land planning policies, transit, or local renewable energy generation.

The City has projected where these homes and jobs will be in space (by traffic zone) out to 2031, with draft estimates for 2041. This BAP model extends those trends out to 2050.

Figure 3 shows population density (people/hectare) by zone in 2016. Population density is clearly concentrated in the downtown and its surroundings.

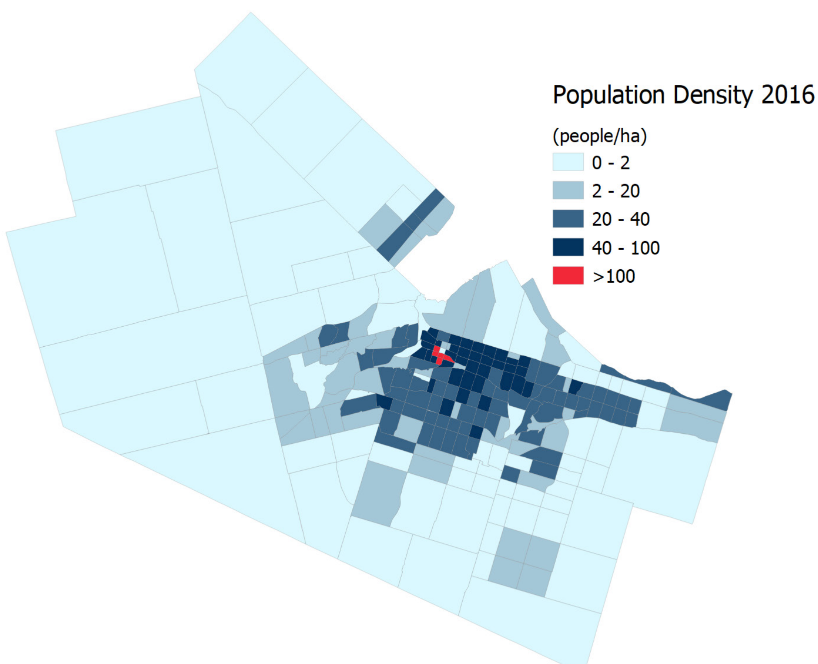


Figure 3. Population density in Hamilton in 2016, by traffic zone.

The increase in population density by 2050 is mapped in Figure 4. New population is projected to concentrate downtown, in strategic growth areas such as nodes and corridors, and as general intensification throughout the urban area. Additional growth at the periphery of the existing urban boundary may also occur, coinciding with potential future expansions of the urban boundary, and designated growth areas.

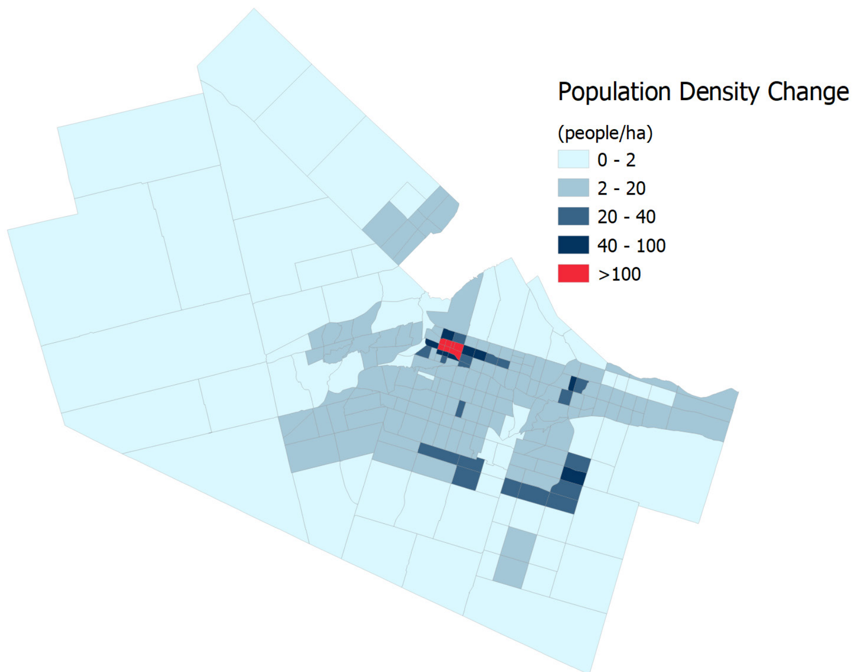


Figure 4. Population density change between 2016 and 2050 in Hamilton, by traffic zone.

In general, employment density (jobs/hectare) is located near the zones where the population is settled and this structure is mostly maintained as employment grows out until 2050 (see Figures 5 and 6). The downtown core is expected to see the largest job increases.

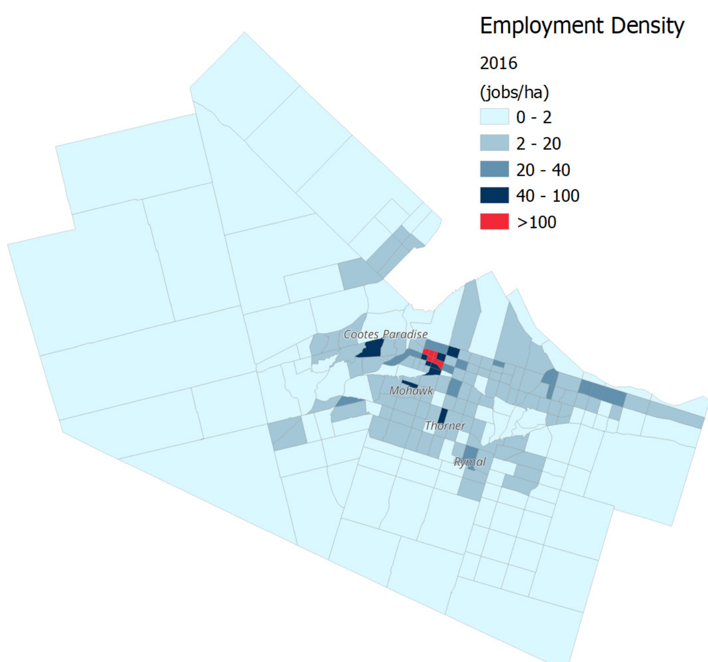


Figure 5. Employment density in Hamilton in 2016, by traffic zone. Cootes Paradise, Mohawk, Thorner, and Rymal neighborhoods are highlighted as employment hubs outside the downtown core.

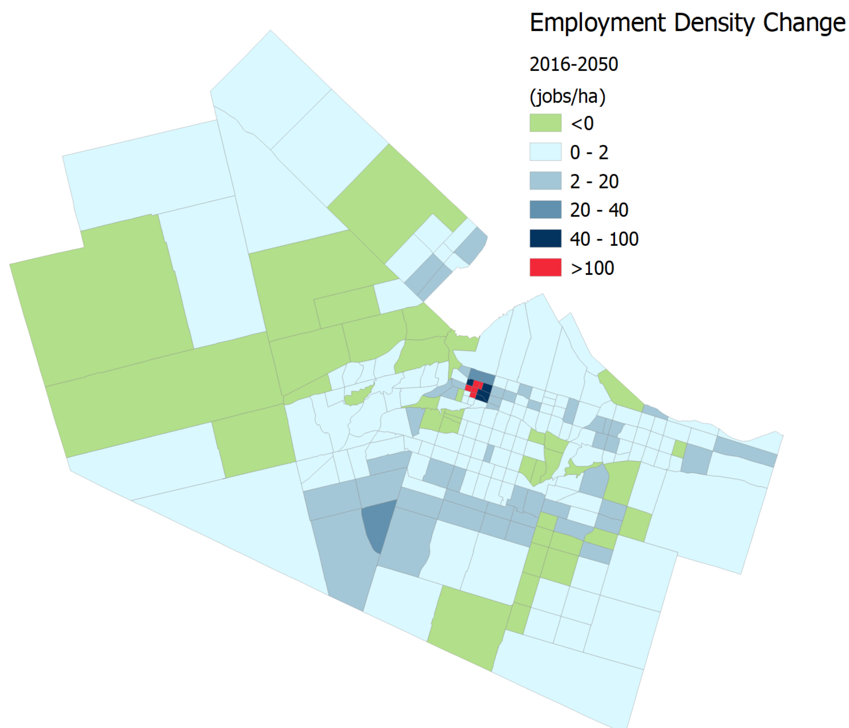


Figure 6. Employment density change in Hamilton, 2016-2050, by traffic zone. (Note: The maximum employment decrease projected for a zone does not exceed -0.32 jobs/ha).

Community Energy

ENERGY BY SECTOR

Community energy consumption for Hamilton is projected to increase by 9% in 2050, from 137 PJ in 2016 to 149 PJ.

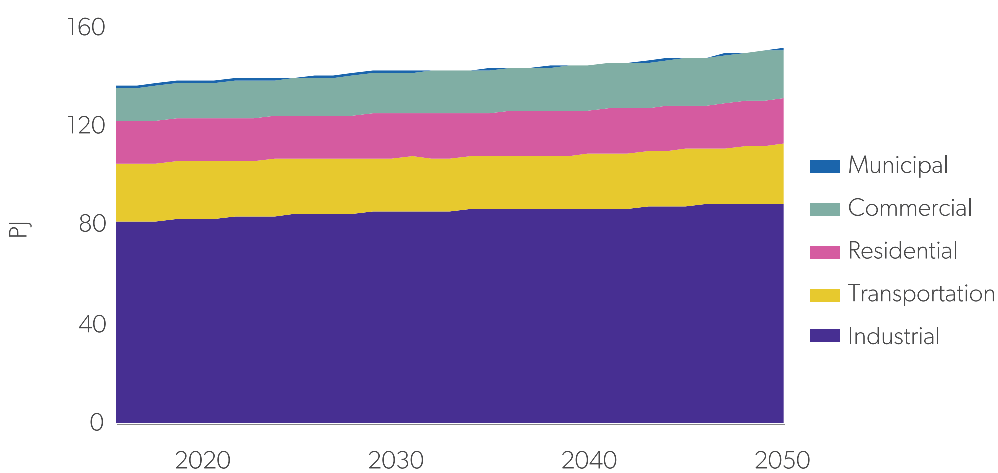


Figure 7. Projected BAP energy consumption (PJ) by sector, 2016-2050.

The majority of the increase in energy consumption is associated with the industrial sector, which is projected to increase from 82 PJ to 89 PJ. The next largest increase is in the commercial sector, which grows from 13 PJ to 19 PJ. Finally, the transportation sector is projected to increase from 23 PJ to 24 PJ (2%).

On the other hand, the residential sector energy consumption is expected to decrease from 17.7 PJ to 17.2 PJ in 2050 (-3%).

Buildings, industry and transportation sector energy use will each be examined in more detail below.

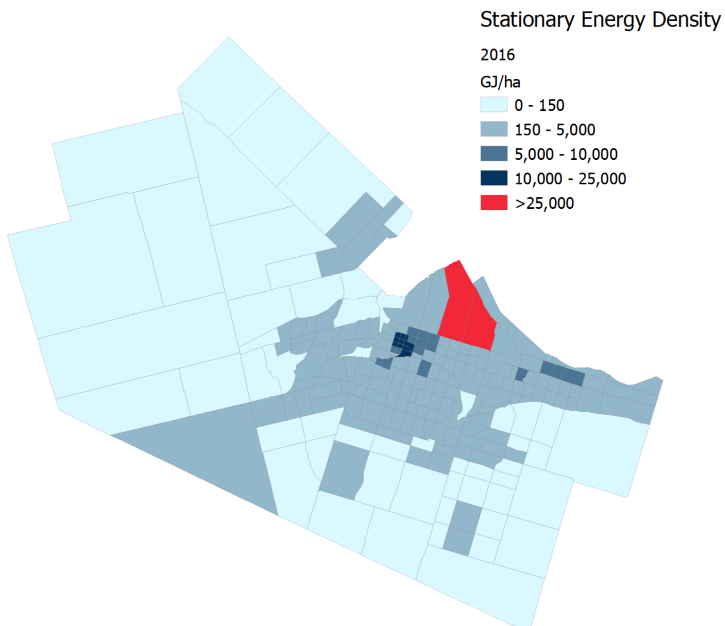


Figure 8. Stationary energy density in Hamilton (GJ/ha) in 2016, by traffic zone.

Geographically, energy density (TJ/ha) is concentrated in the industrial neighborhoods, and also around the downtown area and into the south-west (see Figure 8). Energy density is a critical factor for the economic feasibility of district energy systems, which can be powered renewably and produce local economic benefits. In the BAP, energy density patterns are projected to remain similar, with some increases in the downtown area, as seen in Figure 9.

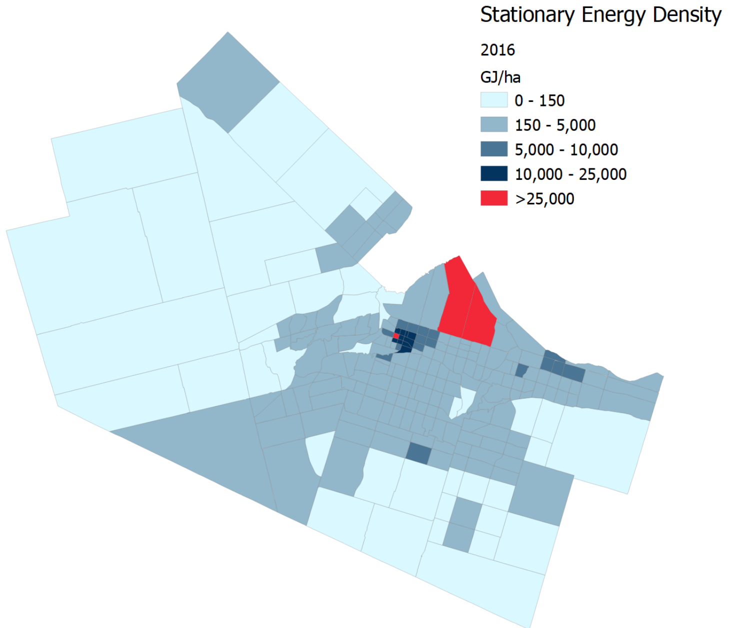


Figure 9. Energy density in Hamilton (TJ/ha) in 2050, by traffic zone.

Generally, population and employment growth drive energy use increases, offset by energy efficiency gains.

ENERGY BY FUEL

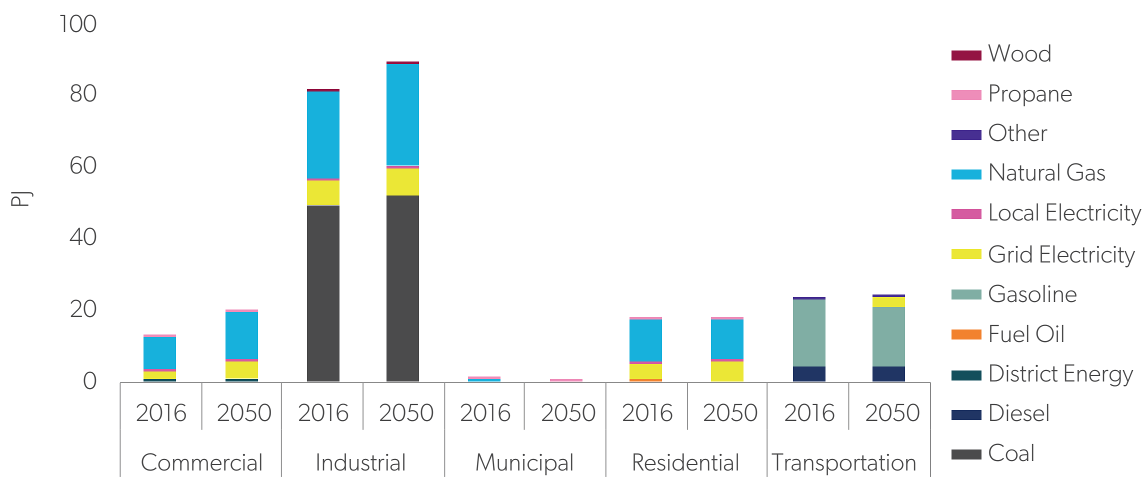


Figure 10. Projected BAP energy consumption (PJ) by sector and fuel, 2016-2050.[2]

The significant coal use seen in Figure 10 (49 PJ in 2016, up 6% to 52 PJ in 2050) is primarily due to Hamilton's steel sector; coal use increases in parallel with the projected growth in the industrial sector.

[2] 'Other' includes geothermal, waste-heat, petroleum-coke, water storage, uranium, ethanol, biodiesel, renewable diesel, cold water, non-energy.

The largest increase in fuel use (41%) is seen with electricity, across all sectors. Its use is projected to increase from 15 PJ to 21 PJ. This growth is driven not only by population and employment growth, but also by the expected shift to electric vehicles, and the increased cooling demands of a warming climate. Natural gas use is expected to grow at a slower rate (12% from 47 PJ to 53 PJ), partly due to declining heating demands.

Gasoline reductions (19 PJ to 17 PJ) reflect the improved efficiency in the transportation sector described above.

Per Capita Energy Use

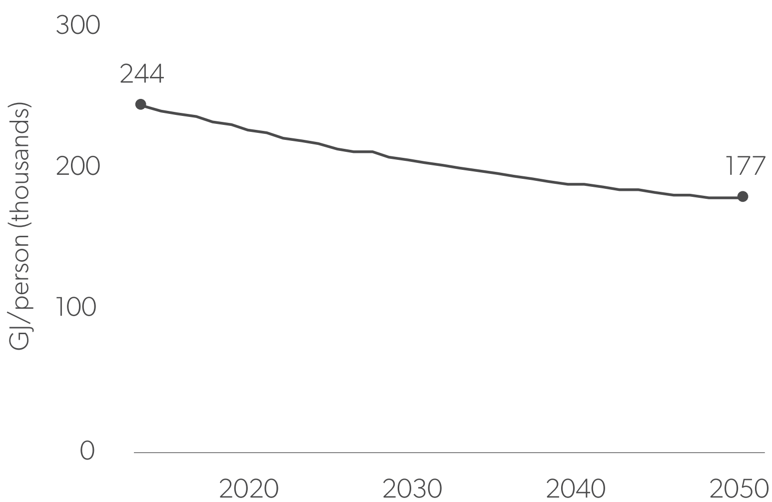


Figure 11. Projected BAP energy per capita (TJ/person), 2016 and 2050.

Per capita, each resident of Hamilton is projected to use 28% less energy in 2050. Energy use will fall from 244.2 GJ/person in 2016 to 175.3 GJ/person in 2050.

Refer to Table 1 in the Appendix for tabulated results of energy by sector and fuel.

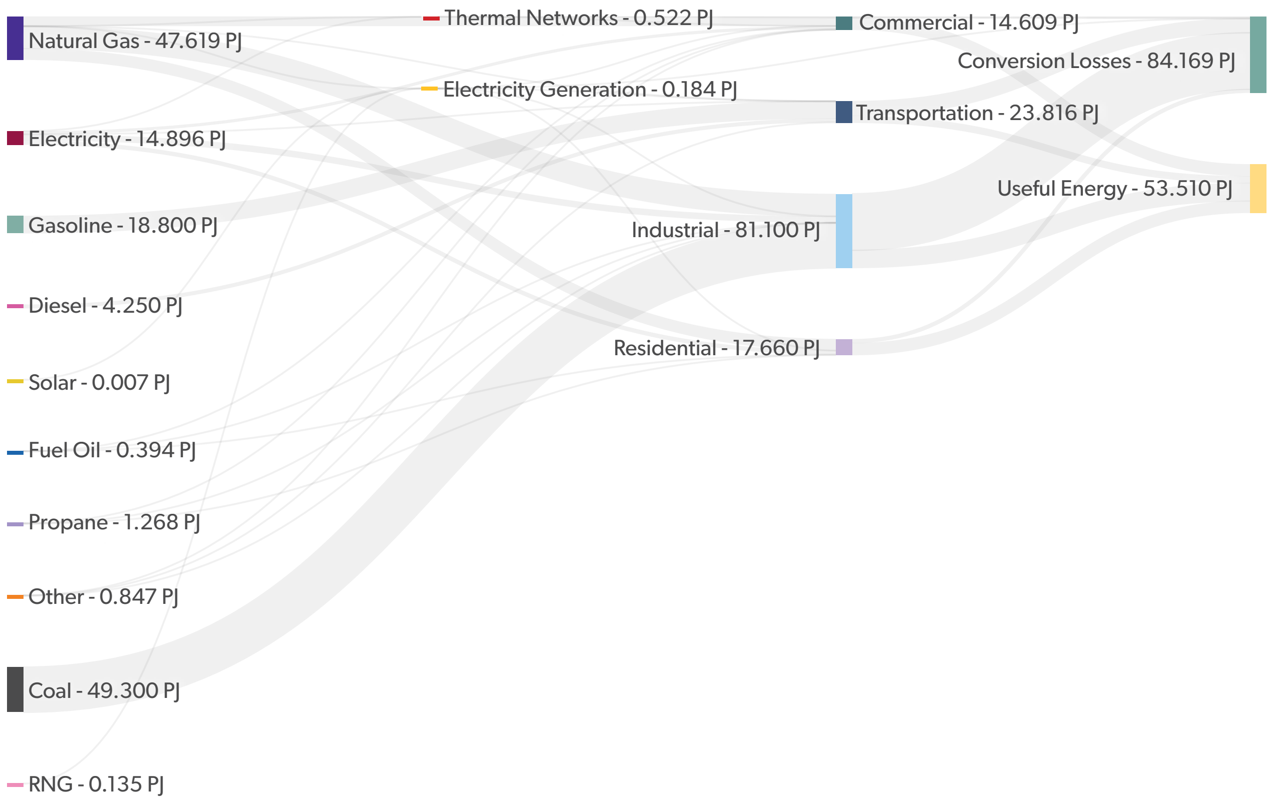


Figure 12. 2016 energy flows and conversions for the city.

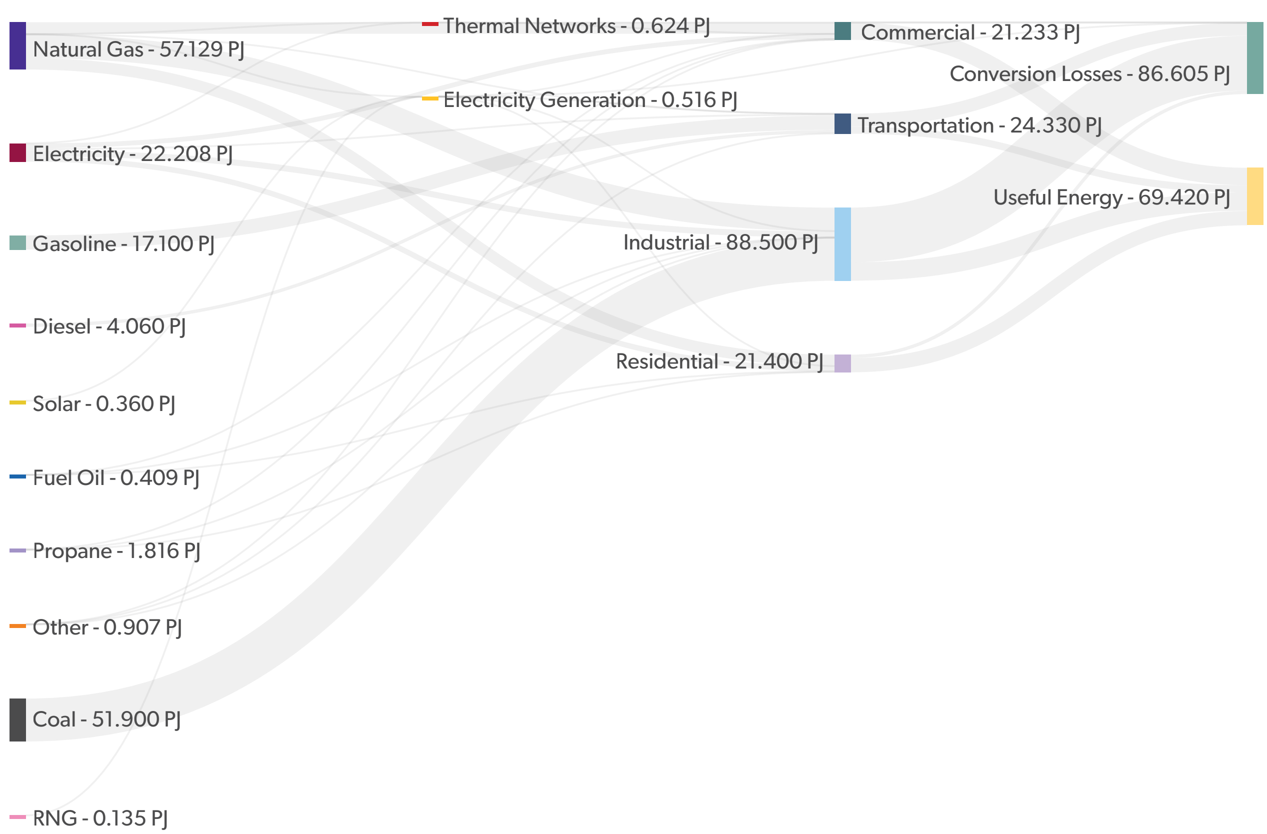


Figure 13. 2050 energy flows and conversions for the city.

ENERGY FLOW AND CONVERSION

Sankey diagrams are particularly useful at identifying opportunities for improved efficiency, as they clearly identify energy waste (i.e. conversion losses). The Sankey diagrams shown in Figures 12 and 13 depict the energy flow by fuel and sector through Hamilton in 2016, and in the 2050 BAP scenario.

In 2016, the conversion losses represented 61%, driven mostly by industrial processes that generate waste heat, and then by inefficient internal combustion engine vehicles and older, inefficient housing stock.

This percentage slightly decreases through to 2050 in the BAP, to 57%. This is due to increased electrification of buildings and transportation. This improved efficiency occurs despite the growth of highly inefficient fossil fuel combustion in the industrial sector.

Local Energy Production

In 2016, Hamilton produced just over 0.221 PJ of local energy (i.e. energy produced within city boundaries, whether in district energy systems or single building installations). This represents less than one percent of local energy demand.

Combined heat and power is treated as local energy generation, despite the fact that it is often fueled by the central power grid and natural gas distribution system. This explains how in 2016, 58% of local energy was generated by natural gas and 12% was generated from electricity procured from provincial distribution systems.

In 2016, almost a third of local energy was generated from renewable sources, primarily methane captured at the landfill and wastewater treatment plant (28%) and a small fraction from solar installations (2%).

In the BAP scenario, local energy generation is expected to increase to 0.689 PJ, driven solely by projected growth of solar installations, which end up representing almost 50% of local energy production. Notwithstanding this increase, in 2050 local energy still represents less than 1% of Hamilton's energy use.

Community Emissions

EMISSIONS BY SECTOR AND BY FUEL

Hamilton's greenhouse gas emissions are projected to increase 10% from 8.7 $MtCO_2e$ in 2016 to 9.6 $MtCO_2e$ in 2050.

The largest increase in emissions, 547 $ktCO_2e$ by 2050 (i.e. the difference between annual emissions in 2016 and the projected annual emissions in 2050), is seen in Hamilton's industrial sector. The commercial sector is also projected to have a large increase in emissions, 315 $ktCO_2e$ more in 2050 than in 2016. Projected employment growth drives increased emissions in both sectors, the larger industrial sector increase is due to its dependence on carbon-intensive coal.

The transportation sector is projected to see a decrease in emissions of 70 $ktCO_2e$ through 2050. This results from fuel efficiency standards and expected incremental uptake of electric vehicles. Nonetheless, the sector remains Hamilton's second largest source of GHGs at 1.6 Mt CO_2e in 2050.

The residential sector sees its overall GHG emissions increased through to 2050 by 70 $ktCO_2e$ compared to 2016 (a 10% increase), despite 53% population growth. In the commercial sector, efficiency improvements and reduced need for space heating do little to offset projected growth.

The above-noted trends are assessed in more detail in the Buildings, Industry and Transportation sections below.

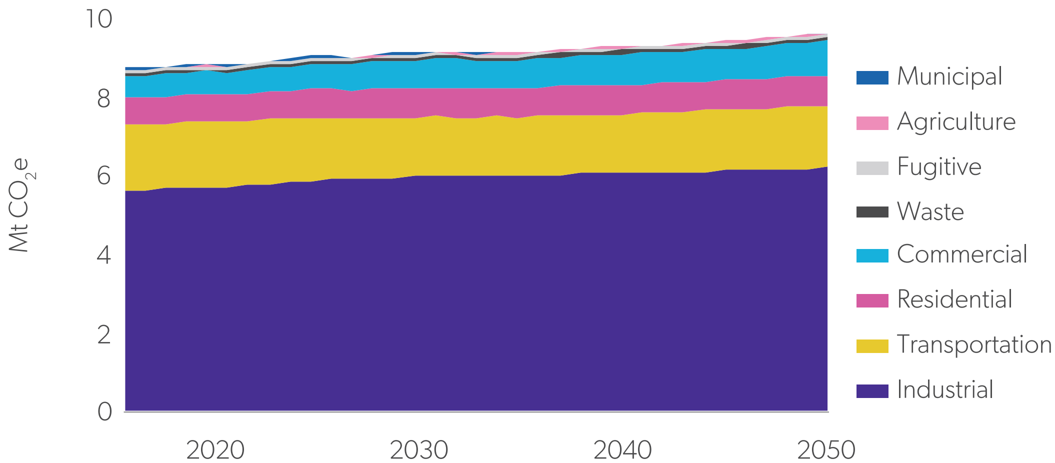


Figure 14. Projected BAP emissions (Mt CO_2e) by sector, 2016-2050

Of the city's fuel use, grid electricity sees the largest GHG emissions increase, from 156 $ktCO_2e$/year in 2016 to 514 $ktCO_2e$/year in 2050. The electricity grid is expected to be more carbon intensive in 2050, and electricity use increases, for cooling and electric vehicles.

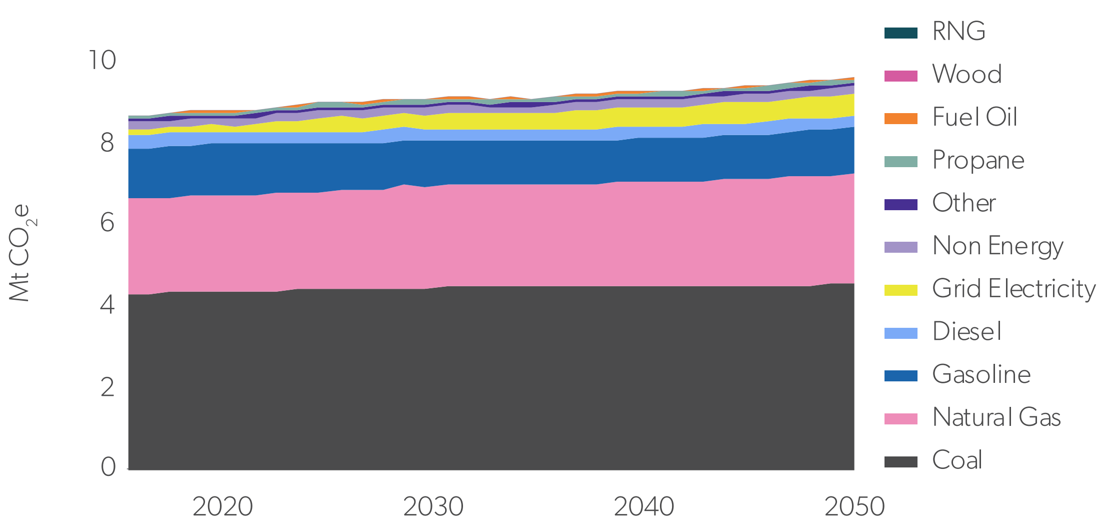


Figure 15. Projected BAP emissions ($ktCO_2e$) by fuel type, 2016-2050.

PER CAPITA EMISSIONS

Per capita emissions are projected to decrease 28% from 15.5 tCO_2e/person per year in 2016 to 11.2 tCO_2e/person in 2050.

Per capita GHG emissions vary widely from municipality to municipality. In 2016 Sudbury's per capita emissions were 7.4 tCO_2e per year, Saskatoon's were 12 tCO_2e, Thunder Bay's emissions were 11 tCO_2e/person, and Edmonton's were 19.6 tCO_2e/person. Edmonton and Sakatoon's per capita emissions are so high in large part due to their electricity system's reliance on coal. Thunder Bay's are high, despite the relatively clean Ontario electricity grid, because of the pulp and paper industry. Hamilton was on the higher side of this spectrum due to the steel manufacturing in the city, which is one of Canada's most carbon-intensive industries.

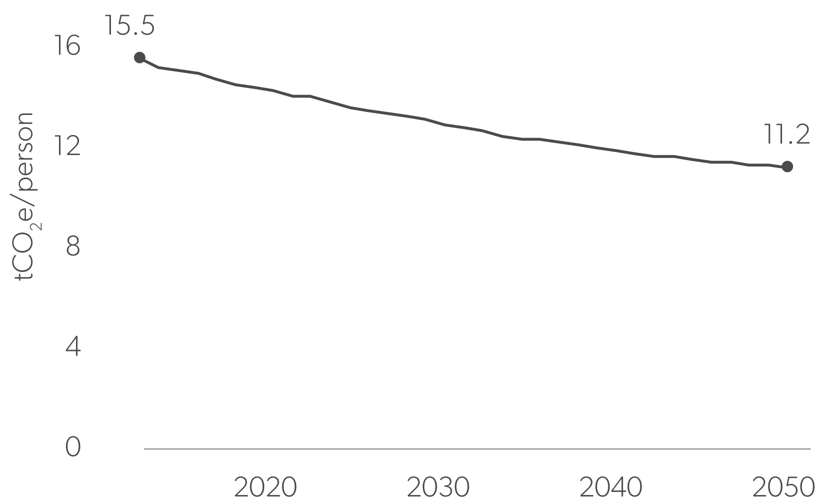


Figure 16. Projected BAP emissions per capita (tCO_2e/person), 2016-2050.

Refer to Appendix 1 for tabulated results of emissions by sector and fuel.

COMMUNITY EMISSIONS BY ZONE, 2050

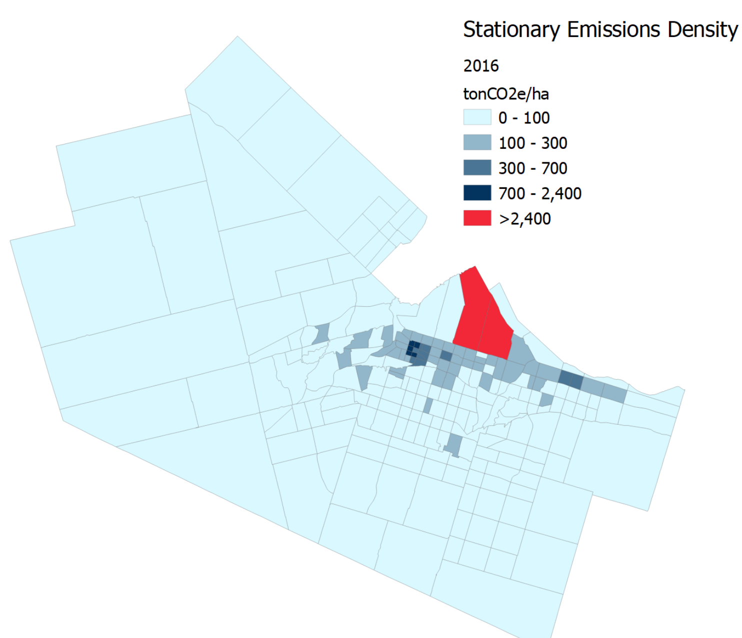


Figure 17. Stationary GHG emissions per hectare, by traffic zone, Hamilton 2016.

Figures 17 and 18 illustrate how GHG emissions from stationary energy consumption vary across Hamilton's traffic zones in 2016 and in 2050. Here stationary energy consumption includes buildings, industry, and energy generation, as well as waste and fugitive sources.[3]

Similar to the community energy map, these maps highlight how GHG emissions in the inner areas differ greatly from the city's outer and rural areas. Emission levels in inner areas reflect mixed-uses and the large industrial emitters, while outer areas mostly reflect residential emissions. GHG emissions are larger in the inner areas reaching more than 700 tCO_2e per hectare in some zones (see Figure 17).

In contrast, emissions are lower in the outer areas, relative to the rest of the city, due to lower density and newer housing stock that is more energy efficient. This distribution is likely to continue through 2050 with only minor changes in some zones.

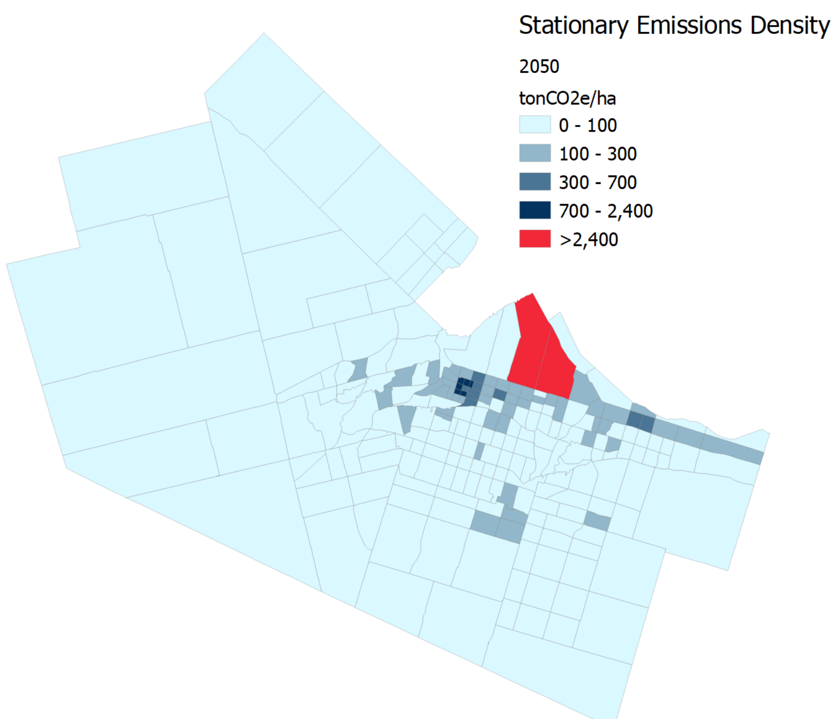


Figure 18. Stationary GHG emissions per hectare, by traffic zone, Hamilton 2050.

Buildings

BUILDING ENERGY USE

Hamilton's buildings consumed 23% of the city's energy in 2016, accounting for 32 PJ (shown in purple in Figure 19). This energy use is split between the residential, municipal and commercial sectors, with a higher energy profile for residential buildings.

[3] Waste and fugitive sources are only displayed on GHG emissions maps, not on energy maps, for an example, see Figure 8.

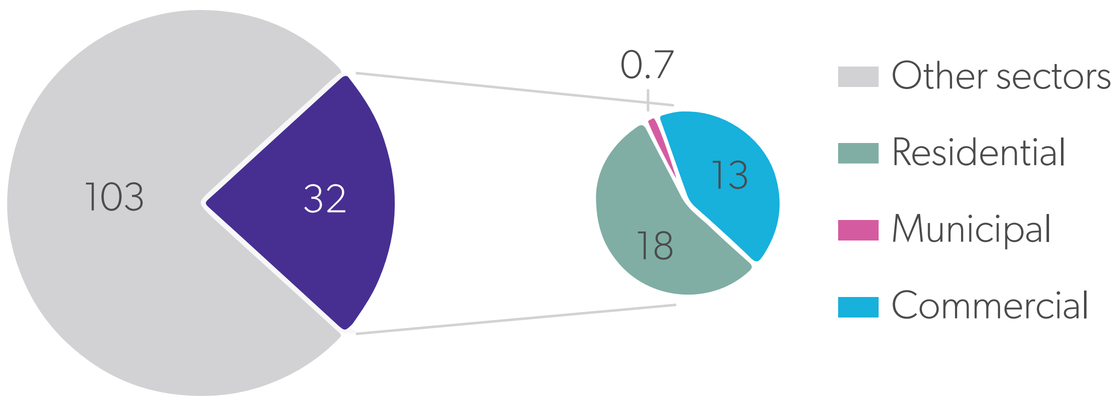


Figure 19. Overall city energy consumption in PJ in 2016. The purple portion represents building sector energy use.

Through 2050 in the BAP scenario, building energy use is projected to increase by 11%, to 36.6 PJ (see Figure 20). The main driver of this growth is commercial buildings, which are projected to increase their annual energy use by 42% in 2050 as compared to 2016. In contrast, energy consumption decreases by 3% in the residential sector.

Most notably, the municipal sector sees building energy use decrease by 53%. This projection is based on the City's Corporate Energy Plan, and is indicative of the scale of energy efficiency potential in Hamilton's broader building stock. This potential will be further explored in the Low-Carbon modelling scenario.

All buildings are projected to become more energy efficient, as older buildings undergo incremental retrofits and new buildings are subject to more stringent energy efficiency requirements. However, the residential sector is expected to see less floor space expansion than the commercial sector, and the commercial sector is also more energy intensive.

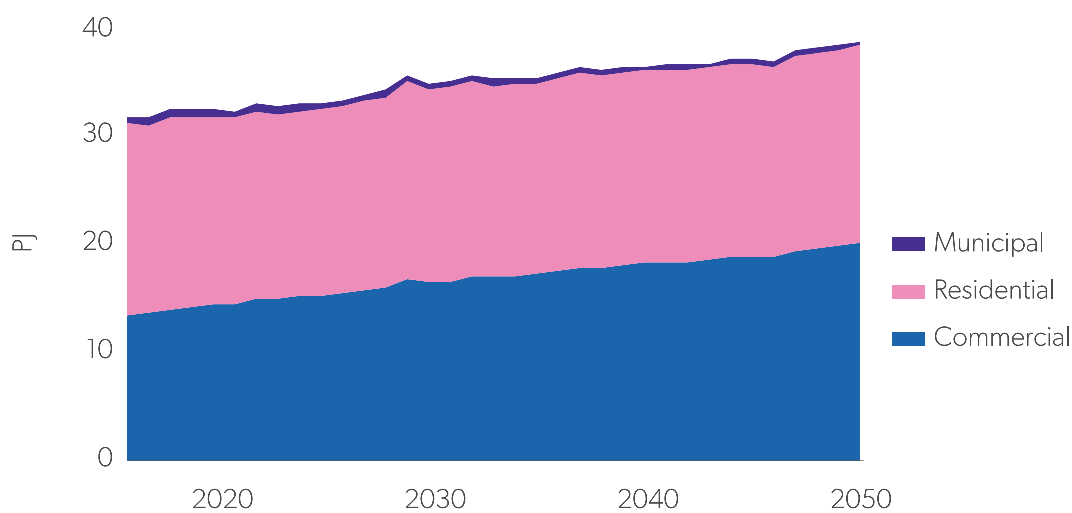


Figure 20. Projected BAP energy consumption for buildings (PJ) by sector, 2016-2050.

As shown in Figure 21, building sector fuel use in a 2050 BAP scenario is expected to see an increase in consumption of grid electricity (26% or 3.8 PJ), followed by natural gas (11% or 5.4 PJ). The relatively small increase in natural gas is partly due to the projected warming from climate change, which will reduce the number of days requiring building heating and increase the number of days requiring electric air conditioning.

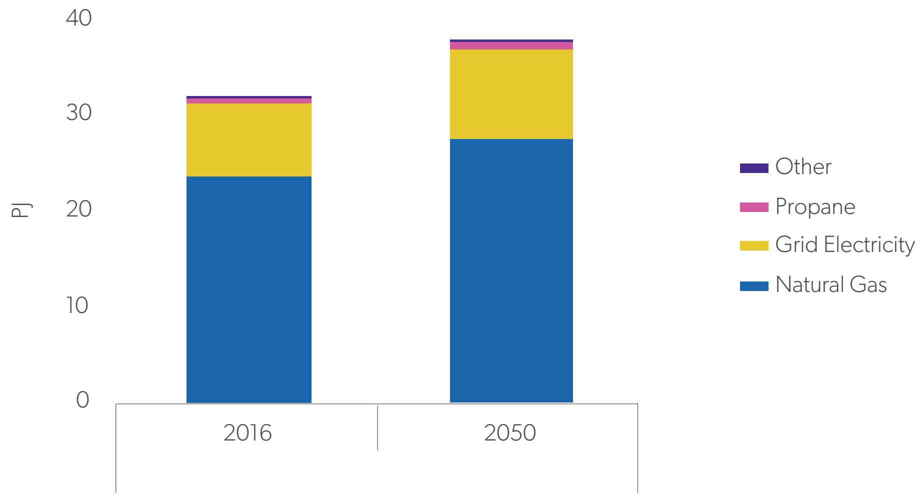


Figure 21. Energy consumption in PJ in 2016 and 2050, by fuel type.[4]

When broken down by sector (Figure 22), it is apparent that natural gas and grid electricity consumption is distributed similarly between commercial and residential buildings in 2016. The increase in buildings' natural gas use by 2050 is driven by the commercial sector, whereas the growth in grid electricity consumption is explained by both the residential and commercial sectors.

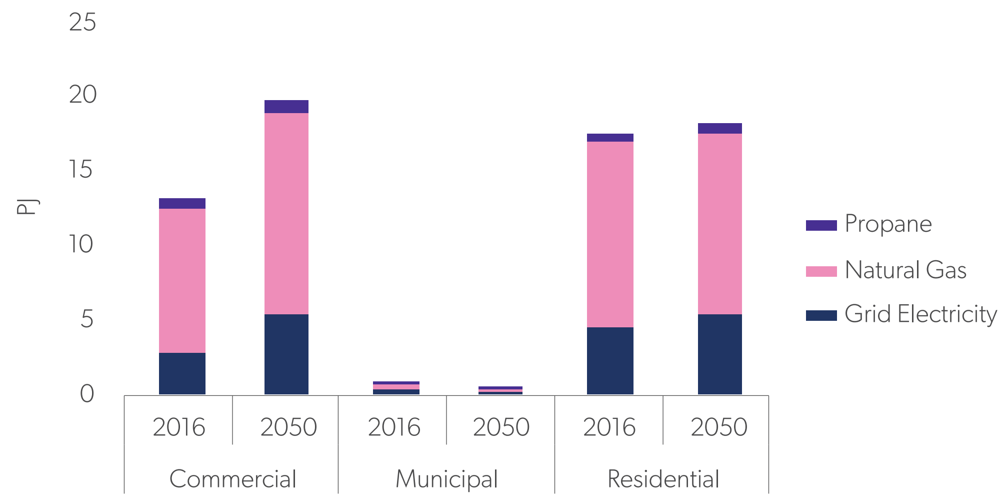


Figure 22. Energy consumption in PJ in 2016 and 2050, by sector and fuel type.[4]

As the number of households in Hamilton grows, it would be logical to expect total residential energy consumption to rise. However, each household is projected to use 36% less energy by 2050, due to incremental retrofits, increasingly stringent building codes and a warming climate. The chart below shows the relatively constant growth in households (orange line) and decrease in household energy intensity expected in the BAP through to 2050.

[4] 'Other' includes district energy, fuel oil, and local electricity.

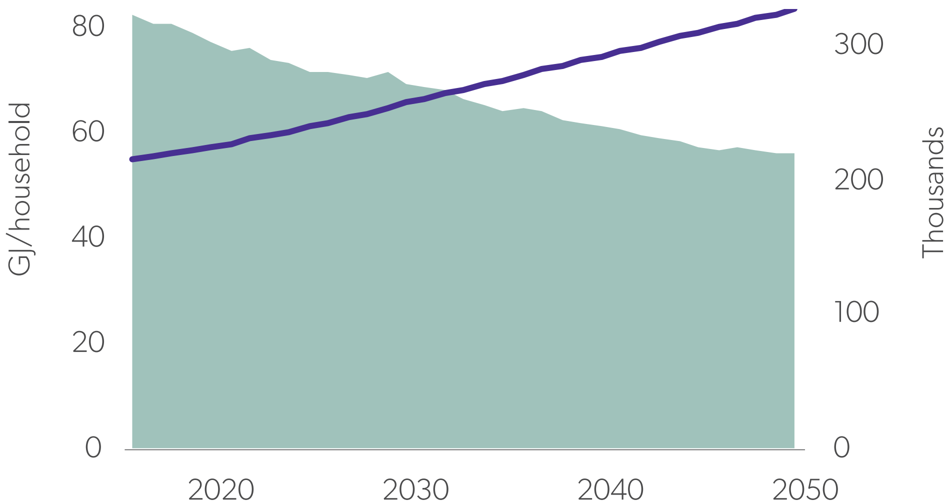


Figure 23. Average household energy intensity (GJ/household) compared with the number of households, 2016-2050.

Space heating is the building sector's largest energy end use. In the residential sector the second largest energy use is water heating, whereas in the commercial sector, the largest end-use source is plug load, followed by lighting and cooling.

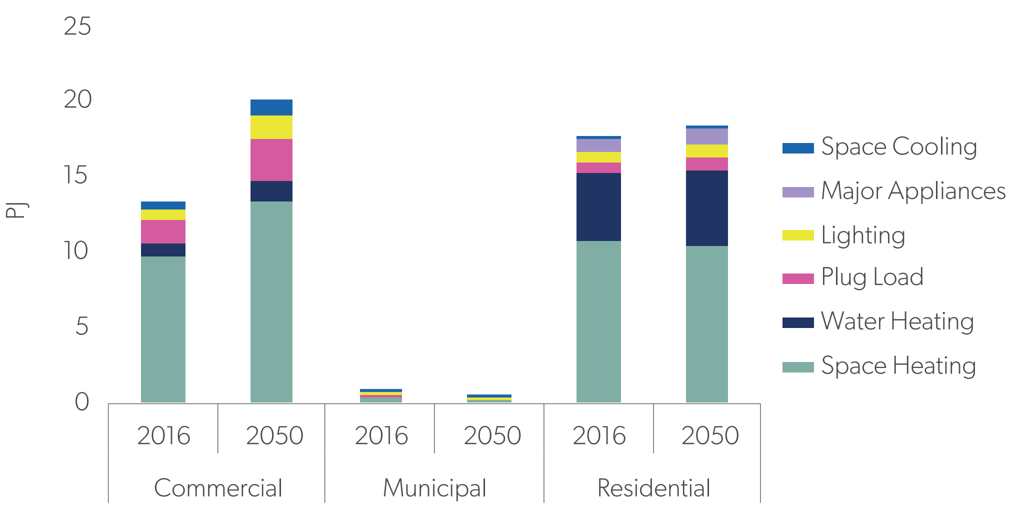


Figure 24. Building energy consumption for 2016 and 2050 (PJ), by end use and sector.

BUILDING EMISSIONS

Similar to energy use trends, GHG emissions from buildings are expected to increase by 29%, from 1.4 $MtCO_2e$ in 2016, to 1.8 $MtCO_2e$ in 2050. This growth is again driven primarily by the commercial sector, which increases its emissions by 56%, being responsible for 53% of all building emissions in 2050, compared to 44% in 2016.

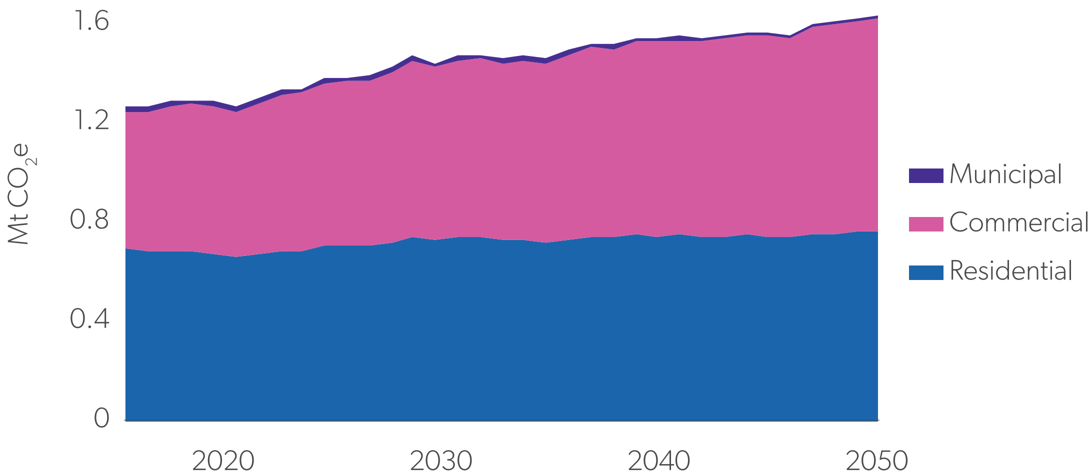


Figure 25. Buildings GHG emissions projection, 2016-2050 ($MtCO_2e$), by sector.

When analyzing this sector's GHG emissions by fuel type, electricity from the grid accounts for a smaller share of the total emissions, as it is primarily produced by non-fossil fueled energy sources.

Space heating has the highest share of emissions by end use in the residential sector, followed by water heating. Plug load and space cooling have a higher presence in the commercial sector, however, much lower than its end use shares represented in terms of energy.

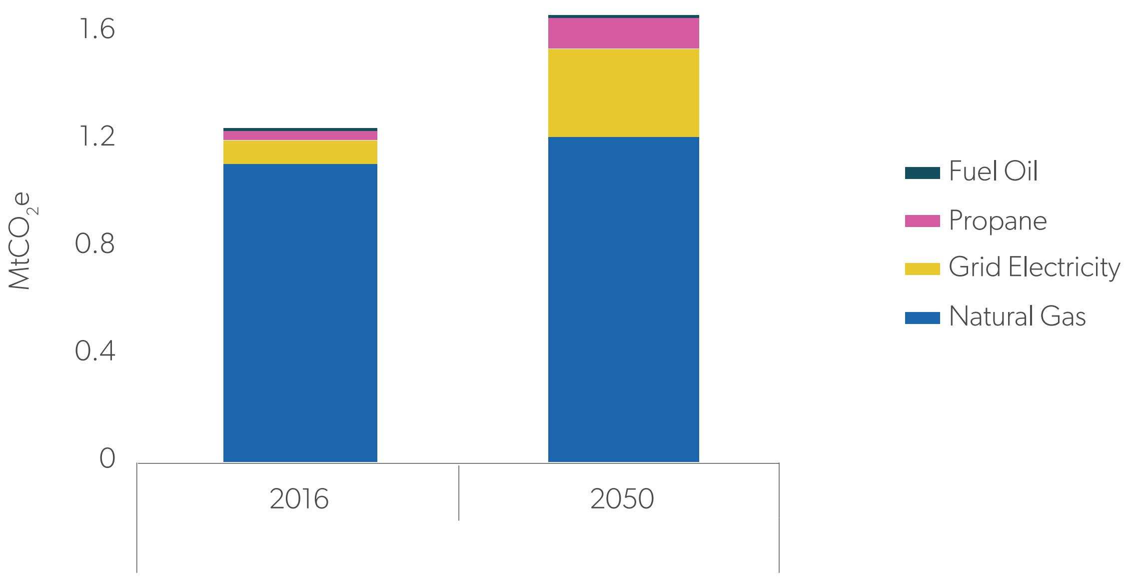


Figure 26. Buildings GHG emissions in 2016 and 2050, by fuel type (Mt CO_2e).

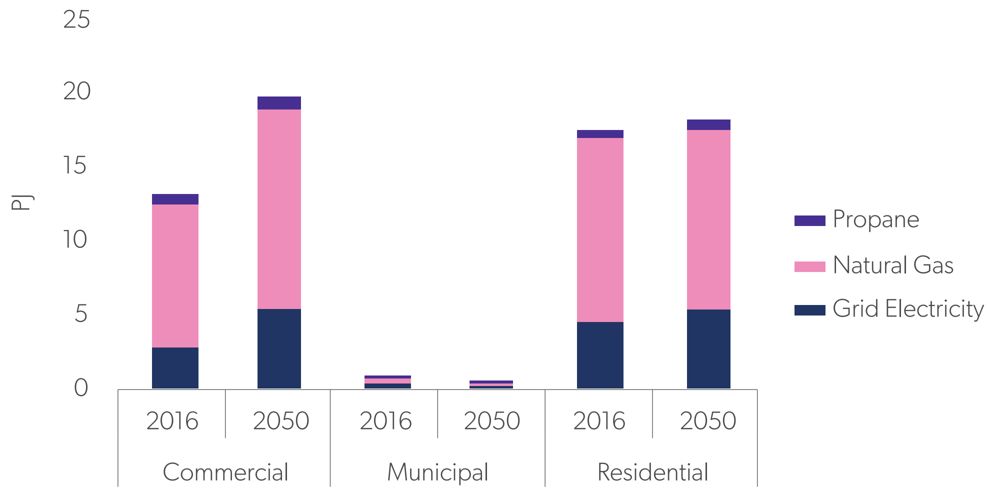


Figure 27. Buildings GHG emissions for 2016 and 2050 (Mt CO_2e), by end use and sector.

Industry

INDUSTRY ENERGY USE

In 2016, 60% of the city's total energy consumption was due to industrial processes, accounting for 82 PJ. Steel is the sector's largest consumer of energy and source of emissions. Steel manufacturing relies on burning fossil fuels, primarily coal and natural gas.

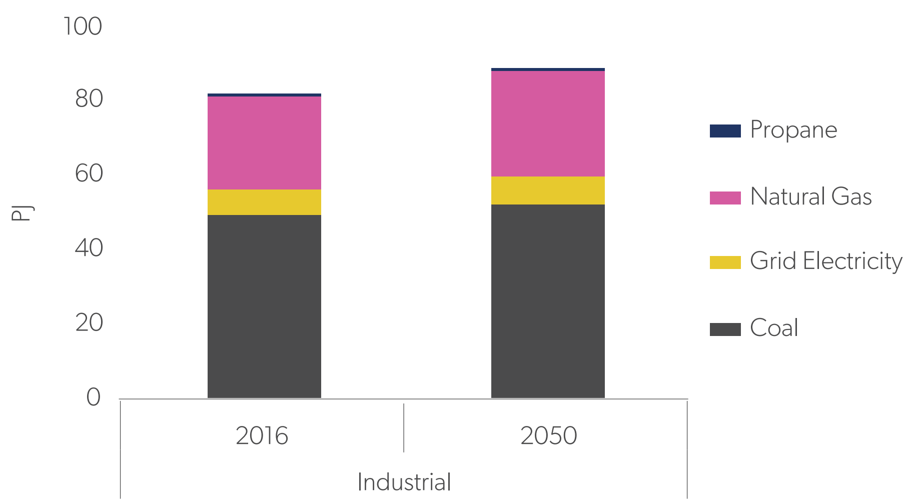


Figure 28. Industrial energy consumption in 2016 and 2050, by fuel type (PJ).[5]

In 2050, industrial process energy use is expected to ramp up 9% with respect to the base year, reaching 87 PJ and maintaining a similar fuel share. Energy use in the industrial sector increases in proportion to employment. In a BAP scenario, by 2050, energy consumption in the industrial sector accounts for 60% of Hamilton's total energy consumption.

[5] 'Other' includes diesel, propane, local electricity, district energy, wood, geothermal, waste-heat, petroleum-coke, water, storage, uranium, ethanol, biodiesel, renewable diesel, cold water, and fugitive emissions.

INDUSTRY EMISSIONS

In the BAP scenario, industry emissions are projected to increase by 10%, going from 5.6 $MtCO_2e$ in 2016 to 6.1 $MtCO_2e$ in 2050. It is apparent that coal is the primary source of this sector's emissions. Coal is used to produce extreme heat in steel smelters.

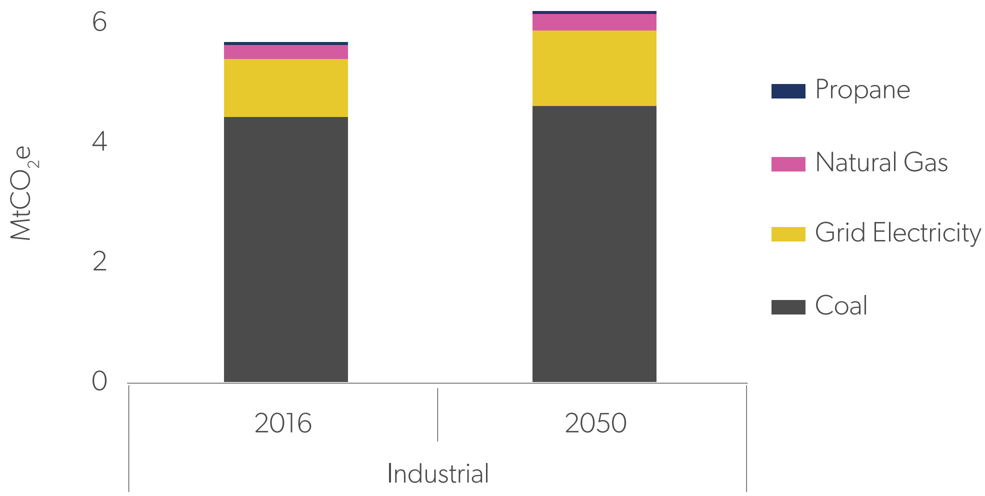


Figure 29. Industrial CO_2e emissions in 2016 and 2050, by fuel type ($MtCO_2e$).[6]

Industry is expected to represent 64% of Hamilton's GHG emissions in 2050

Transportation Sector Energy

TRANSPORTATION ENERGY BY FUEL AND VEHICLE TYPE

In 2016, approximately 17% (23.3 PJ) of Hamilton's energy use occurred in the transportation sector, which includes cars, trucks, transit, rail, and marine in this energy analysis (see Part 2 for more on how transportation energy and emissions are allocated to the city).[7]

Passenger vehicles, including cars and light trucks account for 70% of that total. By 2050, overall transportation energy use increases by 2% to 23.7 PJ. This is due to fuel efficiency improvements and incremental uptake of electric vehicles.[8]

The map in Figure 30 shows the distribution of total vehicle kilometers traveled by personal vehicles, by zone, for Hamilton in 2016. The highest values are concentrated near the boundaries of the urban area, and also near the external rural boundary. In these zones residents need to travel longer distances to work and other essential services.

VKT are projected to increase in 2050, intensifying travels near rural and urban boundaries, but also in inner areas, even in and around downtown (see Figure 31). However, as will be shown below, this significant increase in VKT does not result in an equivalent increase in energy or emissions.

[6] 'Other' includes wood, fuel oil, and propane.

[7] Aviation fuels are only included in the emissions analysis.

[8] In the BAP scenario, a modest 14% uptake of electric vehicles is assumed. This reflects the decreasing cost of EVs and subsidies for purchasing EVs being made available by the federal government.

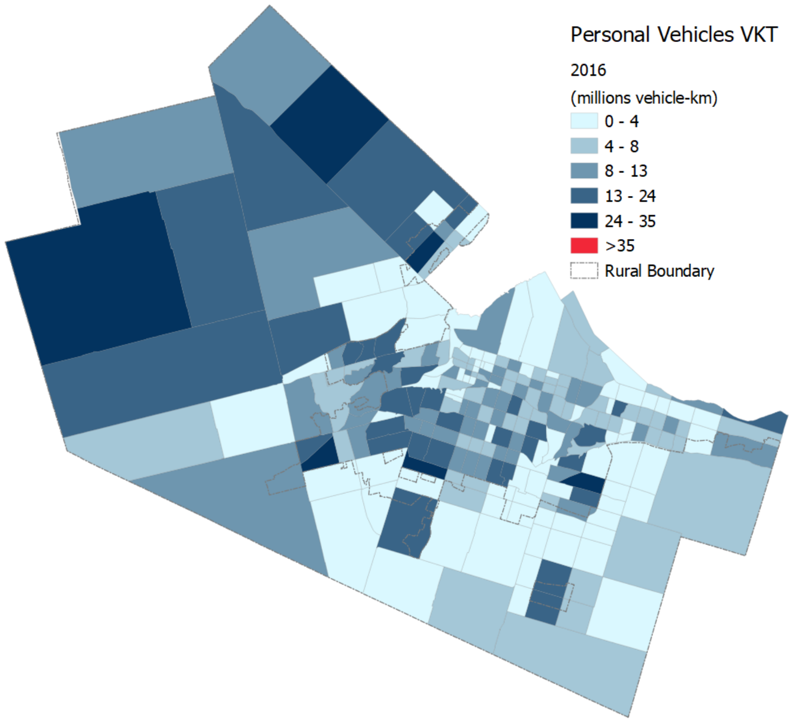


Figure 30. VKT for personal vehicles in Hamilton (millions vehicle-km) in 2016.

Gasoline is the primary fuel source for transportation energy in 2016, accounting for 81% of the sector's energy use, but gasoline is projected to fuel a smaller portion of transportation energy by 2050, accounting for 73% of total energy use. Electric vehicles and charging are anticipated to grow by 2050, from less than 1% of transportation sector energy use in 2016 to 10% in 2050.

There is a noted decline in energy demand in the on-road transportation sector between 2016 and 2035. This is primarily as a result of the projected fuel efficiency standards for vehicles assumed in the BAP, rather than a decrease in vehicle kilometres travelled (VKT). Vehicle fuel consumption rates in the BAP 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.[9]

[9] On March 31, 2020, the U.S. replaced the CAFE standards with less stringent fuel efficiency standards. To date the Federal Government of Canada has not followed course on these reduced standards.

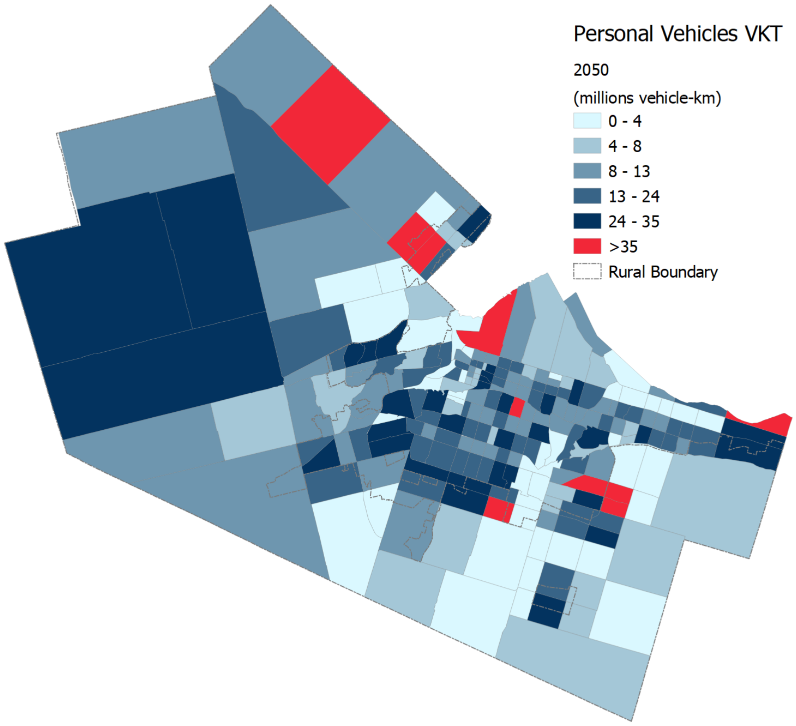


Figure 31. VKT for personal vehicles in Hamilton (millions vehicle-km) in 2050.

No changes in marine and rail transportation traffic or efficiency were assumed in this BAP scenario.

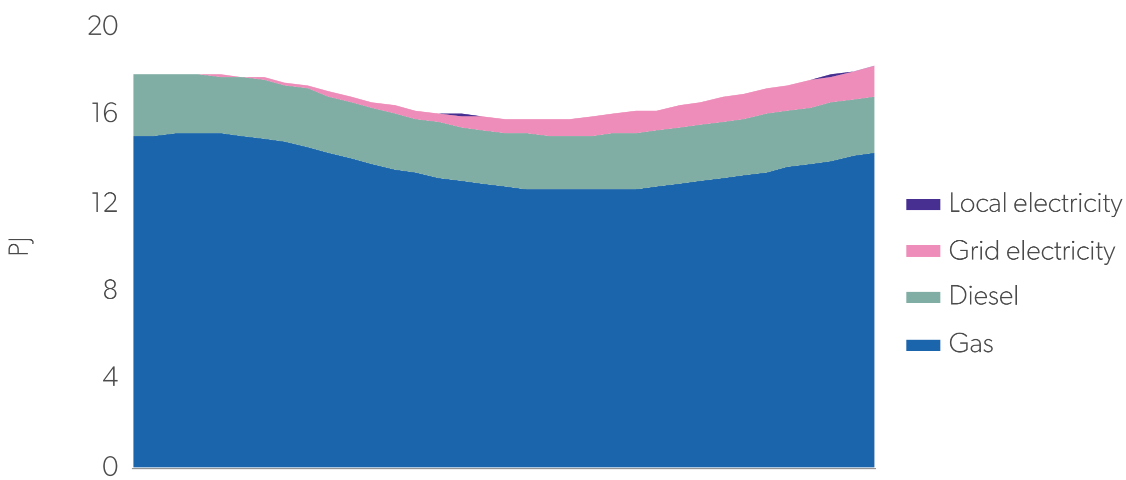


Figure 32. Projected BAP transportation energy use (PJ) by fuel, 2016-2050.[10]

[10] Note: Here diesel includes marine fuels.

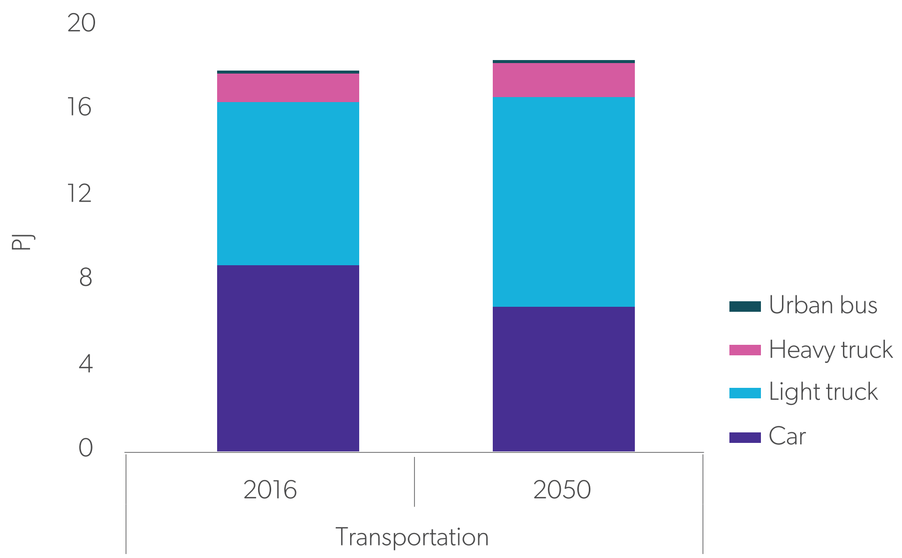


Figure 33. Projected BAP transportation energy use (PJ) by vehicle type, 2016-2050.

Between 2016 and 2050, there is a noticeable decline in energy demand for cars. This decline is driven by three major projected shifts: more stringent vehicle fuel efficiency standards, an increase in the number of electric vehicles (which are more energy efficient than combustion engine vehicles), and a projected shift away from cars to light trucks.

A shift in fuel use to electricity as well as increased efficiency are assumed across all vehicle types, other than marine and rail. Energy consumption in the marine and rail sectors was assumed to be constant from 2016 to 2050.

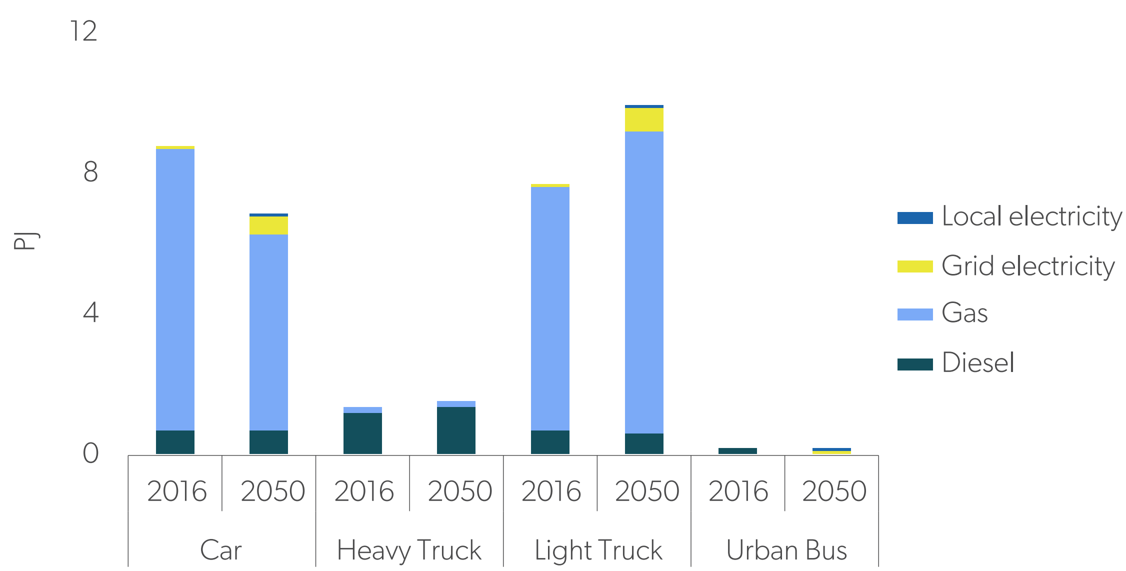


Figure 34. Projected BAP transportation energy use (PJ) by vehicle type and fuel, 2016-2050.

Transportation Sector Emissions

TRANSPORTATION EMISSIONS BY SOURCE AND VEHICLE TYPE

Transportation GHG emissions follow a somewhat different trajectory to transportation energy demand, staying relatively constant between 2016 and 2050. This is due to the fact that in the transportation emissions analysis we include the municipal share of three additional sectors for which we do not have energy use data: rail, marine, and aviation.[11]

GHG emissions from transportation account for 19% of the total emissions for Hamilton in 2016 (1,671 ktCO_2e), and decrease to 17% in 2050 (1,600 ktCO_2e). This difference is due to the sector's projected increased use of the province's low-GHG electricity, as well as the expected improvements in efficiency noted above.

Emissions from gasoline dominate GHG emissions in 2016 for the transportation sector, with 76% of the total arising from gasoline in 2016, 19% from diesel and 6% from aviation fuel. The share of emissions from gasoline decreases slightly over time until it accounts for 73% of transportation emissions in 2050. Electric vehicle charging begins to increase towards 2050 but will only represent 3% of transportation GHG emissions (versus its 10% share of energy demand).

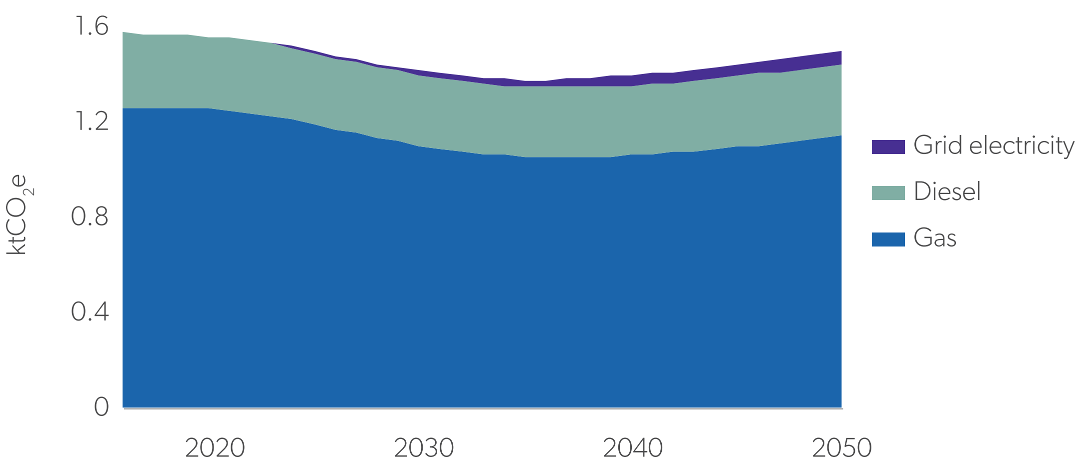


Figure 35. Projected BAP transportation emissions (kt CO_2e) by source, 2016-2050.

[11] Marine, rail and aviation fuel GHG emissions are allocated to the city of Hamilton according to the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) protocol. For more information see the Data, Methods and Assumption Manual in Part 2.

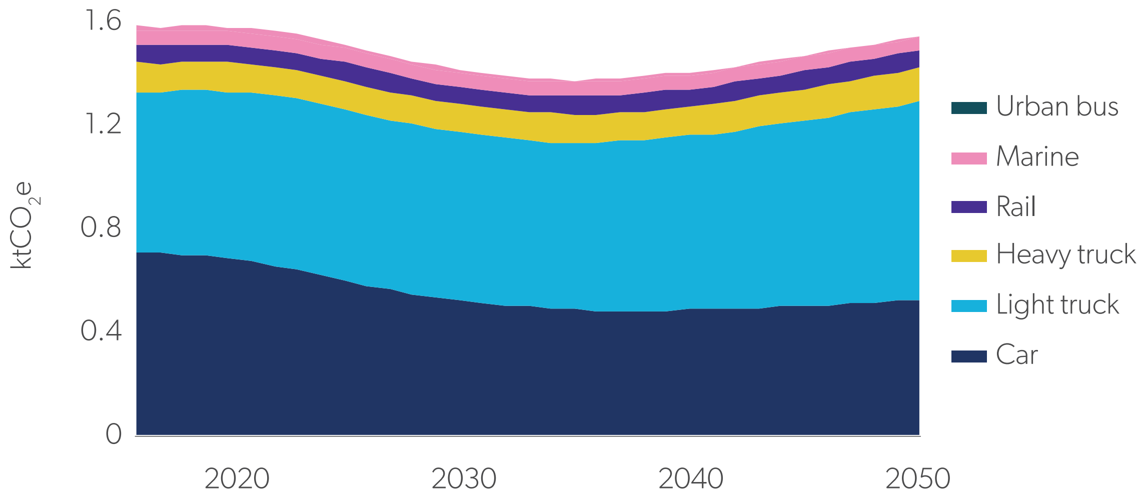


Figure 36. Projected BAP transportation emissions (ktCO_2e) by vehicle type, 2016-2050

Waste Sector Emissions

WASTE EMISSIONS BY TYPE

In 2016, Hamilton produced approximately 215 kt of solid waste, the majority of which was sent to a landfill (52%). This number is projected to increase in step with population and employment growth, to approximately 338 kt per year in 2050, with 45% still expected to go to landfill.

Waste emissions in Hamilton amounted to 58 ktCO_2e in 2016 and are projected to increase to 97 ktCO_2e by 2050; an increase of 67% over the period. Waste emissions include both emissions produced from solid waste and wastewater treated at the central wastewater plant.

Emissions from landfill significantly outweigh emissions from wastewater and compost ('biological'). This is despite the current landfill gas-capture system which is estimated to capture 75% of methane emissions produced at the landfill. The growing population results in additional waste going to landfill, as well as the ongoing decay of existing waste in landfill (that has been added over many years in the past) which continues to produce methane. Wastewater emissions represent approximately 8% of the sector's emissions in 2016. Wastewater emissions are projected to increase from 4.7 kt ktCO_2e to 7.1 ktCO_2e in 2050.

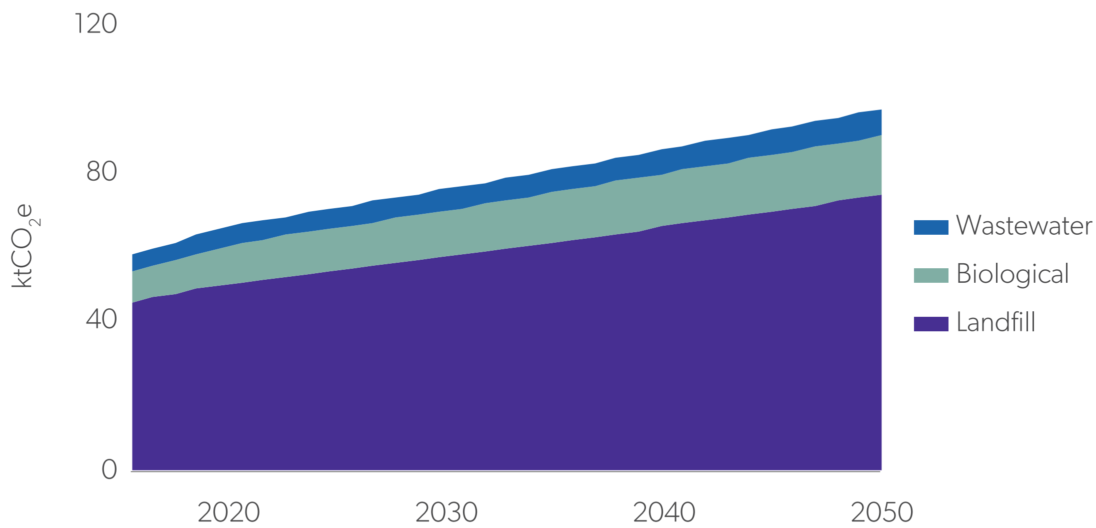


Figure 37. Projected BAP waste GHG emissions (ktCO$_2$e), 2016-2050.

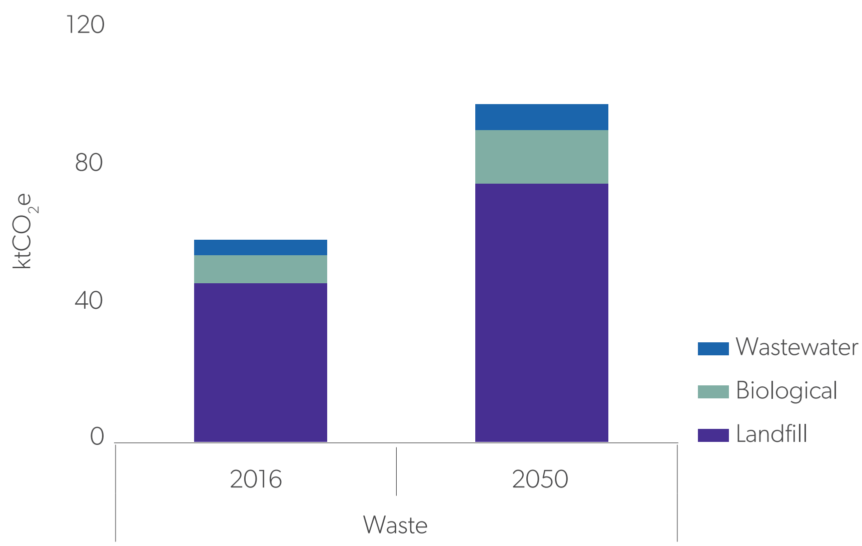


Figure 38. Waste GHG emissions by treatment type (ktCO$_2$e), in 2016 and 2050.

Agriculture and Carbon Sequestration

Hamilton has a large land base dedicated to nature (open and forested lands) as well as agriculture. This section provides an analysis of GHG emissions from livestock ('agriculture') and carbon reductions ('sequestration') due to land-use changes.

The estimation of carbon sequestration is not added to the final total of the city's GHG emissions. It is provided here as a discussion point.

Agriculture

For the baseline year, GHG emissions originating from livestock totaled 32 $ktCO_2e$, less than 1% of total community emissions.

The number of livestock in Hamilton is held constant towards 2050, as a plateau has been reached from 2013 onwards according to Ontario statistics on agricultural activities.[12] As a result, annual GHG emissions from livestock are held constant at 32 $ktCO_2e$ until 2050.

Carbon Sequestration

Projected sequestration from land use changes in the BAP, decreases community GHG emissions in 2050 from 9,623 to 9,309 $ktCO_2e$.

Carbon sequestration and releases are projected to occur throughout the study period. However, in this analysis we are only discussing them as a snapshot in the year 2050. In other words, the 2050 carbon does not capture sequestration or releases projected to occur earlier in the study period.

In a BAP scenario, land use changes are projected to result in -314 $ktCO_2e$ (negative emissions) in the year 2050 due to increased carbon sequestration due to urban and rural forests.

Carbon sequestration represents removal of carbon from the atmosphere, for example from trees and healthy soil. In this model, release of sequestered carbon is measured based on the conversion of forests, grasslands, wetlands to settlement areas, or of agricultural land to developed areas, or of agricultural land transitioning from no-till to till soil management practices. Carbon sequestration is modeled based on forested areas remaining forested. No data was provided on projected tree planting in the City of Hamilton.

Table 1. Net GHG emissions for Hamilton in the BAP scenario, 2050.

SECTOR	GHG EMISSIONS, 2050 ($KTCO_2E$)
Community-wide emissions	9,623
Sequestration	-314
Net total	9,309

In the BAP, Hamilton's largest source of sequestration in 2050 is forested land, with an estimated

[12] Using cattle as an indicator for livestock; the number of cattle has largely remained unchanged from 2013-2019, with approximately 13,300 cattle in the province. "Livestock and Poultry Statistics." 2019. Ministry of Agriculture, Food and Rural Affairs, Ontario. www.omafra.gov.on.ca/english/stats/livestock/index.html

sequestration of -272 $ktCO_2e$.[13] The second-largest carbon sequestration category are trees in developed areas, sequestering approximately -73 $kTCO_2e$ in 2050.

In terms of carbon releases in 2050, the BAP projects a small but steady increase towards tilling, based on historic trends, which results in 23 $ktCO_2e$ of carbon release in 2050. Finally, a very small amount of agricultural land is expected to be developed in 2050, resulting in a release of 8 kt CO_2e.

For more information see the annual results in the Appendix.

Looking to the Low-Carbon Scenario

Hamilton has committed to act on the climate crisis by establishing a community-wide 2050 net-zero GHG emissions target. In order to achieve this target, actions will need to be taken quickly to address the drivers of community emissions. The BAP scenario reveals the following key sources of emissions:

- 98% of GHG emissions in 2050 in the community are due to fossil fuel use for energy.
- About 57% of Hamilton's energy use is wasted in conversion losses.
- Ontario's mostly fossil fuel-free electricity grid is expected to become increasingly carbon-intensive out to 2050.
- Local renewable energy generation is the only source of fossil-fuel free energy available in Hamilton. Currently Hamilton produces less than 1% of its energy from local renewable energy, and this is projected to increase marginally to 1% in the BAP.
- The industrial sector is by far the largest source of GHG emissions in the community due to the use of coal in its steel smelters, single handedly representing more than half of the city's emissions in 2016. Though the steel industry has set an aspirational goal of achieving net-zero by 2050, the BAP does not incorporate this goal.
- Gasoline and diesel for cars and trucks is likely to remain the city's second largest source of emissions out to 2050, despite increased fuel efficiency standards and incremental uptake of EVs.
- Commercial and residential buildings are the city's third and fourth largest source of emissions, primarily from natural gas for space and water heating. However, electricity is projected to represent a larger share of emissions for both out to 2050, due to the increasing carbon intensity of the electricity grid and increasing cooling demand.
- Improved energy efficiency requirements for new buildings, incremental retrofits, and reduced need for space heating will do little to change this sector's carbon footprint out to 2050.
- With current solid waste generation and diversion rates, emissions from waste will continue to grow with a growing population.

The next phase of modelling will explore potential actions to curb these emissions, and will form the basis of Hamilton's Community and Emissions Energy Plan (CEEP).

[13] A negative symbol means that GHG emissions are reduced.

Part 2: Data, Methods, and Assumptions Manual

1. Summary

The Data, Methods and Assumptions (DMA) manual has been created for Hamilton to illustrate the modeling approach used to provide energy and emissions benchmarks and projections. The DMA will also provide a summary of the data and assumptions being used as the foundation for the energy and emissions modeling. This allows for the elements of the modelling to be fully transparent, as well as lay a foundation for the scope of data required for future modelling efforts that the City can build upon.

2. Accounting and Reporting Principles

The GPC is based on the following principles in order to represent a fair and true account of emissions:

- Relevance: The reported GHG emissions shall appropriately reflect emissions occurring as a result of activities and consumption within the Hamilton boundary. The inventory will also serve the decision-making needs of Hamilton, taking into consideration relevant local, subnational, and national regulations. Relevance applies when selecting data sources and determining and prioritizing data collection improvements.
- Completeness: All emissions sources within the inventory boundary shall be accounted for. Any exclusions of sources shall be justified and explained.
- Consistency: Emissions calculations shall be consistent in approach, boundary, and methodology.
- Transparency: Activity data, emissions and factors, and accounting methodologies require adequate documentation and disclosure to enable verification.
- Accuracy: The calculation of GHG emissions should not systematically overstate or understate actual GHG emissions. Accuracy should be sufficient enough to give decision makers and the public reasonable assurance of the integrity of the reported information. Uncertainties in the quantification process should be reduced to the extent possible and practical.

3. Assessment Characteristics

3.1 GEOGRAPHIC BOUNDARY

The geographic boundary for this assessment consists of the City as shown in Figure 39.

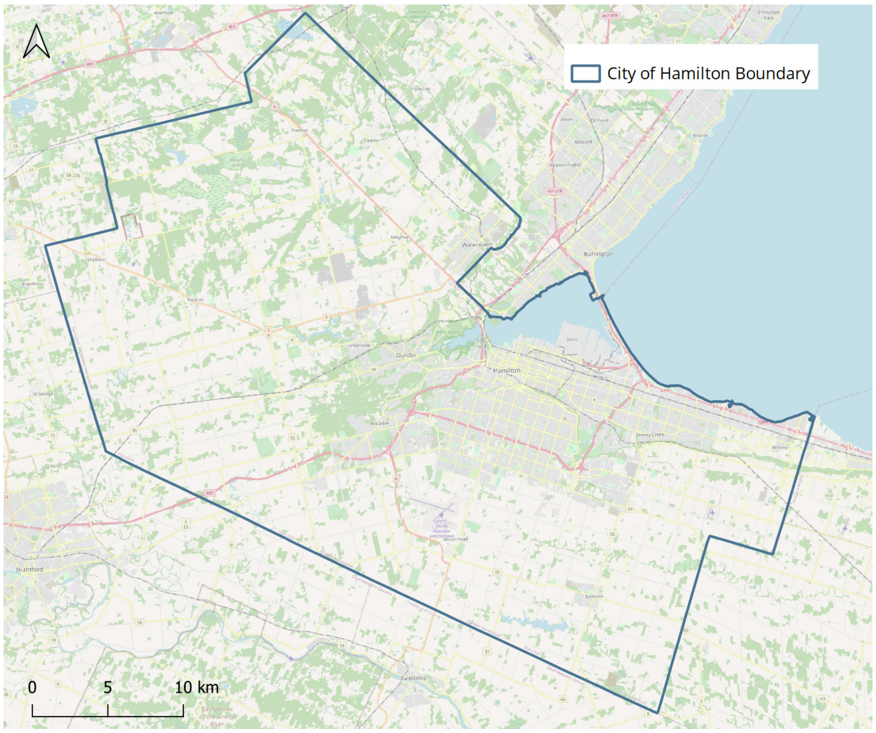


Figure 39. Hamilton geographic boundary.

3.2 TIME FRAME OF ASSESSMENT

The time frame for assessment of Hamilton will be from 2016-2050, with 2016 as a baseline year. The census of 2016 is a key data source used to establish the baseline year. Further, the baseline year is based on model calibration which uses as much observed data as possible in order to provide the most accurate and consistent snapshot as possible.

Refer to Section 6. Scenario Development for more information on Model Calibration and Data and Assumptions.

3.3 ENERGY AND EMISSIONS STRUCTURE

The total energy for a community is defined as the sum of the energy from each of the aspects:

$$Energy_{city} = Energy_{transport} + Energy_{buildings} + Energy_{wastegen}$$

Where:

$Energy_{transport}$ is the movement of goods and people.

$Energy_{buildings}$ is the generation of heating, cooling and electricity.

$Energy_{wastegen}$ is energy generated from waste.

The total GHG for a community is defined as the sum of the GHG from each of the aspects:

$$GHG_{landuse} = GHG_{transport} + GHG_{energygen} + GHG_{waste} + GHG_{agriculture} + GHG_{forest} + GHG_{landcover}$$

Where:

$GHG_{transport}$ is the movement of goods and people.

$GHG_{energygen}$ is the generation of heat and electricity.

GHG_{waste} is liquid and solid waste produced.

$GHG_{agriculture}$ is the production of food.

GHG_{forest} is the area of forest land.

$GHG_{landconvert}$ is the area of land in natural or modified conditions.

3.4 SCOPE

The inventory will include Scope 1, 2, and 3 emissions. Refer to Appendix 3 for a list of GHG emission sources by scope that are included.

Table 2. GPC Scopes

SCOPE	DEFINITION
1	All GHG emissions from sources located within the City boundary.
2	All GHG emissions occurring as a consequence of the use of grid-supplied electricity, heat, steam and/or cooling within the City boundary.
3	All other GHG emissions that occur outside the City boundary as a result of activities taking place within the City boundary.

3.5 EMISSION FACTOR

In order to compile a baseline of emissions within Hamilton, inputs such as energy use, activities by citizens and businesses, and waste products need to be converted to recordable emissions. The following table displays those conversions and their source

Table 3. Emissions Factors for the Hamilton Baseline and Future Scenario

CATEGORY	DESCRIPTION	COMMENT
Natural gas	49 kg CO_2e/GJ	Environment and Climate Change Canada. National Inventory Report 1990-2015: Greenhouse Gas Sources and Sinks in Canada. Part 2. Tables A6-1 and A6-2, Emission Factors for Natural Gas.

CATEGORY	DESCRIPTION	COMMENT
Electricity	2016: 50.8 gCO_2e/kWh 2050: 83.7 gCO_2e/kwh 2016: CO_2: 28.9 g/kWh CH_4: 0.007 g/kWh N_2O: 0.001 g/kWh 2050: CO_2: 82.32 g/kWh CH_4: 0.02 g/kWh N_2O: 0.00 g/kWh	IESO, Annual Planning Outlook January 2020.
Gasoline	g/L CO_2: 2316 CH_4: 0.32 N_2O: 0.66	Environment and Climate Change Canada. National Inventory Report 1990-2015: Greenhouse Gas Sources and Sinks in Canada. Part 2. Table A6–12 Emission Factors for Energy Mobile Combustion Sources
Diesel	g/L CO_2: 2690.00 CH_4: 0.07 N_2O: 0.21	Environment and Climate Change Canada. National Inventory Report 1990-2015: Greenhouse Gas Sources and Sinks in Canada. Part 2. Table A6–12 Emission Factors for Energy Mobile Combustion Sources
Fuel oil	Residential g/L CO_2: 2560 CH_4: 0.026 N_2O: 0.006 Commercial g/L CO_2: 2753 CH_4: 0.026 N_2O: 0.031 Industrial g/L CO_2: 2753 CH_4: 0.006 N_2O: 0.031	Environment and Climate Change Canada. National Inventory Report 1990-2015: Greenhouse Gas Sources and Sinks in Canada. Part 2. Table A6–4 Emission Factors for Refined Petroleum Products

CATEGORY	DESCRIPTION	COMMENT
Propane	g/L Transport CO_2: 1515.00 CH_4: 0.64 N_2O: 0.03 Residential CO_2: 1515.00 CH_4: 0.027 N_2O: 0.108 All other sectors CO_2: 1515.00 CH_4: 0.024 N_2O: 0.108	Environment and Climate Change Canada. National Inventory Report 1990-2015: Greenhouse Gas Sources and Sinks in Canada. Part 2. Table A6–3 Emission Factors for Natural Gas Liquids Table A6–12 Emission Factors for Energy Mobile Combustion Sources
Agricultural: Livestock	Varies per animal Type Kg CH_4/ head	Environment and Climate Change Canada. National Inventory Report 1990-2016: Greenhouse Gas Sources and Sinks in Canada. Part 2 Table A3-30 CH4 Emission Factors for Enteric Fermentation for Cattle from 1990 to 2016 Table A3-37 Emission Factors to Estimate CH4 Emissions from Manure Management for Cattle Subcategories
Waste	Landfill emissions are calculated from the first order decay of degradable organic carbon deposited in landfill. Derived emission factor in 2016 = 0.015 kg CH_4/ tonne solid waste (assuming 75% recovery of landfill methane); 0.050 kg CH_4/tonne solid waste not accounting for recovery. Incineration Emissions: CO_2 emissions are derived from the IPCC method presented in the 2006 Guidelines, Volume 5, Chapter 5, section 5.2.1.1. Composted Biological Emissions Factors: 4 gCH_4/kg solid organic waste and 0.3 g$N_2$0/kg solid organic waste.	Methane gas capture is occurring at the landfill in Hamilton. Landfill emissions: IPCC Guidelines Vol 5. Ch 3, Equation 3.1 ICI Waste tonnage was estimated using per capita numbers for Ontario from Statistics Canada, Table 38-10-0032-0: Disposal of waste, by source.
Wastewater	CH_4: 0.48 kg CH_4/kg BOD N_2O: 3.2 g / (person * year) from advanced treatment 0.005 g /g N from wastewater discharge	CH4 wastewater: IPCC Guidelines Vol 5. Ch 6, Tables 6.2 and 6.3; MCF value for anaerobic digester N2O from advanced treatment: IPCC Guidelines Vol 5. Ch 6, Box 6.1 N2O from wastewater discharge: IPCC Guidelines Vol 5. Ch 6, Section 6.3.1.2

4. Modelling

For this project, CityInSight will be used as the main modelling tool.

4.1 ABOUT CITYINSIGHT

CityInSight is an integrated energy, emissions and finance model developed by Sustainability Solutions Group and whatIf? Technologies. It is an integrated, multi-fuel, multi-sector, partially-disaggregated energy systems, emissions and finance model for cities. The model enables bottom-up accounting for energy supply and demand, including renewable resources, conventional fuels, energy consuming technology stocks (e.g. vehicles, appliances, dwellings, buildings) and all intermediate energy flows (e.g. electricity and heat).

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 (e.g. EV penetration rates). The model accounts for physical flows (i.e. energy use, new vehicles by technology, vehicle kilometres travelled) as determined by stocks (buildings, vehicles, heating equipment, etc.).

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 currencies (e.g. gasoline, electricity, hydrogen) to end uses (e.g. personal vehicle use, 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.

Table 4. Characteristics of CityInSight.

CHARACTERISTIC	RATIONALE
Integrated	CityInSight is designed to model and account for all sectors that relate to energy and emissions at a city scale while capturing the relationships between sectors. The demand for energy services is modelled independently of the fuels and technologies that provide the energy services. This decoupling enables exploration of fuel switching scenarios. Physically feasible scenarios are established when energy demand and supply are balanced.
Scenario-based	Once calibrated with historical data, CityInSight enables the creation of dozens of scenarios to explore different possible futures. Each scenario can consist of either one or a combination of policies, actions and strategies. Historical calibration ensures that scenario projections are rooted in observed data.
Spatial	The configuration of the built environment determines the ability of people to walk and cycle, accessibility to transit, feasibility of district energy and other aspects. CityInSight therefore includes a full spatial dimension that can include as many zones - the smallest areas of geographic analysis - as are deemed appropriate. The spatial component to the model can be integrated with City GIS systems, land-use projections and transportation modelling.
GHG reporting framework	CityInSight is designed to report emissions according to the GHGProtocol for Cities (GPC) framework and principles.

CHARACTERISTIC	RATIONALE
Economic impacts	CityInSight incorporates a full financial analysis of costs related to energy (expenditures on energy) and emissions (carbon pricing, social cost of carbon), as well as operating and capital costs for policies, strategies and actions. It allows for the generation of marginal abatement curves to illustrate the cost and/or savings of policies, strategies and actions.

4.2 MODEL STRUCTURE

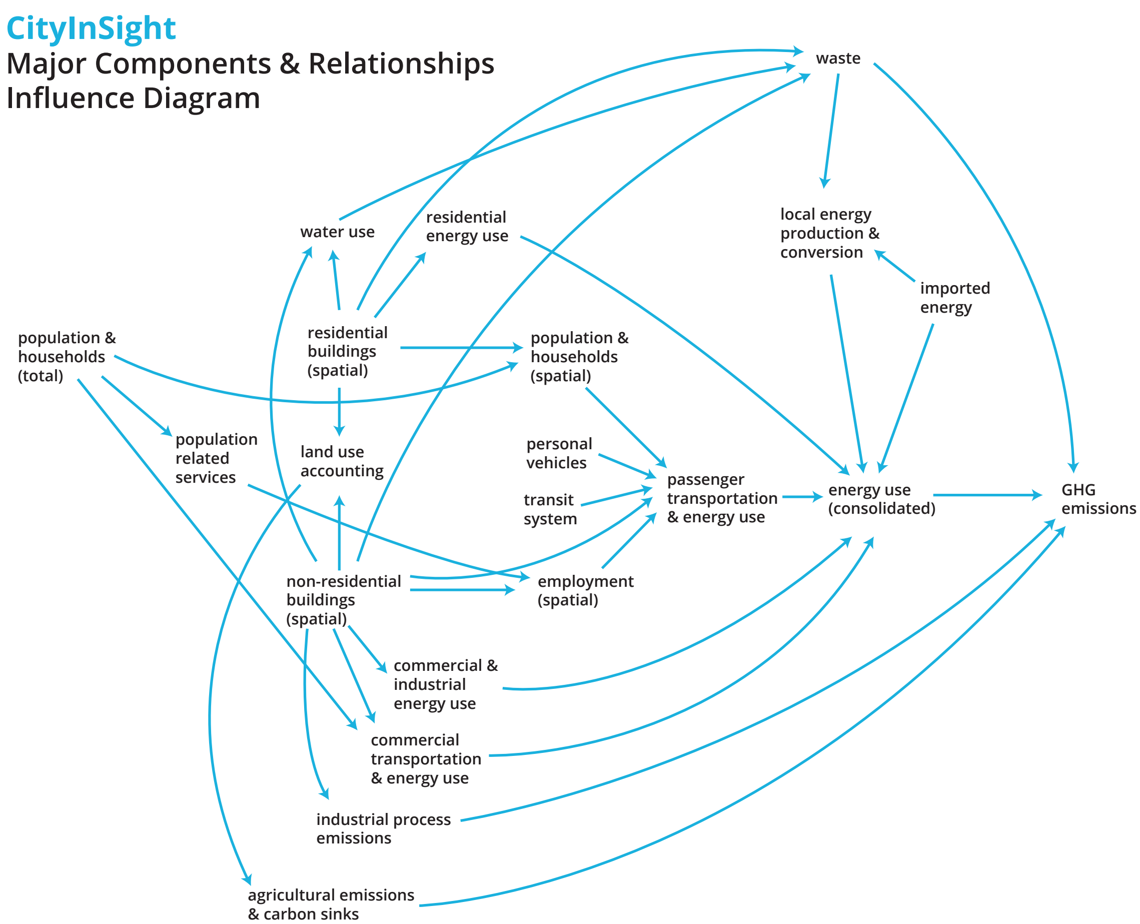


Figure 40. Representation of CityInSight's structure.

The major components of the model, and the first level of modelled relationships (influences), are represented by the blue arrows in Figure 42. Additional relationships may be modelled by modifying inputs and assumptions - specified directly by users, or in an automated fashion by code or scripts running "on top of" the base model structure. Feedback relationships are also possible, such as increasing the adoption rate of non-emitting vehicles in order to meet a particular GHG emissions constraint.

The model is spatially explicit. All buildings, transportation and land use data are tracked within the model through a GIS platform, and by varying degrees of spatial resolution. A zone type system is applied to break up the City into smaller configurations. This enables consideration of the impact of land-use patterns and urban form on energy use and emissions production from a baseline year to future dates using GIS-based platforms. CityInSight's GIS outputs can be integrated with the City's mapping systems.

4.3 STOCKS AND FLOWS

For any given year various factors shape the picture of energy and emissions flows, including: the population and the energy services it requires; commercial floorspace; energy production and trade; the deployed technologies which deliver energy services (service technologies); and the deployed technologies which transform energy sources to currencies (harvesting technologies). The model makes an explicit mathematical relationship between these factors—some contextual and some part of the energy consuming or producing infrastructure—and the energy flow picture.

Some factors are modelled as stocks—counts of similar things, classified by various properties. For example, population is modelled as a stock of people classified by age and gender. Population change over time is projected by accounting for: the natural aging process, inflows (births, immigration) and outflows (deaths, emigration). The fleet of personal use vehicles, an example of a service technology, is modelled as a stock of vehicles classified by size, engine type and model year, with a similarly-classified fuel consumption intensity. As with population, projecting change in the vehicle stock involves aging vehicles and accounting for major inflows (new vehicle sales) and major outflows (vehicle discards). This stock-turnover approach is applied to other service technologies (e.g. furnaces, water heaters) and also harvesting technologies (e.g. electricity generating capacity).

4.4 SUB-MODELS

Population and demographics

City-wide population is modelled using the standard population cohort-survival method, disaggregated by single year of age and gender. It accounts for various components of change: births, deaths, immigration and emigration. The age structured population is important for analysis of demographic trends, generational differences and implications for shifting energy use patterns. In CityInSight these numbers will be calibrated against existing projections developed for the City. New population data was provided by Hamilton planning department

Residential buildings

Residential buildings are spatially located and classified using a detailed set of 30+ building archetypes capturing footprint, height and type (single, double, row, apt. high, apt. low), in addition to year of construction. This enables a “box” model of buildings and the estimation of surface area. Coupled with thermal envelope performance and degree-days the model calculates space conditioning energy demand independent of any particular space heating or cooling technology and fuel. Energy service demand then drives stock levels of key service technologies (heating systems, air conditioners, 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 rate limits to new technology adoption and the effects of lock in. Residential building archetypes are also characterized by number of contained dwelling units, allowing the model to capture the energy effects of shared walls and the urban form and transportation implications of population density.

Non-residential buildings

These are spatially located and classified by a detailed use/purpose-based set of 50+ archetypes, and the floorspace of these non-residential building archetypes can vary by location. Non-residential floorspace produces waste and demand for energy and water, and also provides an anchor point for locating employment of various types.

Spatial population and employment

City-wide population is made spatial by allocation to dwellings, using assumptions about persons-per-unit by dwelling type. Spatial employment is projected via two separate mechanisms: population-related services and employment, which is allocated to corresponding building floorspace (e.g. teachers to school floorspace); and floorspace-driven employment (e.g. retail employees per square metre).

Passenger Transportation

The model includes a spatially explicit passenger transportation sub-model that responds to changes in land use, transit infrastructure, vehicle technology, travel behavior changes and other factors. Trips are divided into four types (home-work, home-school, home-other, and non-home-based), each produced and attracted by a different combination of spatial drivers (population, employment, classrooms, non-residential floorspace). Trips are distributed - that is, trip volumes are specified for each zone of origin and zone of destination pair. For each origin-destination pair trip are shared over walk/bike (for trips within the walkable distance threshold), public transit (for trips whose origin and destination are serviced by transit) and automobile. Following the mode share step, along with a network distance matrix, a projection of total personal vehicles kilometres travelled (VKT) is produced. The energy use and emissions associated with personal vehicles is calculated by assigning VKT to a stock-turnover personal vehicle model. The induced approach is used to track emissions. All internal trips (trips within Hamilton's boundary) are accounted for, as well as half of the trips that terminate or originate within the City's boundary. This approach allows Hamilton to better understand its impact on the peripheries.

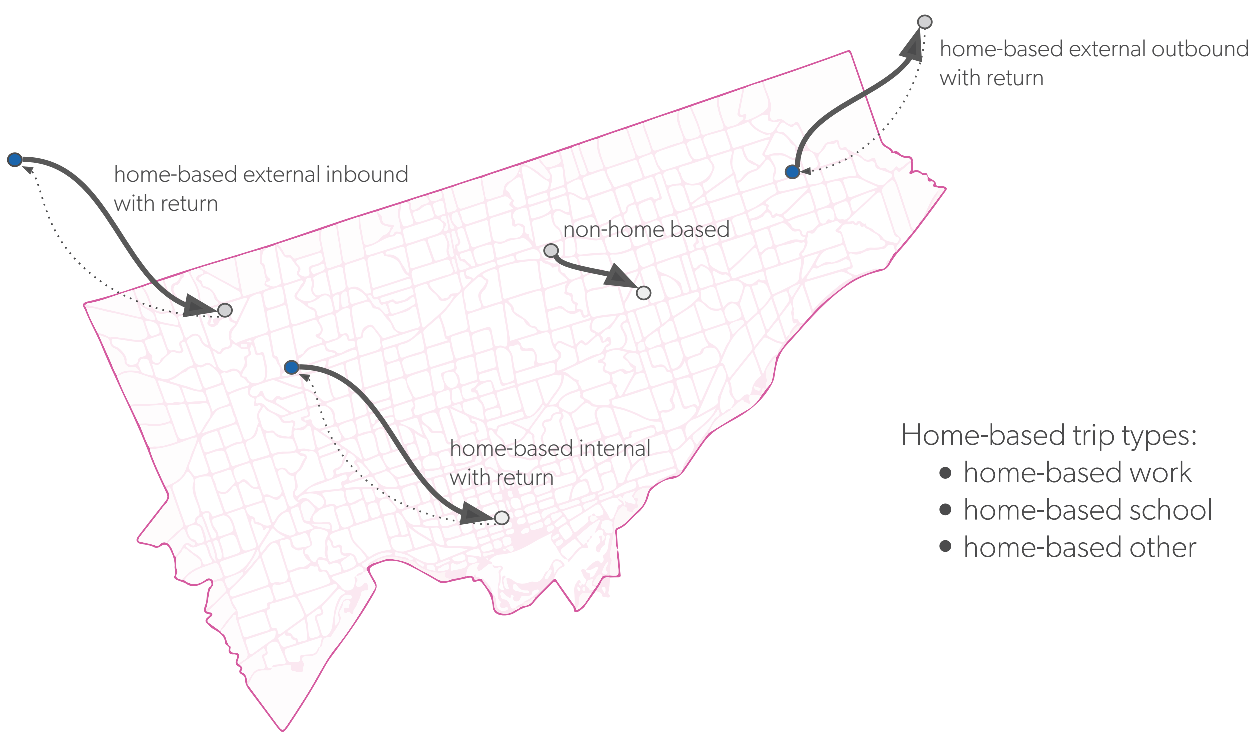


Figure 41. Conceptual diagram of trip categories.

Waste

Households and non-residential buildings generate solid waste and wastewater, and the model traces various pathways to disposal, compost and sludge including those which capture energy from incineration and recovered gas. Emissions accounting is performed throughout the waste sub-model.

Energy flow and local energy production

Energy produced from primary sources (e.g. solar, wind) is modelled alongside energy converted from imported fuels (e.g. electricity generation, district energy, CHP). As with the transportation sub-model, the district energy supply model has an explicit spatial dimension and represents areas served by district energy networks.

Finance and employment

Energy related financial flows and employment impacts—while not shown explicitly—are captured through an additional layer of model logic. Calculated financial flows include the capital, operating and maintenance cost of energy consuming stocks and energy producing stocks, including fuel costs. Employment related to the construction of new buildings, retrofit activities and energy infrastructure is modelled. The financial impact on businesses and households of the strategies is assessed. Local economic multipliers are also applied to investments.

Land Based and Agriculture Emissions

Data used to calculate Agriculture, Forestry, and other Land Use (AFOLU) emissions was found in Statistics Canada Census of Agriculture CANSIM tables of livestock for Hamilton for 2016. Environment Canada's 2016 National Inventory Report was used to obtain emissions factors for livestock and croplands, and the total area classified as woodland was estimated from GIS mapping provided by Hamilton.

Agricultural and land based emissions are calculated as change of activities, uses, and land over time. In the BAP and in future scenarios, land that is predominantly forested or agricultural that is projected to be developed will have population and floor space per person associated with it. Floorspace is assigned through building type, and the resulting net loss of open or undeveloped land results in a net increase in GHG emissions associated with that land.

Carbon Sequestration

In the model, carbon sequestration, or the capture and storage of GHG emissions, is a net effect of growing increased woodlands, forests, and street trees. An absorption factor is added to a type of tree, or land that is recovered and then provided as a total sequestration figure, or in other words as a GHG emissions reduction. This total is kept separate from the total GHG emissions produced in the community, then provided as net GHG emissions for the community.

Carbon absorption factors vary depending on the age of a forest, where an older forest is considered to be a carbon sink that already contains a maximum amount of carbon, whereas a newly planted or developing forest will continue to absorb increasing GHGs as it matures.

The calculation of the sources and sinks involves tracking changes in land use; a net increase in area of forest, wetland, or grassland represents a greater GHG sink and vice versa.

The Intergovernmental Panel on Climate Change's (IPCC, 2019) Guidelines for National Greenhouse Gas Inventories recommend reporting sequestration based on changes within and conversions between land-use types, including: forest land, cropland, grassland, wetlands, and settlements.

4.5 DATA AND ASSUMPTIONS

A detailed table is available under Appendix 2 showing the data used and assumptions made to develop the BAP scenario for Hamilton. A separate breakdown of how the inventory complies with the GHG protocol can be found under Appendix 3.

5. Scenario Development

CityInSight is designed to support the use of scenarios as a mechanism to evaluate potential futures for communities. A scenario is an internally consistent view of what the future might turn out to be—not a forecast, but one possible future outcome. A good set of scenarios is both plausible and surprising, but scenarios can also be misleading if, for example, there are too few so that one scenario is ‘‘good’’ and the other ‘‘bad”.

Another consideration is to ensure that the name of the scenario does not bias the audience. Lastly, scenarios must represent serious considerations defined not only by planning staff, but also by community members.

Scenarios are generated by identifying population projections into the future, identifying how many additional households are required and then applying those additional households according to existing land-use plans and/or alternative scenarios. A simplified transportation model evaluates the impact of the new development on transportation behaviour, building types, agricultural and forest land and other variables.

5.1 BUSINESS-AS-PLANNED SCENARIO

At this stage, using current and future planned policies, it is time to create the first scenario from our assumptions.

The business-as-planned (BAP) scenario will offer a scenario moving towards the year 2050, where there is an absence of new substantive policy measures.

Methodology:

1. Calibrate model and develop 2016 baseline using observed data and filling in gaps with assumptions where necessary;
2. Input existing projected quantitative data to 2050 where available:
   - Population, employment and households’ projections from City by transport zone;
   - Build out (buildings) projections from City by transport zone;
   - Transport modelling from City;
3. Where quantitative projections are not carried through to 2050 (e.g. completed to 2041), extrapolate the projected trend to 2050;
4. Where specific quantitative projections are not available, develop projections through:
   - Analyzing current on the ground action in the City (reviewing actions plans, engagement with staff etc.), and where possible, quantifying the action;
   - Analyzing existing policy that has potential impact for the city, and where possible, quantifying the potential impact.

A list of BAP data sources and assumptions can be found in the BAP Data and Assumptions Table in Appendix 2.

5.2 LOW-CARBON SCENARIO

Using the business-as-planned scenario as a jumping-off point, we now create the low-carbon scenario, mapped out to the target year (usually 2050). All potential actions are identified.

CityInSight is designed to project how the energy flow picture and emissions profile will change in the long term by modelling potential change in the context (e.g. population, development patterns), projecting energy services demand intensities, and projecting the composition of energy system infrastructure, often with stocks.

Policies, actions and strategies

Throughout the CityInSight accounting framework there are input variables—for user assumptions and projections—which collectively comprise an interface to controlling the physical trajectory of the urban energy system and resultant emissions. Different settings for these inputs can be interpreted as alternative behaviour of various actors or institutions in the energy system (e.g. households, various levels of government, industry, etc.). This interface can be directly set or controlled by the model user, to create "what if" type scenarios. The modelling platform upon which CityInSight is built allows for a "higher layer" of logic to operate at this physical-behavioural interface, in effect enabling a flexible mix-and-match approach to behavioral models which connect to the same constraining physical model. CityInSight is able to explore a wide variety of policies, actions and strategies. The resolution of CityInSight enables the user to apply scenarios to specific neighbourhoods, technologies, building or vehicle types or eras, and configurations of the built environment.

Methodology

1. Develop list of potential actions and strategies from consultant expertise, input from city staff and community engagement (i.e. catalogue);
2. Identify the technological potential of each action (or group of actions) to reduce energy and emissions by quantifying actions:
    a. Firstly, if the action or strategy specifically incorporates a projection or target; or,
    b. Secondly, if there is a stated intention or goal, review best practices and literature to quantify that goal;
    c. Thirdly, identify any actions that are either overlapping and/or include dependencies on other actions;
3. Translate the actions into quantified assumptions over time;
4. Apply the assumptions to relevant sectors in the model to develop a low-carbon scenario (i.e. apply the technological potential of the actions to the model);
5. Analyze results of the low-carbon scenario against the GHG reduction target;
6. If the target is not achieved, identify variables which can be scaled up and provide a rationale for doing so;
7. Iteratively adjust variables to identify a pathway to the GHG target;

8. Develop marginal abatement curve for the low-carbon scenario;
9. Define criteria to evaluate low carbon scenario (i.e. identify criteria for multi-criteria analysis);
10. Prioritize actions of low carbon scenario through multi-criteria analysis (along with other criteria e.g. health, prosperity etc.);
11. Revise scenario to reflect prioritization for final low carbon scenario, removing and scaling the level of ambition of actions according to the evaluation results.

6. Addressing Uncertainty

There is extensive discussion of the uncertainty in models and modelling results. The assumptions underlying a model can be from other locations or large data sets and do not reflect local conditions or behaviours, and even if they did accurately reflect local conditions, it is exceptionally difficult to predict how those conditions and behaviours will respond to broader societal changes and what those broader societal changes will be (the “unknown unknowns”).

An analysis of land-use models used to assess climate change impacts for Sydney, Australia, emphasized that the models should be used only for scenario testing and not forecasting because of limits to the possible precision. The importance of this point is demonstrated by the fact that the models considered in this analysis can generate a range of outcomes from the same starting point (Oydell et al., 2007, pg. 10).

The modelling approach identifies four strategies for managing uncertainty applicable to community energy and emissions modelling:

1. Sensitivity analysis: From a methodological perspective, one of the most basic ways of studying complex models is sensitivity analysis, quantifying uncertainty in a model’s output. To perform this assessment, each of the model’s input parameters is described as being drawn from a statistical distribution in order to capture the uncertainty in the parameter’s true value (Keirstead, Jennings, and Sivakumar, 2012).

> **Approach:** Each of the variables will be adjusted to illustrate the impact that an error of that magnitude has on the overall total.

2. Calibration: One way to challenge the untested assumptions is the use of ‘back-casting’ to ensure the model can ‘forecast’ the past accurately. The model can then be calibrated to generate historical outcomes, which usually refers to "parameter adjustments" that "force" the model to better replicate observed data.

> **Approach:** Variables for which there are two independent sources of data are calibrated in the model. For example, the model calibrates building energy use (derived from buildings data) against actual electricity data from the electricity distributor.

3. Scenario analysis: Scenarios are used to demonstrate that a range of future outcomes are possible given the current conditions that no one scenario is more likely than another.

> **Approach:** The model will develop a reference scenario

4. Transparency: The provision of detailed sources for all assumptions is critical to enabling policy-makers to understand the uncertainty intrinsic in a model.

Approach: The assumptions and inputs are presented in this document.

Appendix D.1: Data Tables

COMMUNITY ENERGY

Table 5. Community energy consumption tabulated results, 2016 and 2050 (BAP).

ENERGY BY SECTOR (PJ)	2016	SHARE 2016	2050 (BAP)	SHARE 2050	% +/- 2016-2050
Commercial	13,428,789	10%	19,038,002	13%	42%
Industrial	81,571,437	60%	89,169,966	60%	9%
Municipal	724,732	1%	340,281	0%	-53%
Residential	17,671,871	13%	17,185,473	11%	-3%
Transportation	23,251,634	17%	23,719,708	16%	2%
Total	136,648,464	100%	149,453,431	100%	9%
Energy by fuel (PJ)					
Coal	49,294,380	36%	51,941,550	35%	5%
Diesel	4,249,736	3%	4,054,917	3%	-5%
District Energy	127,260	0%	167,620	0%	32%
Fuel Oil	394,323	0%	401,744	0%	2%
Gasoline	18,843,170	14%	17,070,310	11%	-9%
Grid Electricity	14,824,855	11%	20,956,082	14%	41%
Local Electricity	93,277	0%	132,975	0%	43%
Natural Gas	47,312,496	35%	52,872,359	35%	12%
Other	204,687	0%	276,059	0%	35%
Propane	1,268,582	1%	1,522,535	1%	20%
Wood	35,697	0%	57,014	0%	60%
Total	136,648,464	100%	149,453,431	100%	9%
Energy per Capita (GJ)	243,182		174,202		-28%

COMMUNITY EMISSIONS

Table 6. Per capita emissions, 2016 and 2050 (BAP).

EMISSIONS BY SECTOR (TCO_2E)	2016	2050 (BAP)	% +/- (2016-2050)
Emissions per capita (tCO_2e/person)	15.5	11.2	-28%

Table 7. Community emissions tabulated results, 2016 and 2050 (BAP).

EMISSIONS BY SECTOR (TCO_2E)	2016	SHARE 2016	2050 (BAP)	SHARE 2050	% +/- (2016-2050)
Agriculture and Livestock (AFOLU)	32,070	0%	32,070	0%	0%
Commercial	565,821	6%	881,018	9%	55%
Energy Production	16,553	0%	19,776	0%	19%
Fugitive[14]	58,178	0%	67,226	0%	16%
Industrial	5,594,389	1%	6,141,107	1%	10%
Municipal	21,475	64%	12,053	64%	-44%
Residential	691,884	8%	761,726	8%	10%
Transportation	1,671,042	19%	1,600,565	17%	-4%
Waste	58,155	1%	97,209	1%	67%
Total	8,709,567	100%	9,612,750	100%	10%
EMISSIONS BY FUEL (TCO_2E)	**2016**	**SHARE 2016**	**2050 (BAP)**	**SHARE 2050**	**% +/- (2016-2050)**
Coal	4,313,227	50%	4,544,853	47%	5%
Diesel	315,710	4%	301,292	3%	-5%
Fuel Oil	28,054	0%	29,140	0%	4%
Gasoline	1,263,391	15%	1,142,987	12%	-10%
Grid Electricity	155,960	2%	514,348	5%	230%
Natural Gas	2,319,682	27%	2,694,368	28%	16%
Non-Energy	148,403	2%	196,504	2%	32%
Other	87,433	1%	87,433	1%	0%
Propane	77,591	1%	101,653	1%	31%
RNG	38	0%	38	0%	0%
Wood	79	0%	133	0%	69%
Total	8,709,567	100%	9,612,750	100%	10%

[14] Fugitive emissions account for unintentional emissions associated with the transportation and distribution of natural gas within the city (through equipment leaks, accidental releases etc.) that is used within the buildings sector.

BUILDING SECTOR

Table 8. Buildings sector energy tabulated results, 2016 and 2050 (BAP).

BUILDINGS ENERGY (PJ) BY BUILDING TYPE	2016	SHARE 2016	2050 (BAP)	SHARE 2050	% +/- 2016-2050
Commercial	13,428,789	12%	19,037,997	15%	42%
Industrial	81,571,440	72%	89,169,966	71%	9%
Municipal	724,732	1%	340,281	0%	-53%
Residential	17,671,872	16%	17,185,473	14%	-3%
Total	113,396,833	100%	125,733,718	100%	11%
BUILDINGS ENERGY (PJ) BY FUEL	**2016**	**SHARE 2016**	**2050 (BAP)**	**SHARE 2050**	**% +/- 2016-2050**
Coal	49,294,383	43%	51,941,548	41%	5%
Diesel	394,323	0%	401,744	0%	2%
District Energy	127,260	0%	167,620	0%	32%
Grid Electricity	14,824,533	13%	18,668,506	15%	26%
Local Electricity	93,276	0%	125,923	0%	35%
Natural Gas	47,234,017	42%	52,649,565	42%	11%
Other	124,761	0%	199,263	0%	60%
Propane	1,268,582	1%	1,522,535	1%	20%
Wood	35,697	0%	57,014	0%	60%
Total	113,396,833	100%	125,733,718	100%	11%
BUILDINGS ENERGY (PJ) BY END USE	**2016**	**SHARE 2016**	**2050 (BAP)**	**SHARE 2050**	**% +/- 2016-2050**
Industrial Processes	78,259,977	69%	86,689,744	69%	11%
Lighting	1,768,558	2%	2,519,603	2%	42%
Major Appliances	893,432	1%	1,055,109	1%	18%
Plug Load	2,414,420	2%	3,745,207	3%	55%
Space Cooling	769,309	1%	1,513,064	1%	97%
Space Heating	21,710,682	19%	22,094,113	18%	2%
Water Heating	7,580,454	7%	8,116,879	6%	7%
Total	113,396,833	100%	125,733,718	100%	11%

Table 9. Buildings sector emissions tabulated results, 2016 and 2050 (BAP).

BUILDINGS EMISSIONS ($KTCO_2E$) BY BUILDING TYPE	2016	SHARE 2016	2050 (BAP)	SHARE 2050	% +/- (2016-2050)
Commercial	565,821	8%	881,018	11%	56%
Municipal	21,475	0%	12,053	0%	-44%
Industrial	5,594,389	81%	6,141,107	79%	10%
Residential	691,884	10%	761,726	10%	10%
Total	6,873,569	100%	7,795,904	100%	100%
BUILDINGS EMISSIONS ($KTCO_2E$) BY FUEL	**2016**	**SHARE 2016**	**2050 (BAP)**	**SHARE 2050**	**% +/- (2016-2050)**
Coal	4,313,227	63%	4,544,853	58%	6%
Diesel	28,054	0%	29,140	0%	4%
Grid Electricity	155,956	2%	458,284	6%	-100%
Natural Gas	2,298,623	33%	2,661,802	34%	16%
Propane	77,591	1%	101,653	1%	29%
Wood	42	0%	67	0%	61%
Total	6,873,494	100%	7,795,800	100%	7%
BUILDINGS EMISSIONS (TCO_2E) BY END USE	**2016**	**SHARE 2016**	**2050 (BAP)**	**SHARE 2050**	**% +/- (2016-2050)**
Industrial Processes	5,443,892	79%	6,025,759	77%	8%
Lighting	18,389	0%	62,592	1%	-100%
Major Appliances	13,655	0%	28,865	0%	-53%
Plug Load	32,006	0%	101,406	1%	-66%
Space Cooling	14,785	0%	35,631	0%	-59%
Space Heating	1,010,611	15%	1,168,979	15%	9%
Water Heating	340,157	5%	372,568	5%	3%
Total	6,873,494	100%	7,795,800	100%	7%

TRANSPORTATION SECTOR[15]

Table 10. Transportation sector energy tabulated results, 2016 and 2050 (BAP).

TRANSPORTATION ENERGY (GJ) BY FUEL	2016	SHARE 2016	2050 (BAP)	SHARE 2050	% +/- (2016-2050)
Diesel	4,329,662	19%	4,131,714	17%	-5%
Gas	18,921,647	81%	17,293,101	73%	-9%
Grid electricity	323	0%	2,294,893	10%	709525%
Total	23,251,632	100%	23,719,708	100%	2%
TRANSPORTATION ENERGY (GJ) BY VEHICLE TYPE	**2016**	**SHARE 2016**	**2050 (BAP)**	**SHARE 2050**	**% +/- (2016-2050)**
Car	8,724,935	38%	6,760,249	29%	-23%
Heavy truck	1,347,873	6%	1,532,758	6%	14%
Light truck	7,625,298	33%	9,883,913	42%	30%
Marine	561,482	2%	561,482	2%	0%
Off Road	3,981,927	17%	3,981,927	17%	0%
Rail	718,298	3%	718,298	3%	0%
Urban Bus	291,820	1%	281,081	1%	-4%
Total	23,251,632	100%	23,719,708	100%	2%

Table 11. Transportation Emissions, tabulated results, 2016 and 2050 (BAP).

TRANSPORTATION EMISSIONS (TCO_2E) BY FUEL	2016	SHARE 2016	2050 (BAP)	SHARE 2050	% +/- (2016-2050)
Diesel & marine fuel	315,710	19%	290,255	18%	-5%
Gas	1,263,391	76%	1,177,009	73%	-9%
Grid electricity	3	0%	55,618	3%	1685297%
Aviation Fuel	91,938	6%	87,433	5%	0%
Total	1,671,042	100%	1,610,315	100%	-4%
TRANSPORTATION EMISSIONS ($KTCO_2E$) BY VEHICLE TYPE	**2016**	**SHARE 2016**	**2050 (BAP)**	**SHARE 2050**	**% +/- (2016-2050)**
Car	582,925	35%	442,949	28%	-26%
Light Truck	509,566	30%	107,398	7%	14%

[15] Please note the totals in these transportations tables are slightly higher (<1%) than the transportation sector totals in the community-wide tables above.

TRANSPORTATION EMISSIONS (TCO_2E) BY FUEL	2016	SHARE 2016	2050 (BAP)	SHARE 2050	% +/- (2016-2050)
Heavy Truck	93,977	6%	647,437	40%	23%
Urban Bus	19,466	1%	39,454	2%	0%
Rail	55,408	3%	222,699	14%	-16%
Marine	44,317	3%	50,472	3%	0%
Aviation	87,433	5%	12,472	1%	-34%
Off Road	277,949	17%	87,433	5%	0%
Total	1,671,041	100%	1,610,314	100%	-4%

WASTE AND WASTE WASTER

Table 12. Waste Sector Emissions, 2016 and 2050

WASTE EMISSIONS ($KTCO_2E$) BY FUEL	2016	SHARE 2016	2050 (BAP)	SHARE 2050	% +/- (2016-2050)
Biological	8,302	14%	15,921	16%	92%
Landfill	45,172	78%	74,140	76%	64%
Wastewater	4,681	8%	7,148	7%	53%
Total	58,155	100%	97,209	100%	67%

CARBON SEQUESTRATION

Table 13. Land Use Change Emissions in $KtCO_2e$ per year 2021-2050

LULUCF CATEGORY	SUBCATEGORY	(T/HA/YR)	2021	2026	2031	2036	2041	2046	2050
A. Forest land	1. Forest land remaining forest land	-7.92	-272	-272	-272	-272	-272	-272	-272
B. Cropland	1. Cropland remaining cropland	0.64	23	23	23	23	23	23	23
E. Settlements	1. Settlements remaining settlements	-5.76	-69	-69	-70	-71	-71	-72	-73
E. Settlements	2.1 Forest land converted to settlements	274.48	0	0	0	0	0	0	0
E. Settlements	2.2 Cropland converted to settlements	54.08	1	1	9	1	4	7	8
	Total		-317	-317	-310	-318	-316	-313	-314

Appendix D.2: Key BAP Assumptions

CATEGORY	DATA/ASSUMPTION	SOURCE	SUMMARY APPROACH/METHODOLOGY
Population & employment	Population: 561,919 (2016) 696,356 (2031) 781,203 (2041) Employment: 206,205 (2016) 275,233 (2031) 321,132 (2041) In both cases, linearly projected through to 2050	Population and employment per traffic zone as per City projections and draft estimates through to 2041	Population and employment projections by zone to 2050 are applied and spatially allocated in the model. Post 2041 projections and spatial allocation were not available from the City. The population and employment trends for 2017-2041 were extrapolated to get totals for 2050. Spatial allocation of post 2041 population and employment was distributed according to similar patterns of growth exhibited between 2017-2041.
INDUSTRIAL PROCESS ENERGY			
Industrial energy consumption	Assume energy use intensity and emissions profile stays constant from 2016-2050.	Canadian Energy and Emissions Data Centre: https://cieedacdb.rem.sfu.ca/	
Steel (AMD)	Assume energy use intensity and emissions profile stays constant.	Basic Facility Information for Toxics Reduction Act (TRA) 455/09, ArcelorMittal Dofasco, July 13, 2018 For process fuel and energy intensities: Best Available Techniques (BAT) Reference Document for Iron and Steel Production Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control) 2013. Rainer Remus, Miguel A. Aguado-Monsonet. Serge Roudier, Luis Delgado Sancho	Assume energy use intensity and emissions profile stays constant from 2016-2050. ArcelorMittal Dofasco (AMD)'s steel production uses three blast furnaces which uses coal, coke, oil, natural gas and electricity to turn iron ore into hot metal in a blast furnace, and then this hot metal is turned into steel in a basic oxygen furnace, which uses electricity, natural gas and coke and some produced gasses to fire its operation.

CATEGORY	DATA/ASSUMPTION	SOURCE	SUMMARY APPROACH/METHODOLOGY
LAND USE PROJECTIONS			
Residential and non-residential floor space projections	Population and employment per zone, as per City projections through to 2041. 2041-2050: population and employment trends per zone are projected linearly (based on 2031-2041 data from City).	Places to Grow; GRIDS II consultant presentation to City Council, Q4 2019; Information provided by the City	New building floorspace (residential & non-residential) by zone to 2050 was derived using the population and employment projections provided by the City. New residential floorspace (households/ dwellings) is derived by allocating new dwellings based on the existing persons per unit. New dwellings by type are allocated to zones: - if zone already has dwellings, the existing dwelling type share is used for new builds - if zone does not have dwellings, existing dwelling type share from nearby zones is used for new builds - if population in a zone is projected to decrease, dwellings are removed - greenfield vs. infill designation is based on GIS data provided by the City New non-residential floorspace is derived by allocating new non-residential floorspace according to gross floor area per employee/job. New non-residential floorspace by type is allocated to zones - if zone already has employment, the existing employment sector shares are used along with gross floor area per employee - if zone does not have any employment, the employment shares from nearby zones are used along with gross floor area per employee - if employment in a zone decreases, non-residential buildings are removed - greenfield vs. infill designation is based on GIS data provided by the City

CATEGORY	DATA/ASSUMPTION	SOURCE	SUMMARY APPROACH/METHODOLOGY
BUILDINGS			
New buildings energy performance			
Residential	Starting in 2017: 15% energy improvement from the 2016 baseline for residential, and 13% for MURBs, C&I. As of 2019: new construction is 10% more efficient every 5 years.	Adapted from Report by Environmental Commissioner of Ontario. Conservation: Let's Get Serious 2015-2016. And, based on correspondence with Brendan Hayley , Policy Director at Efficiency Canada.	The Let's Get Serious report forecasts a building energy performance of 15% for low-rise housing, and 13% for large buildings. As of 2019, the province of Ontario has proposed abandoning the Ontario Building Code's more stringent energy efficiency standards in favour of harmonization with the National Building Code, which does not contain energy efficiency requirements. It is unclear whether Ontario will adopt the energy efficiency requirements contained in the National Energy Code. As such, a slightly more conservative 10% energy improvement every 5 years is used.
Multi-residential			
Commercial & Institutional			
Industrial			
Existing buildings energy performance			
Residential	Starting in 2020, retrofit existing building stock exponentially until in 2050 a total of 6% achieve 10% electricity and 10% heating savings	Pembina, Pathway Study on Existing Residential Buildings in Ottawa, 2019 (at 22).	Baseline efficiencies for each building type are derived in the model through calibration with observed data; for existing buildings, a 10% improvement in efficiency is applied.
Multi-residential			
Commercial & Institutional			
Industrial			
Municipal buildings	Starting in 2020, reduce energy intensity in all corporate facilities by 60% by 2050, with an interim goal of 45% by 2030 (against a 2005 base year, retrofits assumed to be implemented linearly)	City of Hamilton Corporate Energy Policy (2014); City of Hamilton Corporate Annual Energy Report (2016)	

CATEGORY	DATA/ASSUMPTION	SOURCE	SUMMARY APPROACH/METHODOLOGY
Fuel share by end use			
Space heating	Stays constant through to 2050	Canadian Energy Systems Analysis Research. Canadian Energy System Simulator. http://www.cesarnet.ca/research/caness-model .	Within the model, the starting point for fuel shares by end use is an Ontario average value for the given building type, which comes from CanESS. From there, the fuel shares are calibrated to track on observed natural gas and electricity use. Once calibrated, end use shares are held constant through the BAU.
Water heating	Stays constant through to 2050		
Space cooling	Stays constant through to 2050		
Projected climate impacts			
Heating & cooling degree days	Heating degree days (HDD) decrease and cooling degree days (CDD) increase from 2016-2050.	Climate Projections taken from Climate Atlas Canada. https://climateatlas.ca/data/city/444/plus30_2030_85/line	To account for the influence of projected climate change, energy use was adjusted according to the number of heating and cooling degree days. Average HDD and CDD values across all models for Hamilton in the RCP8.5 scenario is used. Climate projections are categorized in two representative concentration pathways (RCP) scenarios: a moderate emissions increase (RCP4.5), and a business as usual emissions scenario (RCP8.5).
Grid electricity emissions			
Grid electricity emissions factor	2016: 37.4 gCO_2e/kWh 2050: 83.7 gCO_2e/kwh 2016: CO_2: 35.0 g/kWh CH_4: 0.001 g/kWh N_2O: 0.001 g/kWh 2050: CO_2: 82.32 g/kWh CH_4: 0.02 g/kWh N_2O: 0.00 g/kWh	IESO, Annual Planning Outlook January 2020.	Emissions are expected to increase due to greater reliance on natural gas.

CATEGORY	DATA/ASSUMPTION	SOURCE	SUMMARY APPROACH/METHODOLOGY
Local energy generation			
Biogas (CHP, wastewater treatment plant electricity generation)	1.6 MW (69% capacity factor)	HRPI	CHP capacity is held constant to 2050.
Landfill gas	3.2 MW (36% capacity factor)	HRPI	Landfill gas capacity held constant to 2050.
Solar PV	1.7 MW (15% capacity factor) Starting in 2021, incrementally scale up to 10% of all buildings by 2050, solar PV systems which provide on average 30% of consumption for building electrical load for less than 5 storeys; 10% for multi-unit and commercial buildings	IESO Contracted Renewable Generation list (as of September 302019, updated quarterly). Growth assumption was made by SSG to reflect ongoing uptake of solar PV in net metering arrangements.	9.93418 MW Scale up to 10% of all buildings by 2050 have solar PV systems which provide on average 30% of consumption for building electrical load for less than 5 storeys; 10% for multi-unit and commercial buildings
Solar PV - ground mount	2.0 MW per year between 2018 and 2050 (~80 Ha) resulting in 66 MW	Assumption was made by SSG to reflect a base level of investments in commercial solar PV.	
Energy Storage	No storage deployed.		
District energy (CHP)	Staying constant from 2016: 4.1 eMW CHP, 17.18 MW heating, 19.9 MW cooling), Portlands DE coming online from 2019: 2 eMW CHP, 9.8 MW heating	HCE Inc.	

CATEGORY	DATA/ASSUMPTION	SOURCE	SUMMARY APPROACH/METHODOLOGY
TRANSPORTATION			
Transit			
Expansion of transit	Incremental increase in bus service from 2016 transit service to keep up with population growth through to 2050. Mode share assumed to stay constant to 2016-2050.	Transportation Tomorrow Survey, http://www.transportationtomorrow.on.ca/ In addition to data provided from the City.	Incremental increase in bus service from 2016 transit service to keep up with population growth through to 2050. Mode share assumed to stay constant to 2016-2050.
CNG/ Electric vehicle transit	Fleet turnover reflects increasing transition to CNG and electric. 50% electric and 50% CNG by 2050 (diesel stock completely phased out by 2050)	Transit fleet age and fuel provided by the City up to 2019.	
Clean Fuel Standard	10 g CO_2e/MJ by 2030 - staying constant till 2050.		The Clean Fuel Standard (CFS) will reduce carbon intensity standards for gaseous, liquid, and solid fossil fuels, incentivizing the development of cleaner fuel technologies and low-carbon alternatives. Detailed regulations are outstanding.
Active			
Cycling & walking infrastructure	Active transportation mode share is held constant to 2050.	Transportation Master Plan, review and update (2018)	No change in active transportation mode share assumed 2016-2050.

CATEGORY	DATA/ASSUMPTION	SOURCE	SUMMARY APPROACH/METHODOLOGY
Private & commercial vehicles			
Vehicle kilometers travelled	No data from City or other, derived from the model.	Expert estimates derived from location of residents, jobs, schools, and other services; Average trip lengths derived from Statistics Canada; Car registrations. (see text of DMA for further details)	Vehicle kilometres travelled projections are driven by buildings projections. The number and location of dwellings and non-residential buildings over time in the BAU 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. This estimate is calibrated against Kent Fuel Sales data within the City from 2016-2019.
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.

CATEGORY	DATA/ASSUMPTION	SOURCE	SUMMARY APPROACH/METHODOLOGY
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 BAU.
Electric vehicles (personal/ commercial)	Starting in 2020, 14% new sales by 2030; share holds constant to 2050	Reaching 30% plug-in vehicle sales by 2030: Modeling incentive and sales mandate strategies in Canada (Jonn Axsena; Michael Wolinetz, Transportation Research Part D: Transport and Environment Volume 65, December 2018, Pages 596-617)	Conservative estimate from study used. Moving out to 2050, we assume subsidies do not stay in place, and new sales are held constant.
Electric vehicles (commercial)	25% of new commercial vehicle sales are electric by 2050.	Fleet details provided by the City.	
Electric vehicles (corporate)	25% of new vehicle sales are electric by 2030.	Fleet details provided by the City.	
WASTE			
Waste generation	Existing per capita waste generation rates unchanged. (215,000 tonnes in 2016)	City Website	Waste generation per capita held constant from 2018-2050.
Waste diversion	48% of total waste diverted from landfill in 2016 (diversion of organics/ paper/plastic), increasing incrementally to 55% by 2021.	2014 Solid Waste Management Master Plan	Waste diversion rates increase slightly from 2016-2021, then held constant to 2050.
Waste treatment	Existing waste treatment processes unchanged.	Waste details provided by the City.	No change in waste treatment processes assumed 2016-2050.
Wastewater	Natural gas fueled pelletization system (as of 2021)	Details provided by the City.	Natural gas fueled pelletization system (as of 2021), 500 GJ, on the corporate side.

CATEGORY	DATA/ASSUMPTION	SOURCE	SUMMARY APPROACH/METHODOLOGY
FINANCIAL			
Energy costs	Energy intensity costs by fuel increase incrementally between 2016-2050 per projections.	National Energy Board. (2019). Canada's Energy Future 2016. Government of Canada.	NEB projections extend until 2040; extrapolated to 2050. Energy cost intensities are applied to energy consumption by fuel, derived by the model, to determine total annual energy and per household costs.
Carbon price	April 2019 ($20/tonne); April 2020 ($30/tonne); April 2021 ($40/tonne); April 2022 ($50/tonne). April 2030 ($170/tonne)	Federal government determines the report.	Held constant after 2030. Only applies to combustion emissions (i.e. not waste); and to small emitters (i.e. below 10kt/year). Large emitters (25kt+) are subject to a cap & trade-type system, where they could potentially profit. Medium emitters can opt in (10kt-25kt) and are likely to do so as it is likely to be financially advantageous.
Agricultural / Natural Systems			
Agricultural: Live Stock	Varies per animal Type Kg CH_4/ head Assume no change towards 2050 in livestock.	Agricultural Census; Environment and Climate Change Canada. National Inventory Report 1990-2016: Greenhouse Gas Sources and Sinks in Canada. Part 2 Table A3-30 CH4 Emission Factors for Enteric Fermentation for Cattle from 1990 to 2016 Table A3-37 Emission Factors to Estimate CH_4 Emissions from Manure Management for Cattle Subcategories	

CATEGORY	DATA/ASSUMPTION	SOURCE	SUMMARY APPROACH/METHODOLOGY
Agricultural Land Use & Forest Carbon Storage	128,532 acres of farmland area within the city boundary in 2016. It is reduced to reflect increased area developed for housing and non-residential development. No data provided on urban and rural forest cover, assumed to stay constant through to 2050.	Agricultural Census; Hamilton Agriculture Profile and Economic Impact Report; Hamilton Urban Forest Strategy (draft workplan) 2019; 2019 Refinement to the 2006 IPCC Guidelines on National Greenhouse Gas Inventories (2019 Refinement), Volume 4, Chapter 4, Table 4.9 (Updated), Temperate, Continental, Secondary > 20 years 2019 Refinement to the 2006 IPCC Guidelines on National Greenhouse Gas Inventories (2019 Refinement), Volume 4, Chapter 4, Table 4.4 (Updated), Temperate, Continental, North and South America, Natural (Other Broadleaf) 2006 IPCC Guidelines on National Greenhouse Gas Inventories, Volume 4, Chapter 4, Table 4.3, Temperate, All (No Refinement in 2019)	Land that is currently mostly forested or agricultural and is projected to be developed, will have an increase in GHG emissions associated with it due to assumed release of sequestered carbon, which is calculated using IPCC methodology.

Appendix D.3: GPC Emissions Scope

REASONS FOR EXCLUSION	
N/A	Not Applicable, or not included in scope
ID	Insufficient Data
NR	No Relevance, or limited activities identified
Other	Reason provided in other comments

GPC REF NO.	SCOPE	GHG EMISSIONS SOURCE	INCLUSION	REASON FOR EXCLUSION (IF APPLICABLE)
I		**STATIONARY ENERGY SOURCES**		
I.1		Residential buildings		
I.1.1	1	Emissions from fuel combustion within the city boundary	Yes	
I.1.2	2	Emissions from grid-supplied energy consumed within the city boundary	Yes	
I.1.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	Yes	
I.2		Commercial and institutional buildings/facilities		
I.2.1	1	Emissions from fuel combustion within the city boundary	Yes	
I.2.2	2	Emissions from grid-supplied energy consumed within the city boundary	Yes	
I.2.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	Yes	
I.3		Manufacturing industry and construction		
I.3.1	1	Emissions from fuel combustion within the city boundary	Yes	
I.3.2	2	Emissions from grid-supplied energy consumed within the city boundary	Yes	
I.3.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	Yes	
I.4		Energy industries		
I.4.1	1	Emissions from energy used in power plant auxiliary operations within the city boundary	Yes	

GPC REF NO.	SCOPE	GHG EMISSIONS SOURCE	INCLUSION	REASON FOR EXCLUSION (IF APPLICABLE)
I.4.2	2	Emissions from grid-supplied energy consumed in power plant auxiliary operations within the city boundary	Yes	
I.4.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption in power plant auxiliary operations	Yes	
I.4.4	1	Emissions from energy generation supplied to the grid	Yes	
I.5		Agriculture, forestry and fishing activities		
I.5.1	1	Emissions from fuel combustion within the city boundary	No	ID
I.5.2	2	Emissions from grid-supplied energy consumed within the city boundary	No	ID
I.5.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	No	ID
I.6		Non-specified sources		
I.6.1	1	Emissions from fuel combustion within the city boundary	No	ID
I.6.2	2	Emissions from grid-supplied energy consumed within the city boundary	No	ID
I.6.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	No	ID
I.7		Fugitive emissions from mining, processing, storage, and transportation of coal		
I.7.1	1	Emissions from fugitive emissions within the city boundary	No	ID
I.8		Fugitive emissions from oil and natural gas systems		
I.8.1	1	Emissions from fugitive emissions within the city boundary	Yes	

GPC REF NO.	SCOPE	GHG EMISSIONS SOURCE	INCLUSION	REASON FOR EXCLUSION (IF APPLICABLE)
II		**TRANSPORTATION**		
II.1		On-road transportation		
II.1.1	1	Emissions from fuel combustion for on-road transportation occurring within the city boundary	Yes	
II.1.2	2	Emissions from grid-supplied energy consumed within the city boundary for on-road transportation	Yes	

GPC REF NO.	SCOPE	GHG EMISSIONS SOURCE	INCLUSION	REASON FOR EXCLUSION (IF APPLICABLE)
II.1.3	3	Emissions from a portion of transboundary journeys occurring outside the city boundary, and transmission and distribution losses from grid-supplied energy consumption	Yes	
II.2		Railways		
II.2.1	1	Emissions from fuel combustion for railway transportation occurring within the city boundary	Yes	
II.2.2	2	Emissions from grid-supplied energy consumed within the city boundary for railways	Yes	
II.2.3	3	Emissions from a portion of transboundary journeys occurring outside the city boundary, and transmission and distribution losses from grid-supplied energy consumption	Yes	
II.3		Water-borne navigation		
II.3.1	1	Emissions from fuel combustion for waterborne navigation occurring within the city boundary	Yes	
II.3.2	2	Emissions from grid-supplied energy consumed within the city boundary for waterborne navigation	Yes	
II.3.3	3	Emissions from a portion of transboundary journeys occurring outside the city boundary, and transmission and distribution losses from grid-supplied energy consumption	Yes	

GPC REF NO.	SCOPE	GHG EMISSIONS SOURCE	INCLUSION	REASON FOR EXCLUSION (IF APPLICABLE)
III		**WASTE**		
III.1		Solid waste disposal		
III.1.1	1	Emissions from solid waste generated within the city boundary and disposed in landfills or open dumps within the city boundary	Yes	
III.1.2	3	Emissions from solid waste generated within the city boundary but disposed in landfills or open dumps outside the city boundary	Yes	
III.1.3	1	Emissions from waste generated outside the city boundary and disposed in landfills or open dumps within the city boundary	No	NR
III.2		Biological treatment of waste		
III.2.1	1	Emissions from solid waste generated within the city boundary that is treated biologically within the city boundary	Yes	

GPC REF NO.	SCOPE	GHG EMISSIONS SOURCE	INCLUSION	REASON FOR EXCLUSION (IF APPLICABLE)
III.2.2	3	Emissions from solid waste generated within the city boundary but treated biologically outside of the city boundary	No	ID
III.2.3	1	Emissions from waste generated outside the city boundary but treated biologically within the city boundary	No	NR
III.3		Incineration and open burning		
III.3.1	1	Emissions from solid waste generated and treated within the city boundary	No	NR
III.3.2	3	Emissions from solid waste generated within the city boundary but treated outside of the city boundary	No	NR
III.3.3	1	Emissions from waste generated outside the city boundary but treated within the city boundary	No	NR
III.4		Wastewater treatment and discharge		
III.4.1	1	Emissions from wastewater generated and treated within the city boundary	Yes	
III.4.2	3	Emissions from wastewater generated within the city boundary but treated outside of the city boundary	No	NR
III.4.3	1	Emissions from wastewater generated outside the city boundary	No	NR

GPC REF NO.	SCOPE	GHG EMISSIONS SOURCE	INCLUSION	REASON FOR EXCLUSION (IF APPLICABLE)
IV		**INDUSTRIAL PROCESSES AND PRODUCT USE (IPPU)**		
IV.1	1	Emissions from industrial processes occurring within the city boundary	Yes	ID
IV.2	1	Emissions from product use occurring within the city boundary	No	ID

GPC REF NO.	SCOPE	GHG EMISSIONS SOURCE	INCLUSION	REASON FOR EXCLUSION (IF APPLICABLE)
V		**AGRICULTURE, FORESTRY AND LAND USE (AFOLU)**		
V.1	1	Emissions from livestock within the city boundary	Yes	NR
V.2	1	Emissions from land within the city boundary	Yes	NR
V.3	1	Emissions from aggregate sources and non-CO2 emission sources on land within the city boundary	Yes	NR

GPC REF NO.	SCOPE	GHG EMISSIONS SOURCE	INCLUSION	REASON FOR EXCLUSION (IF APPLICABLE)
VI		**OTHER SCOPE 3**		
VI.1	3	Other Scope 3	No	N/A

Appendix D.4: Methodology for adjusting 2005 baseline energy use intensity targets relative to 2016 energy use intensities

ISSUE

The current CityInSight Community model uses a time horizon that spans a range of 2016 – 2050, with 2016 serving as the baseline conditions for the modeled community. As such, energy use intensity projections made with the model for the city's corporate portfolio will be relative to its 2016 baseline performances. However, the city of Hamilton's energy use intensity targets for their corporate portfolio were made based on their 2005 energy use intensity performances, which is not modelled within the CityInSight Community model's time horizon.

IMPLEMENTED SOLUTION

By using the City of Hamilton's Annual Energy Report for 2016, we were able to calculate the progress made between 2005 and 2016 in the City's corporate energy use intensity: a reduction of 24.1%. Based on this, the City's energy performance targets for their corporate portfolio, originally based on their 2005 energy performance evaluation, were adjusted to their 2016 energy performance evaluation. The result of this adjustment is as shown in Table 1.

Table 14. Comparison of energy use reduction targets for City of Hamilton's corporate portfolio

	2005	2016	2030	2050
2005 Baseline	0%	-24.1%	-45%	-60%
translates to the following energy use reduction with a 2016 Baseline		0%	-28.5%	-48%

APPENDIX E: Net-Zero Modelling Results

June 2021

Purpose

This document reports the energy use and greenhouse gas (GHG) emissions modelling results for the net-zero by 2050 scenario designed for the City of Hamilton. The net-zero assumptions that feed into the model were produced in consultation with the City and stakeholders and are outlined in a separate document.

The model results are shown in comparison to the base year (2016) and business-as-planned (BAP) energy use and emissions projections to 2050. The final results of the base year and BAP model were provided to the City in November 2020.

Disclaimer

Reasonable skill, care and diligence has been exercised to assess the information acquired during the preparation of this analysis, but no guarantees or warranties are made regarding the accuracy or completeness of this information. This document, the information it contains, the information and basis on which it relies, and the associated factors are subject to changes that are beyond the control of the author. The information provided by others is believed to be accurate but has not been verified.

This analysis includes strategic-level estimates of energy efficiency and greenhouse gas reduction potential represented by the proposed Community Energy and Emissions Plan (CEEP). The intent of this analysis is to help inform project stakeholders about the potential savings represented by the CEEP in relation to the modeled Business-as-Planned scenario. It should not be relied upon for other purposes without verification. The authors do not accept responsibility for the use of this analysis for any purpose other than that stated above, and do not accept responsibility to any third party for the use, in whole or in part, of the contents of this document.

This analysis applies to the City of Hamilton and cannot be applied to other jurisdictions without further analysis. Any use by the City of Hamilton, its sub-consultants or any third party, or any reliance on or decisions based on this document, are the responsibility of the user or third party.

Contents

Acronyms

BAP	business-as-planned
CEEP	Community Energy and Emissions Plan
CO_2e	carbon dioxide equivalent
EUI	energy use intensity
EV	electric vehicle
GHG	greenhouse gas
ICE	internal combustion engine
MT	megatonne
PJ	petajoule
PUV	personal use vehicle
REC	renewable electricity certificate
RNG	renewable natural gas

Units

GHG emissions

1 $MtCO_2e$ =	1,000,000 tCO_2e
1 $ktCO_2e$ =	1,000 tCO_2e
1 tCO_2e =	1,000 $kgCO_2e$
1 $kgCO_2e$ =	1,000 gCO_2e

Energy

1 MWh =	1,000 kWh
1 MWh =	3.6 GJ
1 GJ =	278 kWh
1 GJ =	1,000,000 J
1 MJ =	0.001 GJ
1 TJ =	1,000 GJ
1 PJ =	1,000,000 GJ

Introduction

This report outlines the modelling results of a technically-feasible and community-informed net-zero greenhouse gas (GHG) emissions pathway by 2050 for the entire city of Hamilton. It provides the technical analysis that underpins the city's Community Energy and Emissions Plan.

Net-zero carbon emissions means that any emissions that are released within the geographic boundary of the city in 2050 are offset by sequestration or the purchase of carbon offsets from other jurisdictions. This net-zero scenario maximizes local GHG reduction efforts before turning to sequestration and the purchase of offsets. It does so by:

1. First seeking to avoid unnecessary greenhouse gas emitting behaviour (e.g. sending organics to landfill);
2. Then turning to avoid unnecessary energy use (the primary source of the city's GHG emissions) and improving the efficiency of remaining energy uses; and
3. Finally, switching any remaining fossil fuel use to renewable energy sources.

The emphasis on energy conservation and efficiency helps reduce the need for costly additional energy generation capacity.

This report begins with an overall description of the community's energy and GHG emissions reduction from 2016 to 2050 by fuel and sector in the net-zero scenario, followed by more detailed sector-by-sector analysis.[1] This analysis includes a description of each modelled action and its associated GHG reduction in 2050 as compared to a business-as-planned scenario.

It is important to note that some actions have little or no emissions reductions associated with them but are critical to reducing the overall energy demand of the net-zero scenario and maximizing co-benefits like social wellbeing, public health, and local economic benefits.

All data associated with figures included in the body of the report can be found in the data tables at the end of this document.

Method

The modelling software used for this project is CityInSight, an energy, emissions, and finance model developed by SSG and whatIf? Technologies. The model supports the use of scenarios as a mechanism to evaluate potential futures for communities. A scenario is an internally consistent view of what the future might turn out to be—not a forecast, but one possible future outcome. Scenarios must represent serious considerations defined by City staff and community members. In order to build a scenario, critical input from stakeholders is needed to define the scope and magnitude of the carbon-reducing targets set in the model. More details about the engagement process can be found in the Final Report.

The municipal greenhouse gas inventory included for the baseline in the model is aligned with the Global Protocol for Community-Scale GHG Emissions Inventories (GPC).

For further information on modeling methodology, see the Baseline and Business-as-Planned 2016-2050 Energy and Emissions Report (Nov. 2020), at Part 2: Data, Methods and Assumptions Manual.

[1] 2016 is used as a base year as it is the most recent year available of the Federal Government's Census, which is a key data source for the model.

Net-Zero Pathway: Overall Energy + Emissions Outcomes

ENERGY REDUCTION, EFFICIENCY + FUEL SWITCHING

In order to reduce GHG emissions it is essential to reduce energy use and switch remaining fuel consumption from fossil fuels to clean energy sources. The net-zero pathway for Hamilton fosters an impressive shift in energy use by 2050 (see Figure 1), reducing the overall consumption by 24% compared with the BAP scenario.

Whereas natural gas in 2016 accounted for more than one third of energy use in the city, by 2050 it is completely removed from Hamilton's energy matrix. On the other hand, coal, gasoline, electricity from the grid, and diesel consumption, which combined account for 64% of total energy consumption in 2016, are dramatically reduced to only 4%. These are replaced primarily by renewable electricity, emissions-free biochar, green hydrogen, and renewable natural gas (see Table 1 at the end of this report for more detailed data).

In a net-zero scenario, the city's main energy sources become: carbon-free (or 'green') hydrogen (33% of the total), followed by biochar (24%), renewable electricity (29%),[2] as well as renewable natural gas ('RNG', 9%). This is a major transformation on how the community uses energy.

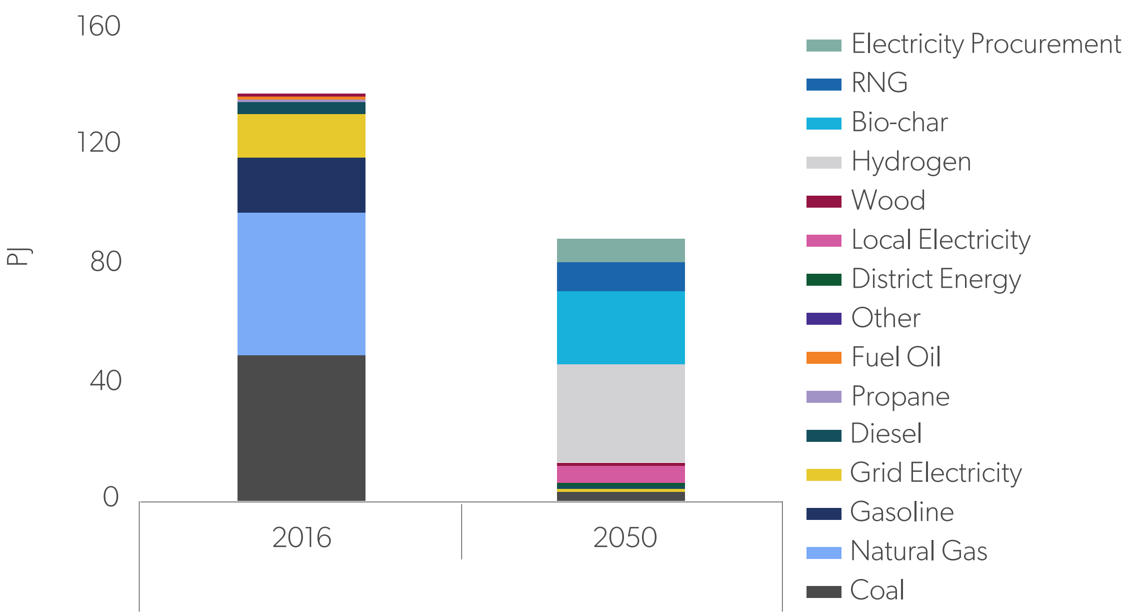


Figure 1. Hamilton's energy consumption in petajoules, by source, in the base year and the net-zero scenario in 2050.[3]

[2] Renewable electricity includes installations owned by the community (labelled as Local Electricity in Figure 1) and also from the purchase of renewable energy credits (labelled as RECs in Figure 1).

[3] 'Other' category in this chart includes propane, wood, district energy, fuel oil, and waste heat mainly.

WHERE ENERGY IS USED

Remaining the main energy consumer in Hamilton, the industrial sector reduces its energy demand by 15% by 2050 (see Figure 2). Transportation energy use in 2050 reduces more significantly, 50% by 2050, mostly due to the impressive energy efficiency of EVs,[4] and reduction in personal use vehicles. Residential buildings use 23% less energy in 2050 than in 2016; commercial buildings use 30% less. The municipal sector is projected to only consume 0.1% of community energy in 2050, as such it is not visible in Figure 2.

All sectors are analyzed in more detail below.

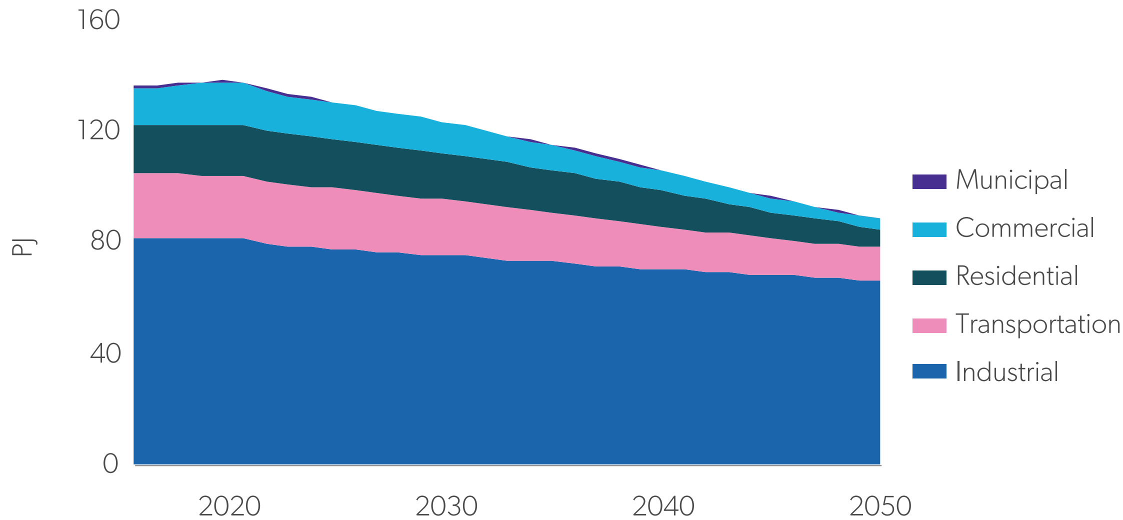


Figure 2. Net-zero pathway community energy use by sector (petajoules), 2016-2050.

HOW ENERGY IS USED

Transportation, space heating, and industrial process efficiency improvements drive major reductions in energy consumption in the net-zero scenario (see Figure 3), showing a 50%, 46%, and 12% reduction from their 2016 energy use respectively. The rest of the end-use categories play a much smaller role in overall energy reduction.

[4] Electric vehicles convert over 77% of the electrical energy from the grid to power at the wheels, whereas the internal combustion energy vehicles convert about 12%–30%. U.S. Department of Energy (n.d.) All-electric vehicles. Retrieved from: https://fueleconomy.gov/feg/evtech.shtml.

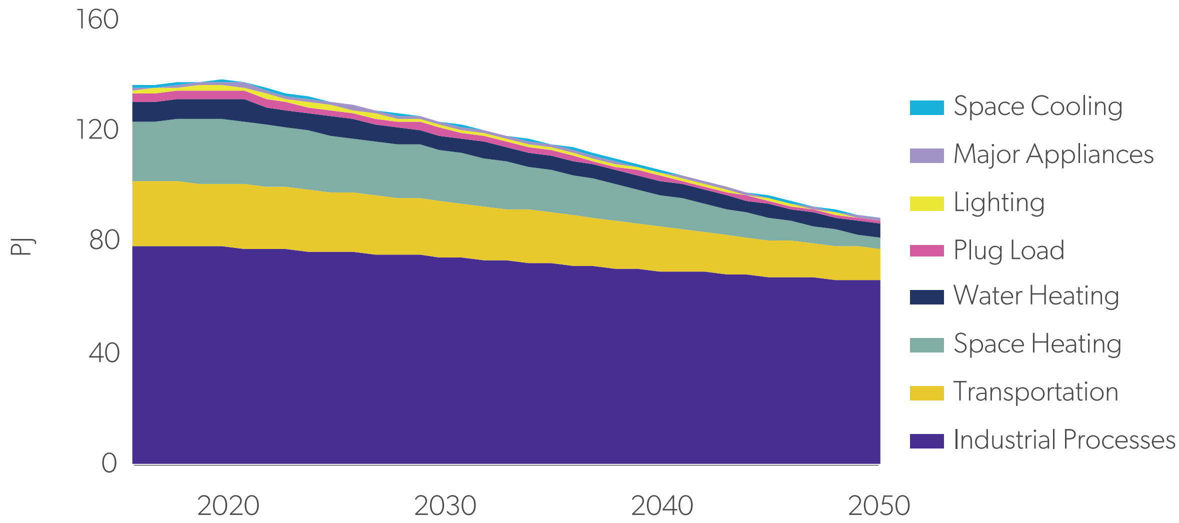


Figure 3. Net-zero pathway community energy use by end use (petajoules), 2016-2050.

EMISSION REDUCTIONS

By 2050, the net-zero pathway reduces GHG emissions by 95% compared to 2050 BAP levels (see Figure 4). This is an impressive outcome over a 30-year time period in an energy supply market currently dominated by fossil fuels.

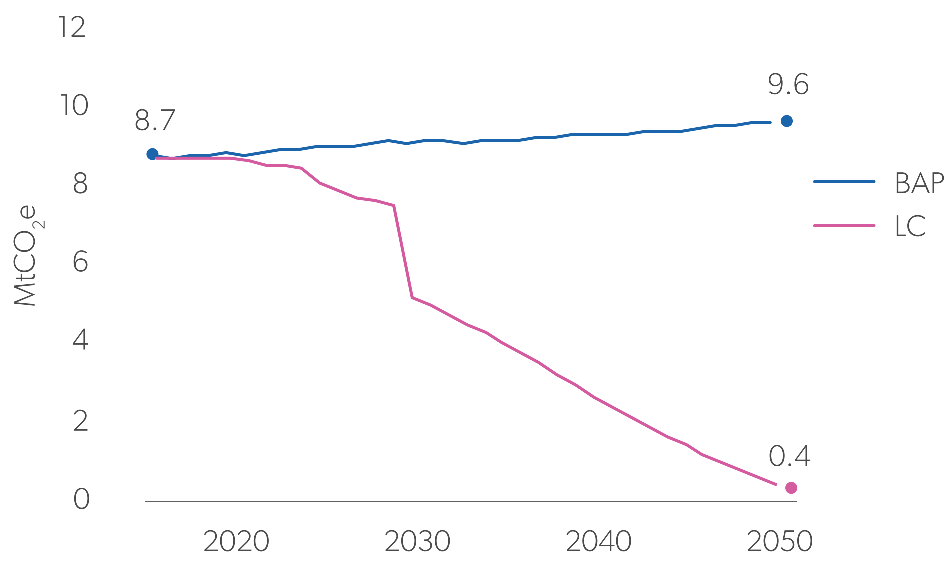


Figure 4. Net-zero pathway (blue) vs BAP scenario (orange) total community emissions (megatonnes of CO_2e), 2016-2050.

The following wedge chart shows how the dozens of net-zero pathway actions (or 'targets') build on one another to reduce the 2050 BAP emissions by 95%. A comprehensive table of modelled actions is provided in the separate document: "Table of Business-as-Planned and Low-Carbon Actions."

In order to achieve net-zero emissions by 2050, the remaining carbon gap will need to be addressed via the purchase of offsets or in future CEEP iterations via new technological developments, regulations or policies.

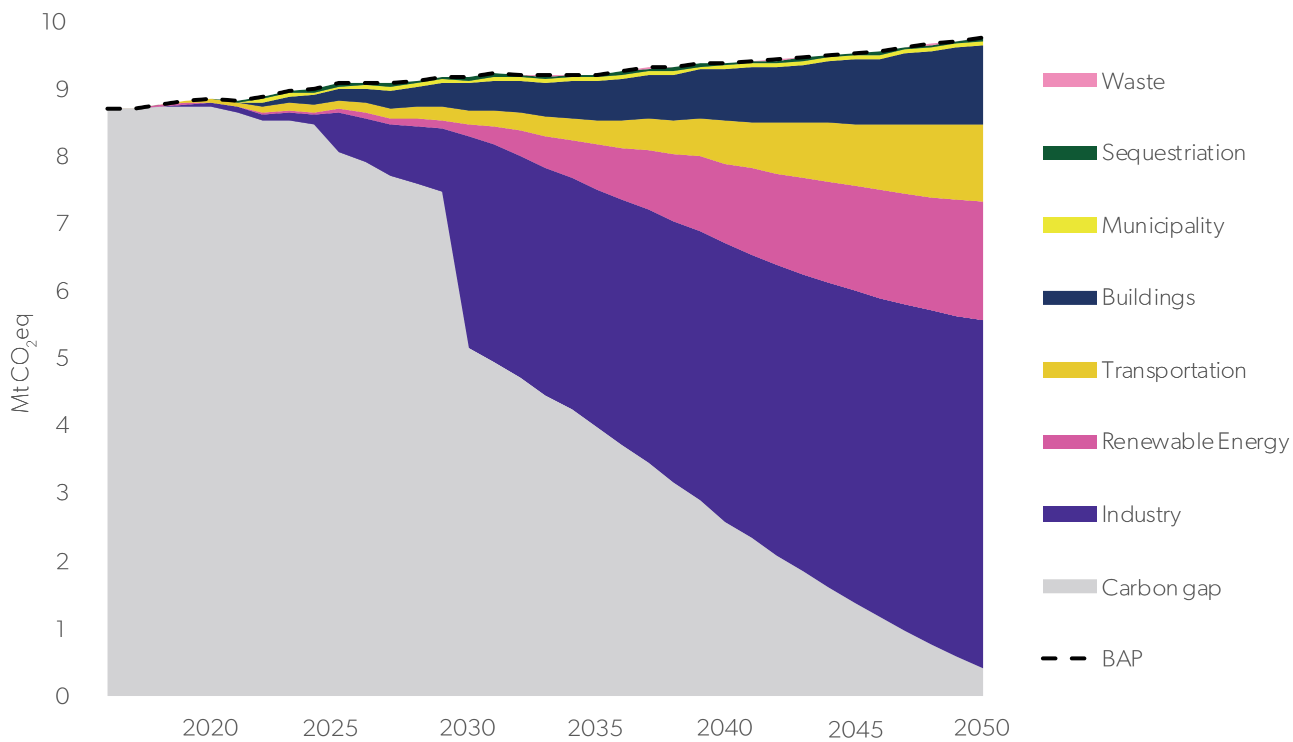


Figure 5. A wedges diagram illustrating the emissions reductions from a business-as-planned scenario associated with net-zero pathway actions (megatonnes of CO_2e). Note: For visual clarity, modelled actions have been grouped together by sector. A complete list of modelled actions is provided in Appendix A.

The emissions reduction of each modelled action is interdependent with other modelled actions. The wedges diagram shows the emissions reduction effect of implementing all actions considered. Only implementing some will affect the emissions reduction effectiveness of the others.

Industrial actions account for the biggest GHG reduction in the net-zero pathway, followed by the use of renewable energy sources such as RNG, renewable electricity, and green hydrogen.

Figure 5 includes the introduction of a carbon capture and sequestration (CCS) system in 2030 addressing GHG emissions from the steel mill; however, as the consumption of coal and natural gas at the steel mill is projected to decline through to 2050, the CCS becomes less relevant. Nevertheless, it is important for reducing cumulative emissions between 2030 and 2050.

The dramatic expansion of renewable and low-carbon energy use in the community ensures remaining energy consumption generates as few emissions as possible.

EMISSIONS BY ENERGY SOURCE

Natural gas emissions are completely removed from Hamilton's inventory in 2050, and emissions from coal, gasoline, diesel, and grid electricity are reduced by 97%, 95%, 75% and 99% respectively compared with 2016 (see Figure 6). The introduction of blue hydrogen (i.e., hydrogen produced from natural gas combustion) in the industrial sector in 2030 does reduce the sector's GHG emissions profile, but not completely, until it is replaced with zero-emissions green hydrogen by 2050. In contrast, the increase in biochar, RNG, and renewable electricity consumption does not translate into higher overall emissions as they are free or low emissions.

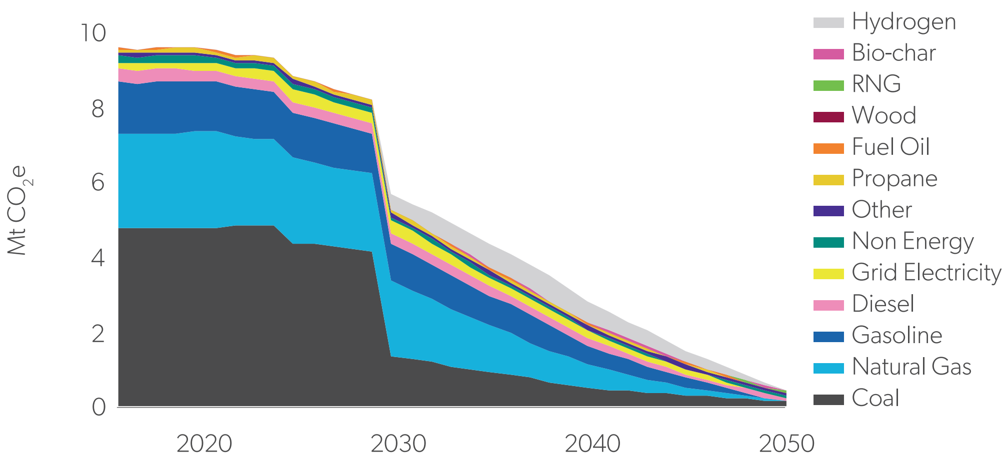


Figure 6. Net-zero pathway emissions by energy source (megatonnes of CO_2e), 2016-2050.[5]

EMISSIONS BY SECTOR

The net-zero pathway reduces emissions in all sectors. The greatest decrease in terms of net emissions comes from the industrial sector (5.4 Mt CO_2e, 97% compared with 2016) followed by transportation (1.5 Mt CO_2e, 88% compared with 2016), see Figure 7. Residential and commercial sectors come next with reductions of 0.7 and 0.5 MtCO_2e respectively (98% and 99% reductions compared with 2016). Transportation becomes the largest source of GHG emissions in 2050, with mainly aviation emissions remaining, but accounting only for 0.2 Mt CO_2e.

Waste emissions are reduced by 62%. The municipal sector reduces its emissions by 99%.

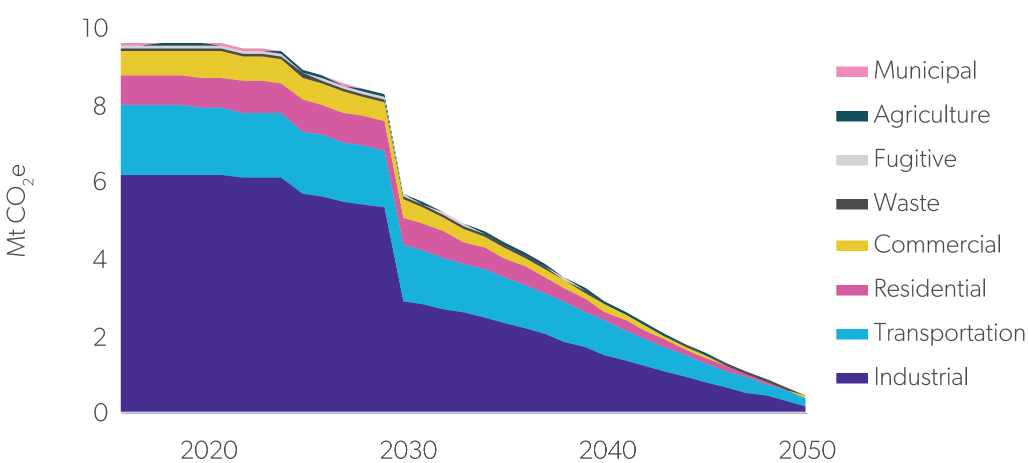


Figure 7. Net-zero pathway emissions by sector (megatonnes of CO_2e), 2016-2050.

[5] The 'Other' category includes emissions mainly from fuel oil, wood, propane, and biochar.

Net-Zero Pathway: Sector-by-Sector Energy + Emissions Outcomes

INDUSTRY

MODELLED ACTION	DESCRIPTION	% GHG REDUCTIONS NET-ZERO VS. BAP 2050
Steel mill carbon capture	In 2030 a carbon capture and storage system is installed at the steel mill with 50% of coal emissions reduced.	1.0%* (*note: an important source of cumulative GHG reductions between 2030-2050)
Steel fuel switch	Fuel switching at the steel mill: • Biochar replaces 10% of coal in 2025, up to 50% by 2050. • Blue hydrogen replaces 30% (relative to 2016) of coal use in 2030, increasing to 50% by 2040. • Blue hydrogen is replaced by green hydrogen starting in 2035 and 100% is achieved by 2050.	43.9%
Industrial efficiency	Improve industrial efficiency by 50% by 2050 in secondary industry facilities (non-steel).	8.0%

The industrial sector is the main energy consumer and GHG emitter in Hamilton in 2016. Steel is the primary industry in Hamilton, and specific actions were modelled for it. The priority was switching coal consumption to clean energy sources (see Figure 8), mainly hydrogen and biochar. Hydrogen comes first as ‘blue’ hydrogen in 2030, replacing 30% of total coal in 2016. This means that producing this energy source is still using fossil fuels but CO_2 emissions are being captured and sequestered. The transition to green hydrogen was assumed starting in 2035, achieving a 100% share in 2050. The remaining energy needs are met with the use of biochar which is a renewable fuel with low GHG emissions.

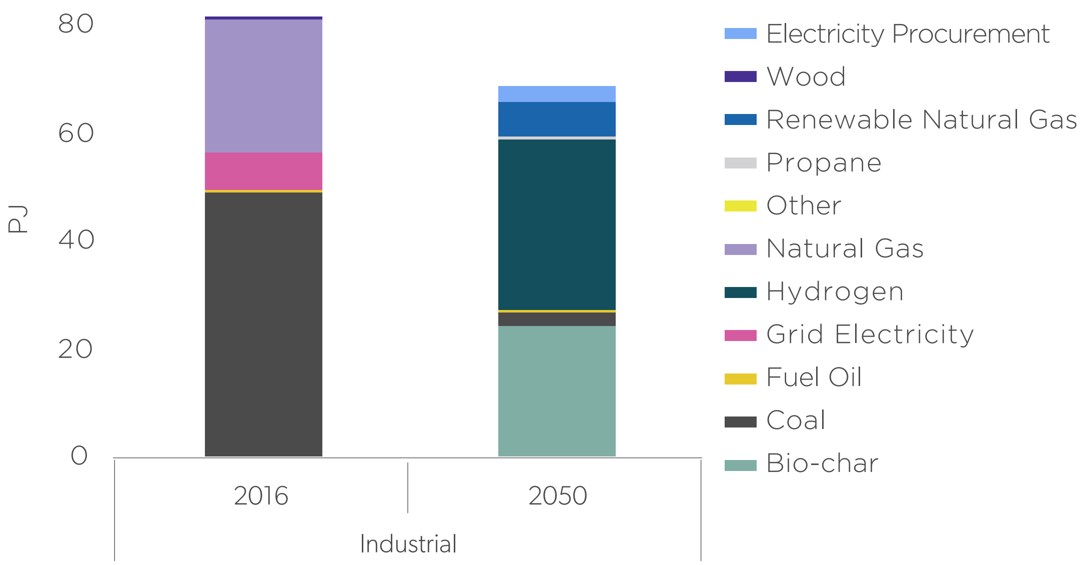


Figure 8. Industrial energy consumption by fuel type (petajoules), 2016 vs 2050.

For the remaining industry (a.k.a., secondary industry), 50% energy efficiency targets help explain a reduction in the overall industrial energy consumption of 15% shown in Figure 8. The Ontario 2019 Conservation Achievable Potential Study describes numerous measures that can be applied across the industrial sector to achieve deep energy efficiency improvements. However, no specific measures were modelled in CityInSight.

Industrial emissions show a dramatic reduction in 2050 (97% compared with 2016), as in addition to the decrease in energy consumption, new energy sources are zero- or low-emissions (see Figure 9).

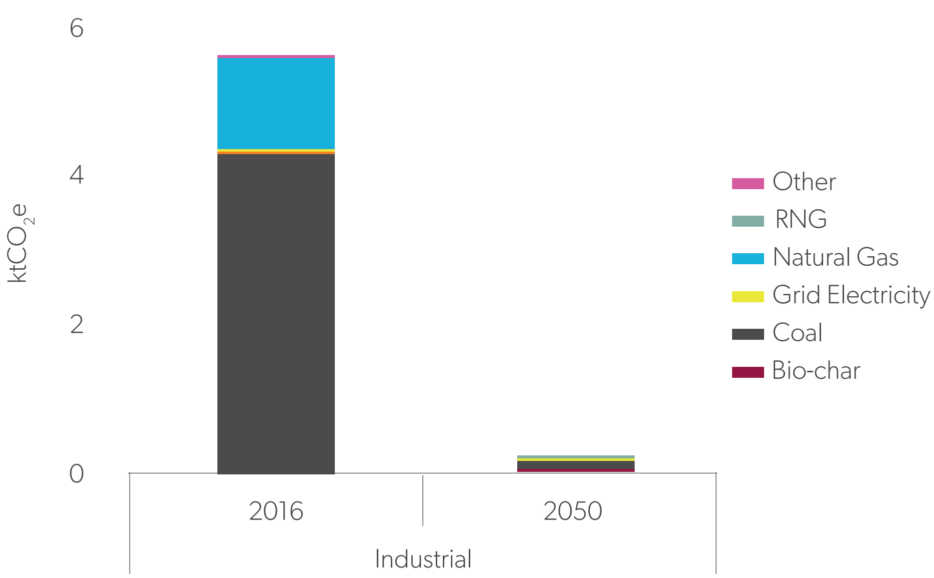


Figure 9. Industrial emissions by fuel type (megatonnes of CO_2e), 2016 vs 2050.

TRANSPORTATION

MODELLED ACTION	DESCRIPTION	% GHG REDUCTIONS NET-ZERO VS. BAP 2050
PUV electrification	10% of light-duty vehicles sales per year by 2025 are net-zero emissions; 30% by 2030; and 100% by 2040.	6.6%
Commercial fleet electrification	By 2050: • All heavy-duty vehicles are green-hydrogen based; and • Light-duty commercial vehicles are 100% electric.	4.0%
Trip reduction	• Private vehicle trips decline by 9% per person and vehicular trip lengths declined 6% by 2050. • All areas of Hamilton are affected.	0.9%
Marine efficiency	Increase efficiency by 50% by 2050.	0.2%
Electrify transit system	• Existing CNG fleet transitioned to RNG by 2025. • All other buses to be electric by 2035.	0.1%
E-bikes & EV car-share	By 2050, 10% of trips up to 10km are completed by E-Bike or EV Car-Share.	0.1%
Increase transit mode share	Increase transit mode share to 12% by 2031, then 15% by 2050 in the urban and whitebelt zones.	0.02%
Active mode shift	By 2050, mode shift 50% of 2km trips to walking and 5km to cycling in the urban and whitebelt zones.	0.00%

The transformation of the transportation sector over the 2016-2050 time period results in 88% reduced emissions (Figure 10).

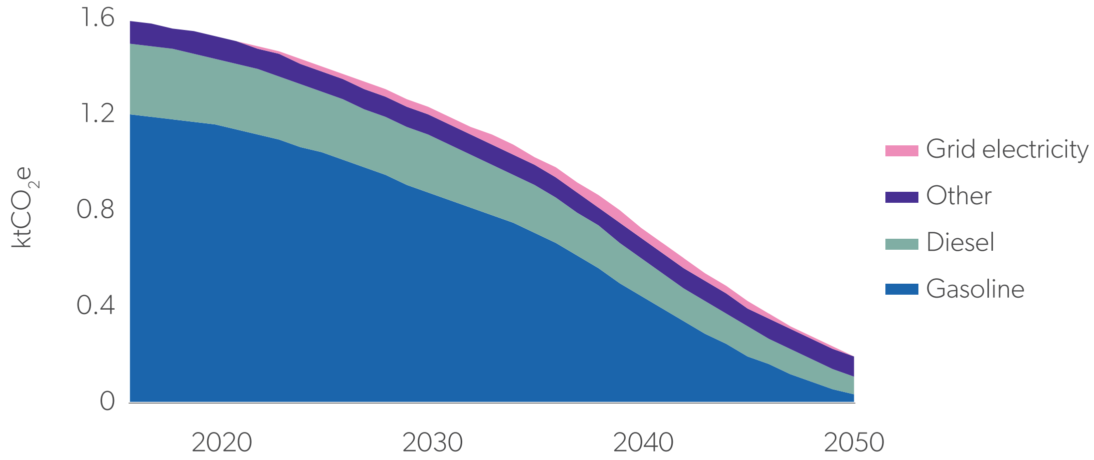
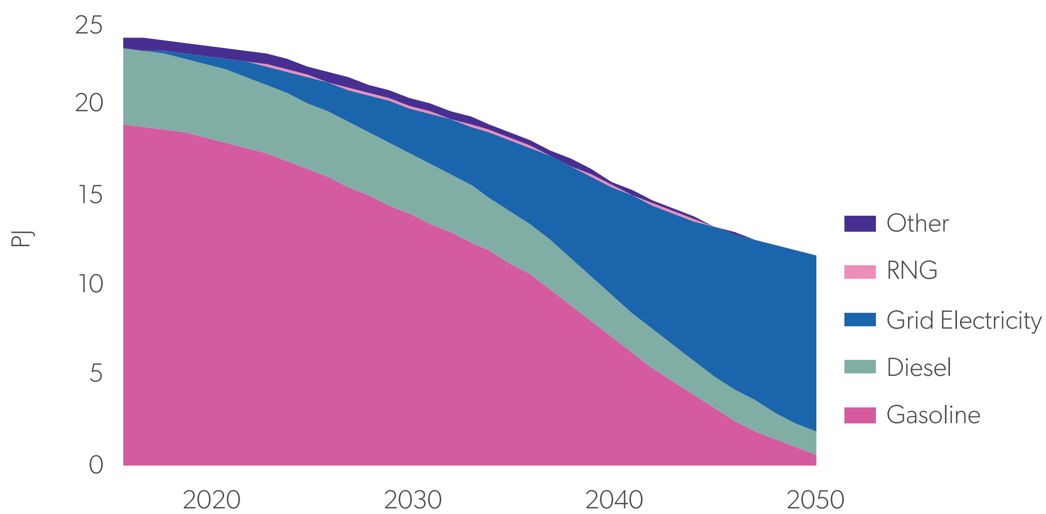


Figure 10. Transportation emissions for the net-zero pathway by fuel type, 2016-2050.[6]

The main driver for this decrease (89%) is the shift from internal combustion engines (ICE) to electric vehicles (EV), replacing gasoline and diesel demand with electricity. While originally coming from the provincial grid, this electricity is increasingly replaced with local renewable sources. Actions that avoid trip generation and trip distance also help reduce GHG emissions in Hamilton, accounting for 7% of the reductions in the transportation sector.

In addition to increased transit and active modes share in the urban and whitebelt zones (see Figure 12), the replacement of gasoline by electricity involves an important decrease in energy consumption (see Figure 11), as electric vehicles are much more efficient than their ICE counterparts.



Transportation energy consumption for the net-zero pathway by fuel type, 2016-2050.[7]

[6] 'Other' category includes aviation fuel and natural gas.

[7] 'Other' includes natural gas, ethanol, biodiesel, hydrogen, and RNG. Aviation fuel is not included in this chart as there was no data available for the energy analysis; 'Grid electricity' includes purchase of renewable energy certificates.

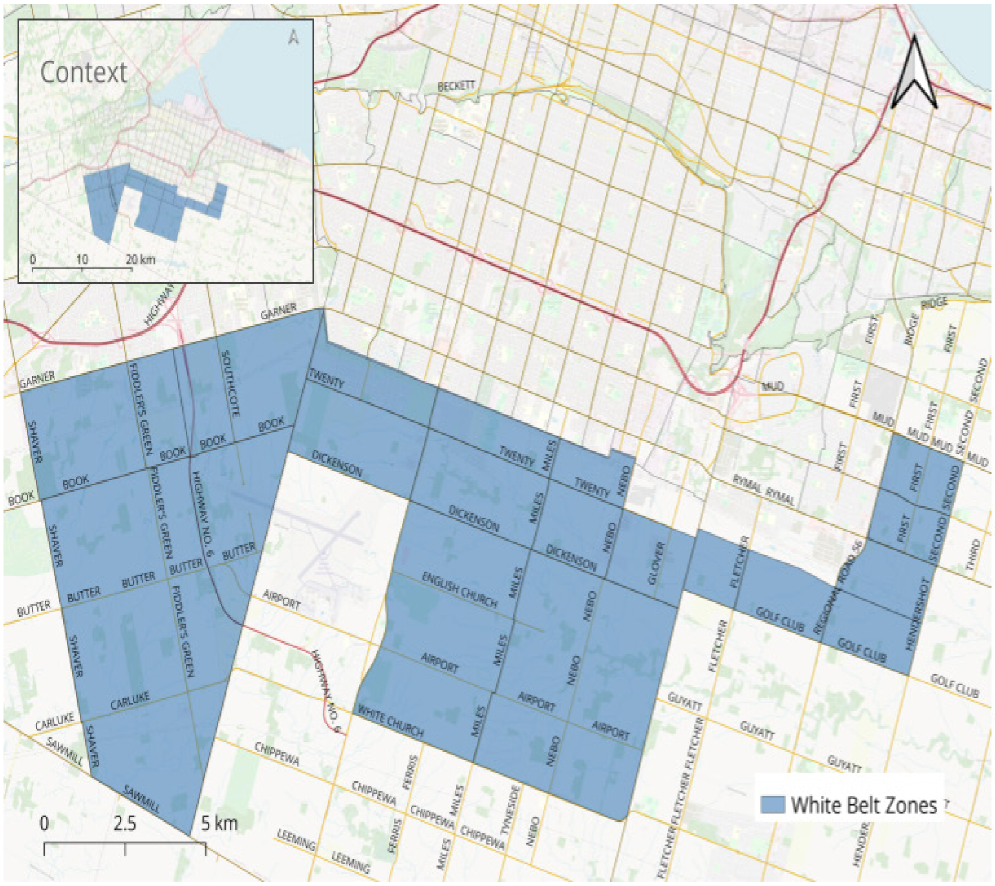


Figure 11. Traffic zones containing whitebelt zones.

(Note: Some whitebelt zones only cover a portion of the traffic zone they are in.)

COMMERCIAL AND RESIDENTIAL BUILDINGS

MODELLED ACTION	DESCRIPTION	% GHG REDUCTIONS NET-ZERO VS. BAP 2050
Heat pumps (for space and water heating)	• 90% of all pre-1980 dwellings switch to heat pumps by 2050. • 100% for all post-1980 dwellings switch to heat pumps by 2050.	4.3%
Retrofit non-residential	Starting in 2022, increase efficiency for 100% of commercial buildings by 50% by 2050.	2.7%
New non-residential EUI	• In 2026, new buildings are 30% more efficient. • In 2031, new buildings are 60% more efficient.	1.4%

MODELLED ACTION	DESCRIPTION	% GHG REDUCTIONS NET-ZERO VS. BAP 2050
Retrofit dwellings	• Starting in 2022, by 2050, all existing dwellings built before 1980 achieve average thermal savings of 50%; electrical savings of 50% (not including electrification of space and water heating). • Starting in 2035, retrofit 100% of all dwellings built between 1980 and 2016 by 2050 (following pre-1980 dwellings). Achieve on average thermal savings of 50%; electrical savings of 50% (not including electrification of space and water heating).	2.8%
New dwelling EUI	• Only 20% of new dwellings to be single-detached by 2050 (a steady decline from rates in 2016). • In 2026, new buildings are 30% more efficient. • In 2031, new buildings are 60% more efficient.	0.4%

Commercial and residential buildings in Hamilton account for 23% of energy consumption and 14% of GHG emissions in 2016. Energy efficiency is the main priority in the building sector via implementation of new building energy performance guidelines and deep energy retrofits of existing buildings. Along with the incorporation of highly energy-efficient heat pumps, these actions help drive energy consumption from buildings down by 23% between 2016 and 2050 (see Figure 13).

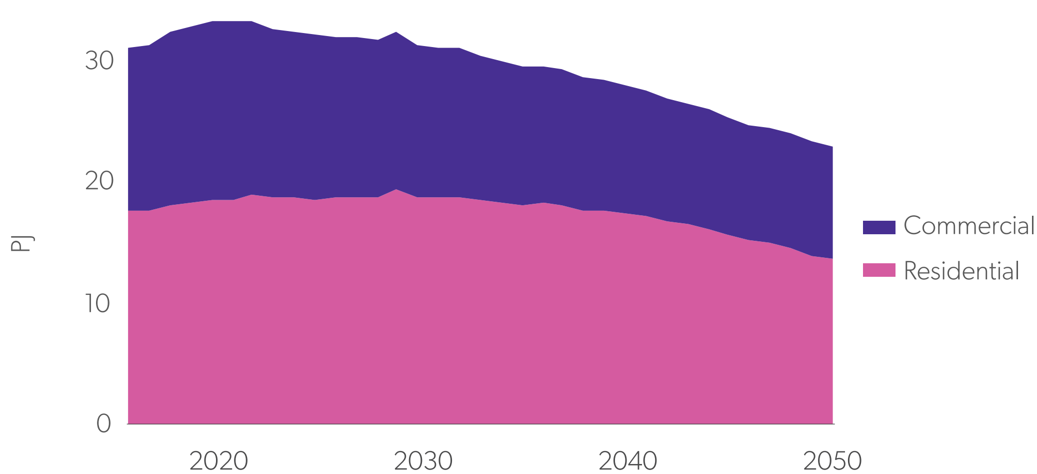


Figure 12. Buildings energy consumption by sector, 2016-2050.

The identification of buildings built before 1980, which are typically less energy efficient, can be useful for implementation planning purposes. The following figure shows how much pre-1980 residential and non-residential floor space is in each of the city's traffic zones.

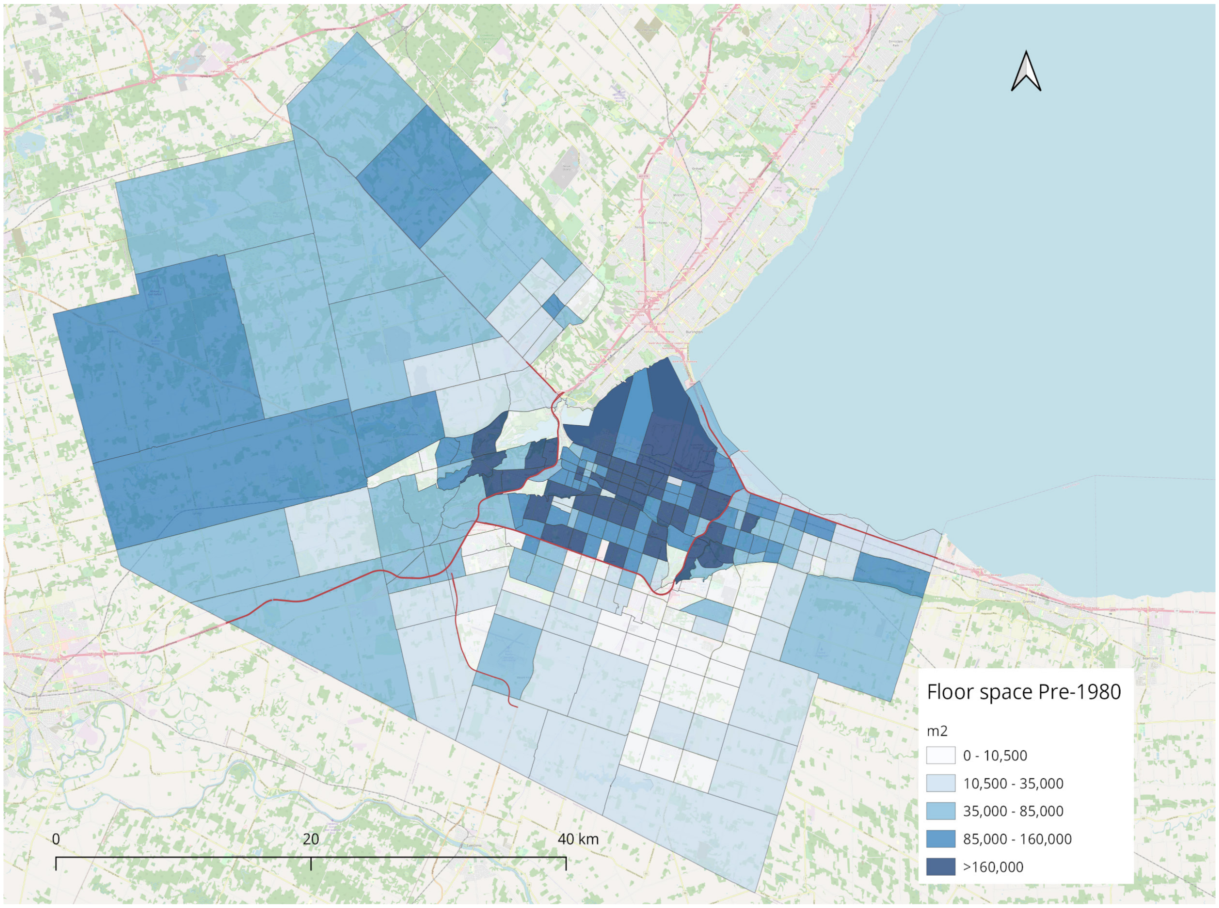
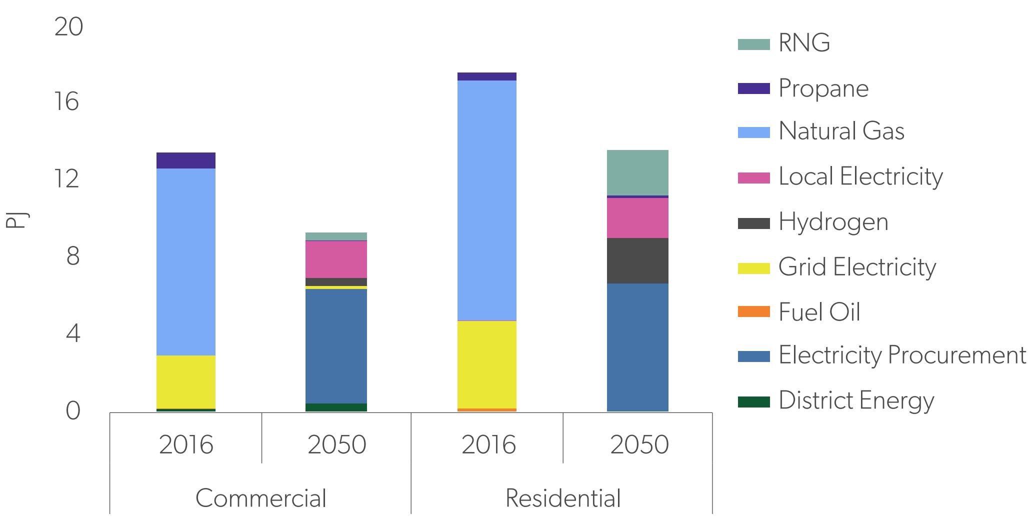


Figure 13. Floor space (m²) for buildings pre-1980 in Hamilton in 2016.

Whereas in 2016 the dominating energy source for commercial and residential buildings is natural gas and electricity from the provincial grid, by 2050 green hydrogen, renewable electricity and RNG become the sector's predominant sources (see Figure 15).



Commercial and residential buildings energy consumption by sector and fuel type (petajoules), 2016 and 2050.

(Note: "Electricity Procurement'' refers to the purchase of renewable energy certificates. District Energy has been allocated 100% to commercial floor space, but in reality it is likely to be used by a mix of commercial and residential spaces.)

This shift in the energy mix results in a 99% and 98% emissions reduction in the commercial and residential sectors respectively by 2050 (see Figure 16).

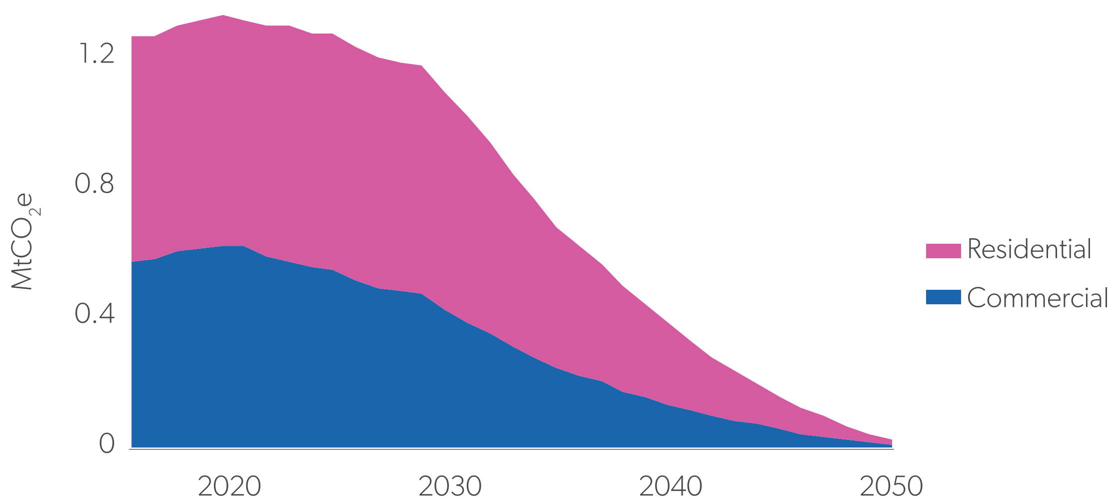


Figure 14. Commercial and residential buildings emissions by sector 2016 through 2050.

MUNICIPAL

MODELLED ACTION	DESCRIPTION	% GHG REDUCTIONS NET-ZERO VS. BAP 2050
New municipal EUI	By 2050, all new municipal buildings achieve net-zero emissions.	0.5%
Retrofit municipal	By 2050, • all municipal buildings are retrofitted to achieve 50% thermal efficiency and 50% electrical efficiency, then switch to heat pumps for space and water heating.	0.04%
Electrify municipal fleet	• 100% of new small and light-duty vehicles are electric by 2040 • 100% of new heavy-duty vehicles switch to clean hydrogen in 2040	0.04%

Although the City of Hamilton Corporation GHG emissions account only for 0.2% of the total city emissions in 2016, it plays an important leadership role in the community. A zero-emissions municipal fleet will be operating in 2040, and all municipal buildings will be net-zero by 2050. Under this scenario, municipal energy use decreases by 65% by 2050 compared to 2016.

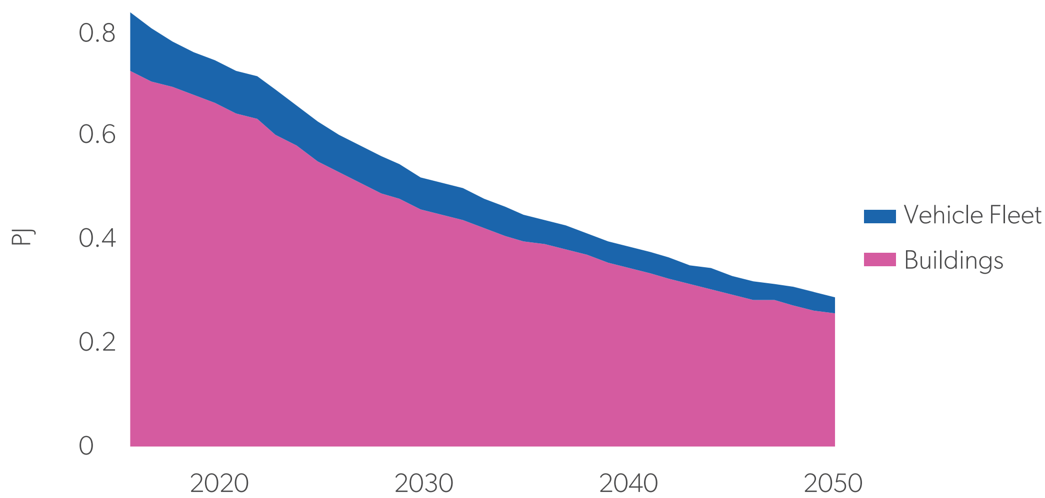


Figure 15. Municipal energy consumption by subsector (petajoules), 2016 - 2050.

Accordingly, emissions in the municipal sector decrease by 99% by 2050 (see Figure 18).

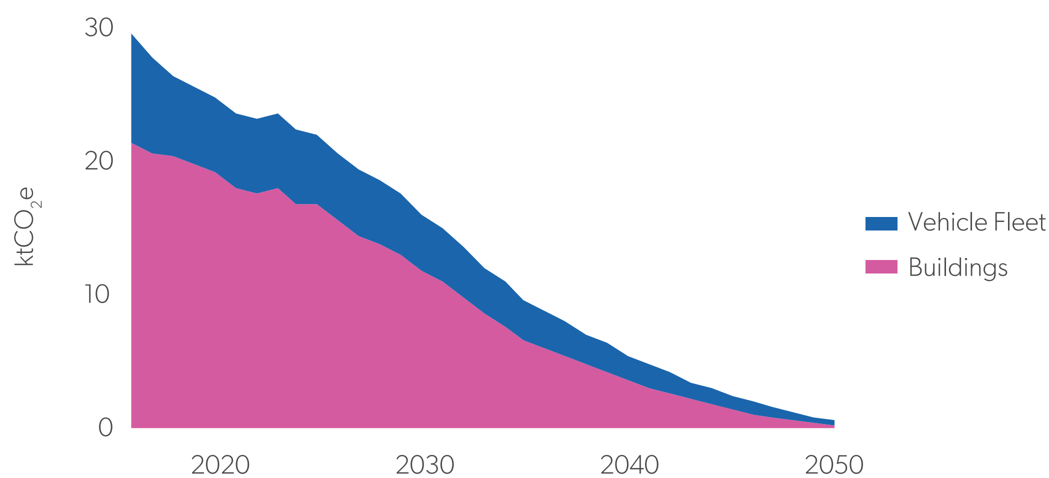


Figure 16. Municipal emissions by subsector (kilotonnes), 2016 - 2050.

WASTE, WATER, AND WASTEWATER

MODELLED ACTION	DESCRIPTION	% GHG REDUCTIONS NET-ZERO VS. BAP 2050
RNG and anaerobic digestion	• By 2050, 95% of organic waste is sent to anaerobic digestion for local energy use. • Purchase remaining RNG needed to replace all remaining natural gas demand by 2050, starting in 2025.	5.8%
Water efficiency	By 2050, 25% reduction in water consumption (behaviour change, leak detection system, greywater reuse).	0.03%
Wastewater efficiency	Increase efficiency by 30% by 2050.	0.02%

Waste and wastewater emissions reduce by 62% over the 2016 to 2050 period (see Figure 19), primarily due to 95% of organic waste being rerouted to anaerobic digestion. This strategy enables local renewable natural gas generation and avoids landfill methane emissions. Notwithstanding this significant shift in organic waste treatment, historic landfill is expected to continue to produce methane at the landfill through 2050 (the landfill gas capture system is assumed to capture 75% of emissions).

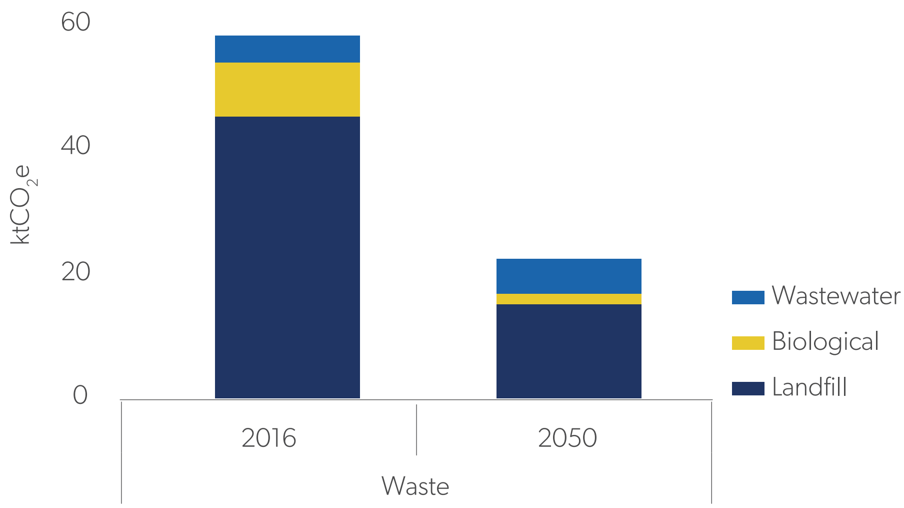


Figure 17. Waste and wastewater emissions by treatment type (kilotonnes of CO_2e), 2016 vs 2050.

RENEWABLE ENERGY

MODELLED ACTION	DESCRIPTION	% GHG REDUCTIONS NET-ZERO VS. BAP 2050
Renewable Energy Certificate (RECs)	In 2050, for each MWh of central electricity demand remaining after local renewable energy production, purchase a Renewable Energy Certificate (REC).	6.1%
Green Hydrogen	In order to replace remaining natural gas in the city, starting in 2030, green hydrogen (produced via renewable energy) is pumped into the natural gas distribution system.	5.0%
Wind	Installation of 250 MW by 2050 inside or outside the city, starting in 2022 with 50 MW installed every 4 years, starting in 2030.	0.7%
Ground mount solar PV	Installation of 280 MW, 10 MW every year from 2022 to 2050, inside or outside city boundary (prioritizing inside).	0.3%
District energy expansion	• Additional 25.4 MW of industrial waste heat for heating is added. • Additional 7.1 MW of industrial waste heat for cooling is added. • Corresponding expansion of the downtown DE network to service an additional 232,000 m^2 of commercial floor space (in reality this could be allocated to a mix of residential and commercial spaces.)	0.1%
Rooftop solar PV - existing buildings	• Starting in 2022, installation of solar PV on pre-2016 buildings, achieving on average 30% of building electric load (not including any potential increased electricity load from fuel switching to electric space and water heating). • Solar PV is scaled up to 50% of the electric load of these buildings by 2050.	0.2%
Rooftop solar PV - New residential buildings	As of 2031, all new homes have 30% annual load coverage by solar PV (not including additional electricity demand due to fuel switching in space and water heating).	0.2%
Rooftop solar PV - New non-residential buildings	In 2026 new commercial buildings include solar PV panels.	0.2%
Rooftop solar PV - Existing municipal buildings	50% of municipal building square footage adds PV to 50% of rooftop area, covering 30% of the related building area's electrical load.	0.01%

As a final critical step to achieve net-zero by 2050, remaining fossil fuel energy uses need to be replaced by renewable energy. Due to the expected continued and increased reliance on fossil fuels by the provincial electricity grid, the switch to renewable energy will require directly generating renewable energy or purchasing renewable energy from outside of city boundaries to offset remaining emissions in the city. The City has strategic opportunities to increase local production of renewable energy via solar energy, RNG from local organic waste, as well as capturing waste heat from the industrial sector. Some potential areas for district energy expansion fuelled by industrial waste heat from the steel industry are identified in Figure 20. These areas are based on a cost-benefit analysis undertaken of available waste heat. The waste heat source was identified in a Hamilton Community Energy Inc. and Hamilton Chamber of Commerce study (see the document: "Table of Business-as-Planned and Low-Carbon Actions").

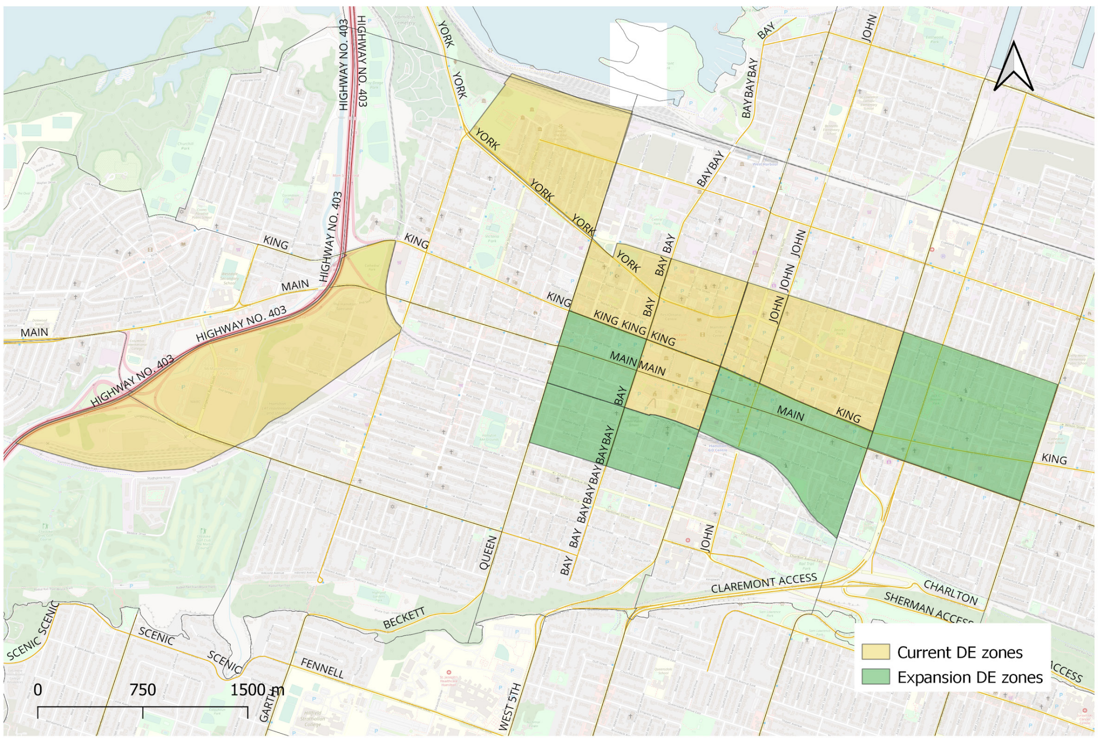


Figure 18. Current district energy and potential expansion zones.

CARBON SEQUESTRATION

MODELLED ACTION	DESCRIPTION	% GHG REDUCTIONS NET-ZERO VS. BAP 2050
Tree planting	From 2022 to 2050, 50,000 trees are planted each year.	0.03%

In order to capture and sequester some portion of the remaining community GHG emissions, the net-zero scenario also includes an ambitious tree planting action. Although in 2050 this action represents a small share of the community's reduction from its projected business-as-planned GHG emissions, this action represents important cumulative GHG emissions reductions in years leading up to 2050 (about 1.1 $MtCO_2e$). This action also represents many important co-benefits, including increased resilience to extreme weather events, cleaner air, and community wellbeing.

Sensitivity Analysis

Changing key parameters in the model will affect the net-zero emissions pathway for Hamilton. Uncertainty is inherent in the projection of future emissions, it is naturally present when modelling future scenarios. A sensitivity analysis can help understand how these uncertainties could affect the overall results.

The net-zero pathway is made of countless assumptions, this sensitivity analysis shows what happens when you change the inputs of one of several key inputs, namely:

- The methane global warming potential (from 34 to 84),
- The heating degree day (HDD) assumption,
- The provincial electricity grid emissions factor,
- The vehicle kilometre travelled (VKT) assumption,
- The residential retrofit assumption.

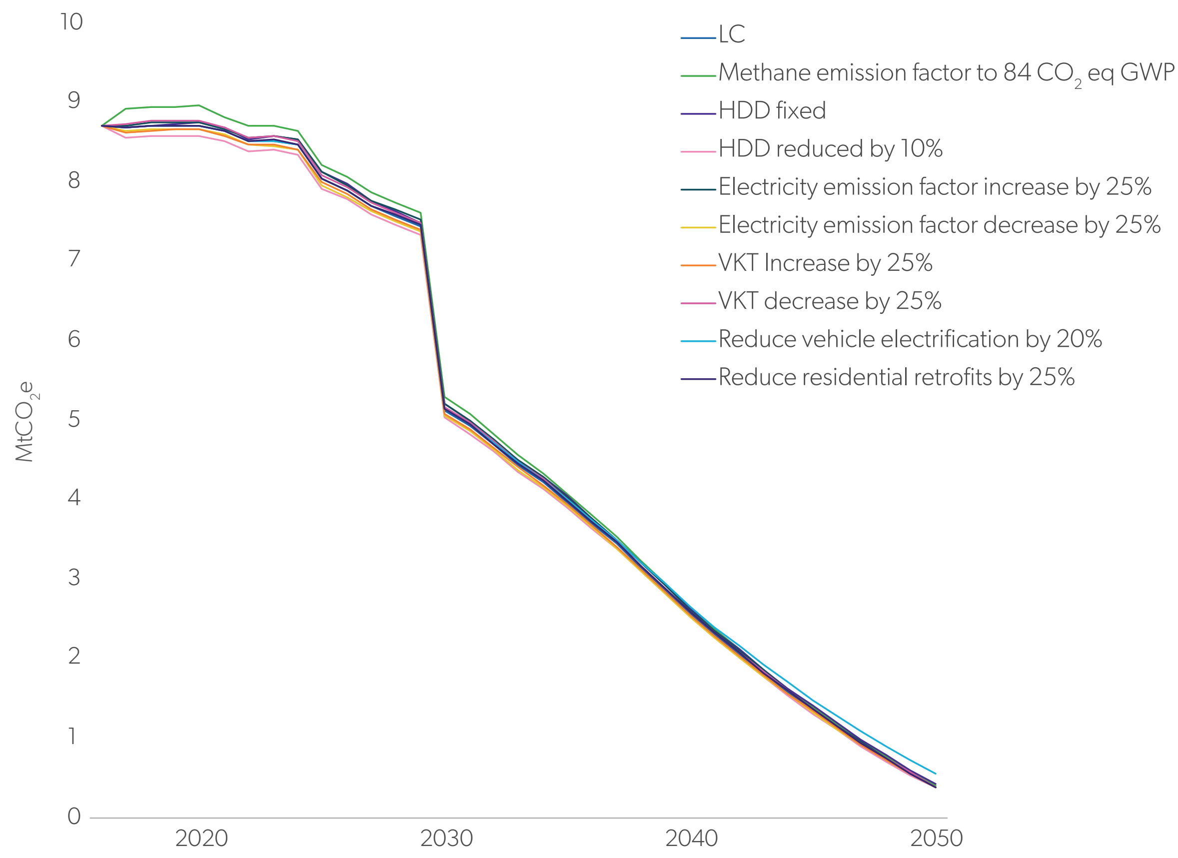


Figure 19. Sensitivity analysis of Hamilton's net-zero scenario emissions, when various individual inputs are changed.

Figure 22 shows that the maximum variation is seen when vehicle electrification is reduced by 20%, increasing emissions in 2050, which would imply reducing emissions by 93.5% instead of 95.5% in 2050 as compared to BAP emissions.

Countless other variables could have also been assessed. This analysis is illustrative to give a sense of the impact of individual assumptions in the net-zero scenario modelled. If many different assumptions are adjusted at once, the impact would be greater. For this reason, the Implementation Strategy that forms part of the CEEP, includes incremental CEEP reviews and updates based on annual reports of community emissions and program implementation metrics. This regular, transparent review process will enable adaptive management, that is, it will enable changes based on new information that arises.

Data Tables

COMMUNITY ENERGY

Table 1. Community energy consumption tabulated results, 2016 and 2050 (net-zero).

ENERGY BY SECTOR (PJ)	2016	SHARE 2016	2050	SHARE 2050	% +/- 2016-2050
Commercial	13,428,789	10%	9,361,685	9%	-30%
Industrial	81,571,437	60%	69,568,176	67%	-15%
Municipal	724,732	1%	256,871	0%	-65%
Residential	17,671,871	13%	13,650,850	13%	-23%
Transportation	23,251,634	17%	11,658,511	11%	-50%
Total	136,648,464	100%	104,496,093	100%	-24%
ENERGY BY FUEL (PJ)	**2016**	**SHARE 2016**	**2050**	**SHARE 2050**	**% +/- (2016-2050)**
Bio-char	0	0%	24,653,280	24%	100%
Coal	49,294,380	36%	2,452,162	2%	-95%
Diesel	4,249,736	3%	1,272,432	1%	-70%
District Energy	127,260	0%	388,187	0%	205%
RECs	0	0%	27,359,940	26%	100%
Fuel Oil	394,323	0%	173,695	0%	-56%
Gasoline	18,843,170	14%	515,429	1%	-97%
Grid Electricity	14,824,855	11%	66,310	0%	-100%
Hydrogen	0	0%	34,376,767	34%	100%
Local Electricity	93,277	0%	3,212,663	3%	3344%
Natural Gas	47,312,496	35%	0	0%	-100%
Other	204,687	0%	114,803	0%	-44%
Propane	1,268,582	1%	281,605	0%	-78%
RNG	0	0%	9,700,687	10%	100%

ENERGY BY SECTOR (PJ)	2016	SHARE 2016	2050	SHARE 2050	% +/- 2016-2050
Wood	35,697	0%	28,134	0%	-21%
Total	136,648,464	100%	104,496,093	100%	-23%
Energy per Capita (GJ)	244		112		

COMMUNITY EMISSIONS

Table 2. Per capita emissions, 2016 and 2050.

EMISSIONS BY SECTOR (TCO_2E)	2016	2050 (BAP)	% +/- (2016-2050)
Emissions per capita (tCO_2e/person)	15.5	0.6	-96%

Table 3. Community emissions tabulated results, 2016 and 2050.

EMISSIONS BY SECTOR (TCO_2E)	2016	SHARE 2016	2050	SHARE 2050	% +/- (2016-2050)
Agriculture and Livestock (AFOLU)	32,070	0%	32,070	8%	0%
Commercial	565,821	7%	7,826	2%	-99%
Energy Production	16,553	0%	0	0%	-100%
Tree Planting	0	0%	-37,624	-9%	100%
Fugitive[8]	58,178	1%	0	0%	-100%
Industrial	5,594,389	64%	159,435	40%	-97%
Municipal	21,475	0%	174	0.04%	-99%
Residential	691,884	8%	12,386	2%	-98%
Transportation	1,671,042	19%	200,476	50%	-88%
Waste	58,155	1%	22,360	4%	-62%
Total	8,709,567	100%	397,102	100%	-95%
EMISSIONS BY FUEL (TCO_2E)	**2016**	**SHARE 2016**	**2050**	**SHARE 2050**	**% +/- (2016-2050)**
Bio-char	0	0%	30,406	8%	100%
Coal	4,313,227	50%	115,865	29%	-97%
Diesel	315,710	4%	78,208	20%	-75%
Fuel Oil	28,054	0%	12,367	3%	-56%
Gasoline	1,263,391	15%	34,274	9%	-97%
Grid Electricity	155,960	2%	1,625	0%	-99%
Hydrogen	0	0%	0	0%	100%
Natural Gas	2,319,682	27%	0	0%	-100%

[8] Fugitive emissions account for unintentional emissions associated with the transportation and distribution of natural gas within the city (through equipment leaks, accidental releases etc.) that is used within the buildings sector.

EMISSIONS BY SECTOR (TCO_2E)	2016	SHARE 2016	2050	SHARE 2050	% +/- (2016-2050)
Non Energy	148,403	2%	16,806	4%	-89%
Other	87,433	1%	87,433	22%	0%
Propane	77,591	1%	17,224	4%	-78%
RNG	38	0%	2,838	1%	7305%
Wood	79	0%	57	0%	-28%
Total	8,709,566	100%	397,102	100%	-95%

BUILDINGS SECTOR

Table 4. Buildings sector energy tabulated results, 2016 and 2050.

BUILDINGS ENERGY (GJ) BY BUILDING TYPE	2016	SHARE 2016	2050	SHARE 2050	% +/- 2016-2050
Commercial	13,428,789	12%	9,362,006	10%	-30%
Industrial	81,571,440	72%	69,566,820	75%	-15%
Municipal	724,732	1%	256,798	0%	-65%
Residential	17,671,872	16%	13,651,957	15%	-23%
Total	113,396,833	100%	92,837,582	100%	-18%
BUILDINGS ENERGY (GJ) BY FUEL	**2016**	**SHARE 2016**	**2050**	**SHARE 2050**	**% +/- 2016-2050**
Bio-char	0	0%	24,653,283	27%	100%
Coal	49,294,383	43%	2,452,162	3%	-95%
District Energy	127,260	0%	388,187	0%	205%
Fuel Oil	394,323	0%	173,695	0%	-56%
Grid Electricity	14,824,534	13%	18,951,672	17%	8%
Hydrogen	0	0%	34,353,968	37%	100%
Local Electricity	93,275	0%	1,755,861	5%	4994%
Natural Gas	47,234,017	42%	0	0%	-100%
Other	124,761	0%	98,328	0%	-21%
Propane	1,268,582	1%	281,605	0%	-78%
RNG	0	0%	9,700,686	10%	100%
Wood	35,697	0%	28,134	0%	-21%
Total	113,396,833	100%	92,837,582	100%	-18%
BUILDINGS ENERGY (GJ) BY END USE	**2016**	**SHARE 2016**	**2050**	**SHARE 2050**	**% +/- 2016-2050**
Industrial Processes	78,259,977	69%	69,119,054	74%	-12%
Lighting	1,768,558	2%	1,801,051	2%	2%
Major Appliances	893,432	1%	1,310,570	1%	47%
Plug Load	2,414,420	2%	2,938,393	3%	22%

BUILDINGS ENERGY (GJ) BY BUILDING TYPE	2016	SHARE 2016	2050	SHARE 2050	% +/- 2016-2050
Space Cooling	769,309	1%	888,290	1%	15%
Space Heating	21,710,682	19%	11,731,511	13%	-46%
Water Heating	7,580,454	7%	5,048,712	5%	-33%
Total	113,396,833	100%	92,837,582	100%	-18%

Table 5. Buildings sector emissions tabulated results, 2016 and 2050.

BUILDINGS EMISSIONS (TCO_2E) BY BUILDING TYPE	2016	SHARE 2016	2050	SHARE 2050	% +/- (2016-2050)
Commercial	565,821	8%	7,826	4%	-99%
Municipal	21,475	0%	174	0%	-99%
Industrial	5,594,389	81%	159,435	89%	-97%
Residential	691,884	10%	12,386	7%	-98%
Total	6,873,569	100%	179,821	100%	100%

BUILDINGS EMISSIONS (TCO_2E) BY FUEL	2016	SHARE 2016	2050 (BAP)	SHARE 2050	% +/- (2016-2050)
Bio-char	0	0%	30,406	17%	100%
Coal	4,313,227	63%	115,865	64%	-97%
Fuel Oil	28,054	0%	12,367	7%	-56%
Grid Electricity	155,956	2%	1,064	1%	-99%
Hydrogen	0	0%	0	0%	100%
Natural Gas	2,298,623	33%	0	0%	-100%
Propane	77,591	1%	17,224	10%	-78%
RNG	0	0%	2,838	2%	100%
Wood	42	0%	34	0%	-21%
Total	6,873,494	100%	179,798	100%	-97%

BUILDINGS EMISSIONS (TCO_2E) BY END USE	2016	SHARE 2016	2050 (BAP)	SHARE 2050	% +/- (2016-2050)
Industrial Processes	5,443,892	79%	159,266	89%	-97%
Lighting	18,389	0%	88	0%	-100%
Major Appliances	13,655	0%	82	0%	-99%
Plug Load	32,006	0%	4,009	2%	-87%
Space Cooling	14,785	0%	46	0%	-100%
Space Heating	1,010,611	15%	6,033	3%	-99%
Water Heating	340,157	5%	10,275	6%	-97%
Total	6,873,494	100%	179,798	100%	-97%

TRANSPORTATION SECTOR[9]

Table 6. Transportation sector energy tabulated results, 2016 and 2050.

TRANSPORTATION ENERGY (GJ) BY FUEL	2016	SHARE 2016	2050	SHARE 2050	% +/- (2016-2050)
Diesel	4,329,662	19%	1,288,907	11%	-236%
Gas	18,921,647	81%	515,429	4%	-3571%
Grid Electricity	322	0%	8,374,580	72%	100%
Local Electricity	2	0%	1,456,802	12%	
Hydrogen	0	0%	22,794	0%	100%
Total	23,251,631	100%	11,658,512	100%	-99%
TRANSPORTATION ENERGY (GJ) BY VEHICLE TYPE	**2016**	**SHARE 2016**	**2050**	**SHARE 2050**	**% +/- (2016-2050)**
Car	8,724,935	38%	2,497,881	21%	-249%
Heavy truck	1,347,873	6%	24,972	0%	-5298%
Light truck	7,625,298	33%	3,762,945	32%	-103%
Marine	561,482	2%	561,482	5%	0%
Off Road	3,981,927	17%	3,981,927	34%	0%
Rail	718,298	3%	718,298	6%	0%
Urban Bus	291,820	1%	111,007	1%	-163%
Total	23,251,632	100%	11,658,512	100%	-99%

Table 7. Transportation Emissions, tabulated results, 2016 and 2050.

TRANSPORTATION EMISSIONS (TCO_2E) BY FUEL	2016	SHARE 2016	2050	SHARE 2050	% +/- (2016-2050)
Grid electricity	3	0%	561	0%	16458%
RNG	0	0%	0	0%	-
Diesel	315,710	19%	78,208	39%	-75%
Gas	1,263,391	76%	34,274	17%	-97%
Other	91,938	6%	87,433	44%	-5%
Total	1,671,042	100%	200,476	100%	-88%
TRANSPORTATION EMISSIONS (TCO_2E) BY VEHICLE TYPE	**2016**	**SHARE 2016**	**2050**	**SHARE 2050**	**% +/- (2016-2050)**

[9] Please note the totals in these transportations tables are slightly higher (<1%) than the transportation sector totals in the community-wide tables above.

TRANSPORTATION EMISSIONS (TCO_2E) BY FUEL	2016	SHARE 2016	2050	SHARE 2050	% +/- (2016-2050)
Car	582,925	35%	14,433	7%	-98%
Light truck	509,566	30%	20,534	10%	-96%
Heavy truck	93,977	6%	152	0%	-100%
Urban bus	19,466	1%	129	0%	-99%
Rail	55,408	3%	55,408	28%	0%
Marine	44,317	3%	22,157	11%	-50%
Aviation	87,433	5%	87,433	44%	0%
Off road	277,949	17%	227	0%	-100%
Total	1,671,041	100%	200,473	100%	-88%

WASTE AND WASTEWATER

Table 8. Waste Sector Emissions, 2016 and 2050.

WASTE EMISSIONS (TCO_2E) BY FUEL	2016	SHARE 2016	2050	SHARE 2050	% +/- (2016-2050)
Biological (i.e. compost)	8,302	14%	1,937	9%	-77%
Landfill	45,172	78%	14,715	66%	-67%
Wastewater	4,681	8%	5,707	26%	22%
Total	58,155	100%	22,360	100%	-62%

CARBON SEQUESTRATION

Table 9. Land-Use Change Emissions 2022-2050 (NZS).

(TCO_2E/YR)	2025	2030	2035	2040	2045	2050
Tree planting (50,000/year)	-37,432	-37,502	-37,530	-37,559	-37,596	-37,631

Appendix F: Large-Scale Renewable Energy Planning Practices

June 2021

Contents

ACRONYMS	
BAP	Business-as-planned [scenario]
GHG	Greenhouse gases
kWh	kilowatt-hour
IESO	Independent Electricity System Operator
LDC	Local distribution company
MW	Megawatt
NREL	National Renewable Energy Laboratory
NZS	Net-zero scenario
PJ	Petajoule
RNG	Renewable natural gas
TWh	terawatt hour

Introduction

This document builds on specific elements of the Actions Catalogue[1] by providing greater insight into renewable energy technologies, policies and best practices, with a focus on opportunities for the City of Hamilton and its key sectors. In particular, this document aims to inform the short-term implementation aspects of Hamilton's Community Energy and Emissions Plan.

The deployment of renewable energy is critical to the City's target of net-zero emissions by 2050. A core question that arises is on which land, or surface should these activities be located. Land is a constrained resource subject to competing demands for food security, housing, biodiversity, and access to water, amongst others. This brief begins with a discussion of policies that expedites the deployment of renewable energy while maintaining or enhancing other assets that land provides to the community, such as agricultural production.

Context

To provide greenhouse gas emissions (GHG)-free energy to the city of Hamilton, based on the current and increasing central provincial grid emissions, renewable energy technologies will need to be deployed by the City, residents and businesses. Figure 1 illustrates the changing fuel mix out to 2050 in the Hamilton net-zero scenario (NZS). Note that green hydrogen is also generated by renewable electricity.

In the NZS, despite the fact that total energy consumption falls from the 2016 total of 137 PJ (Figure 2) to 107 PJ by 2050 (Figure 3), imported electricity increases from 15 PJ to 27 PJ, and local renewable electricity generation increases from 0.2 PJ to 3.5 PJ. District energy increases from 0.5 PJ to 1.8 PJ. While there is an increase in electricity use between 2016 and 2050, the difference is moderate, increasing from 22 to 27 PJ.[2] Local electricity generation increases by a factor of 20 by 2050 in the NZS when compared to the BAP. In order to achieve net-zero emissions there will be extensive activity in local renewables between 2020 and 2050. It is therefore important to develop planning policy that enables renewable generation.

[1] Produced for the City of Hamilton's Community Energy and Emissions Plan by SSG in April 2020.

[2] Note that local renewable energy and renewable energy certificates (RECs) replace all grid electricity in the NZS in 2050.

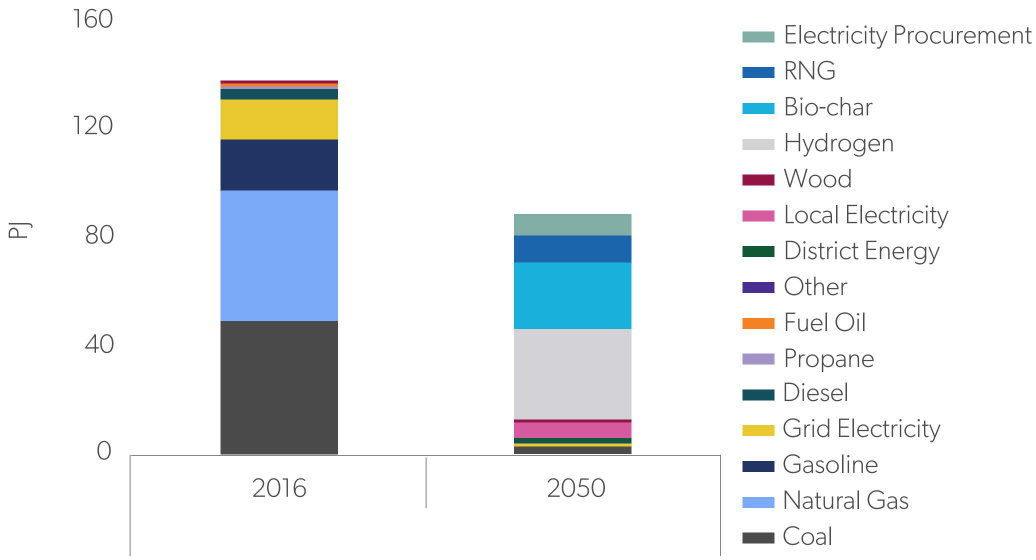


Figure 1. Energy transition in Hamilton

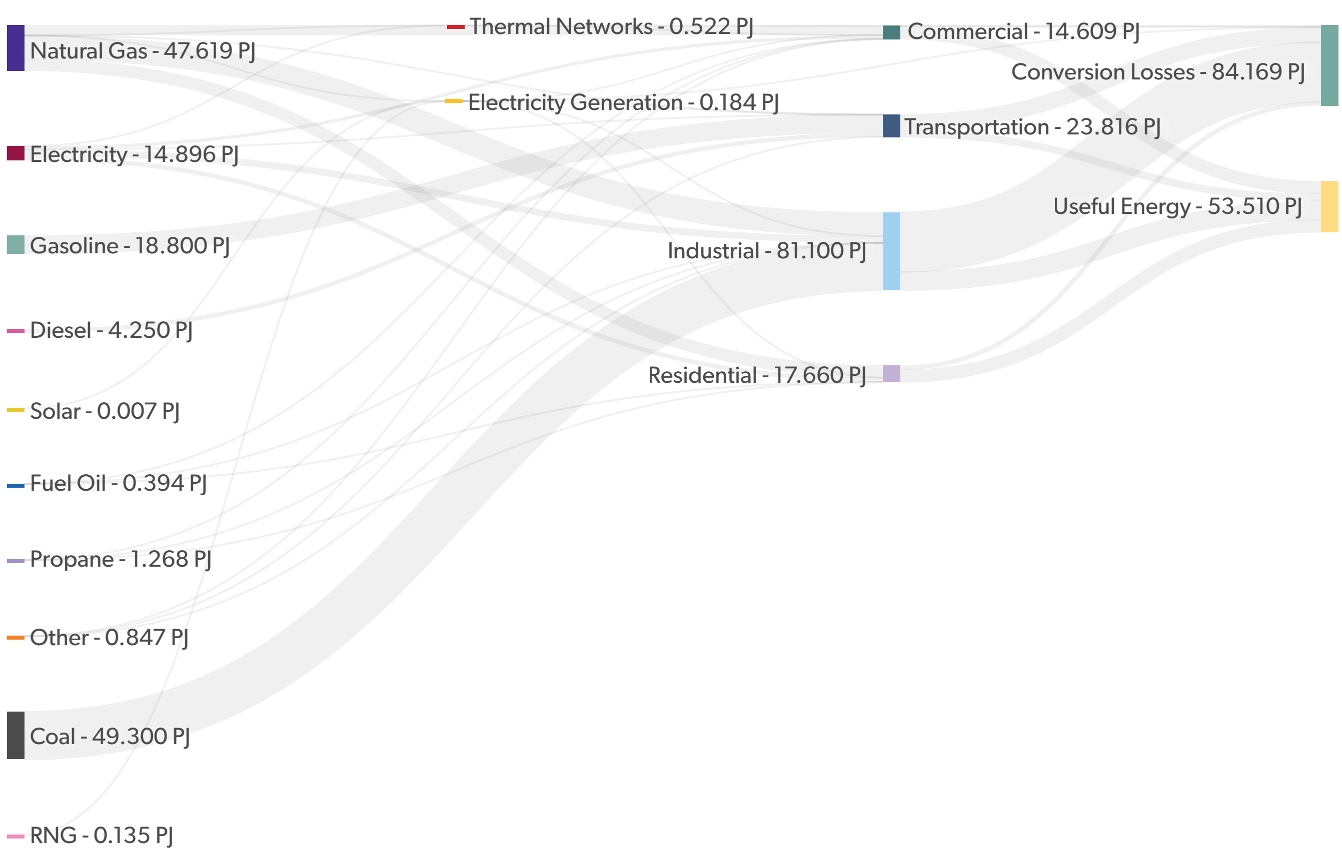


Figure 2. Sankey diagram of energy flows in Hamilton, 2016. (The 'Other' category includes emissions mainly from bio-energy.)

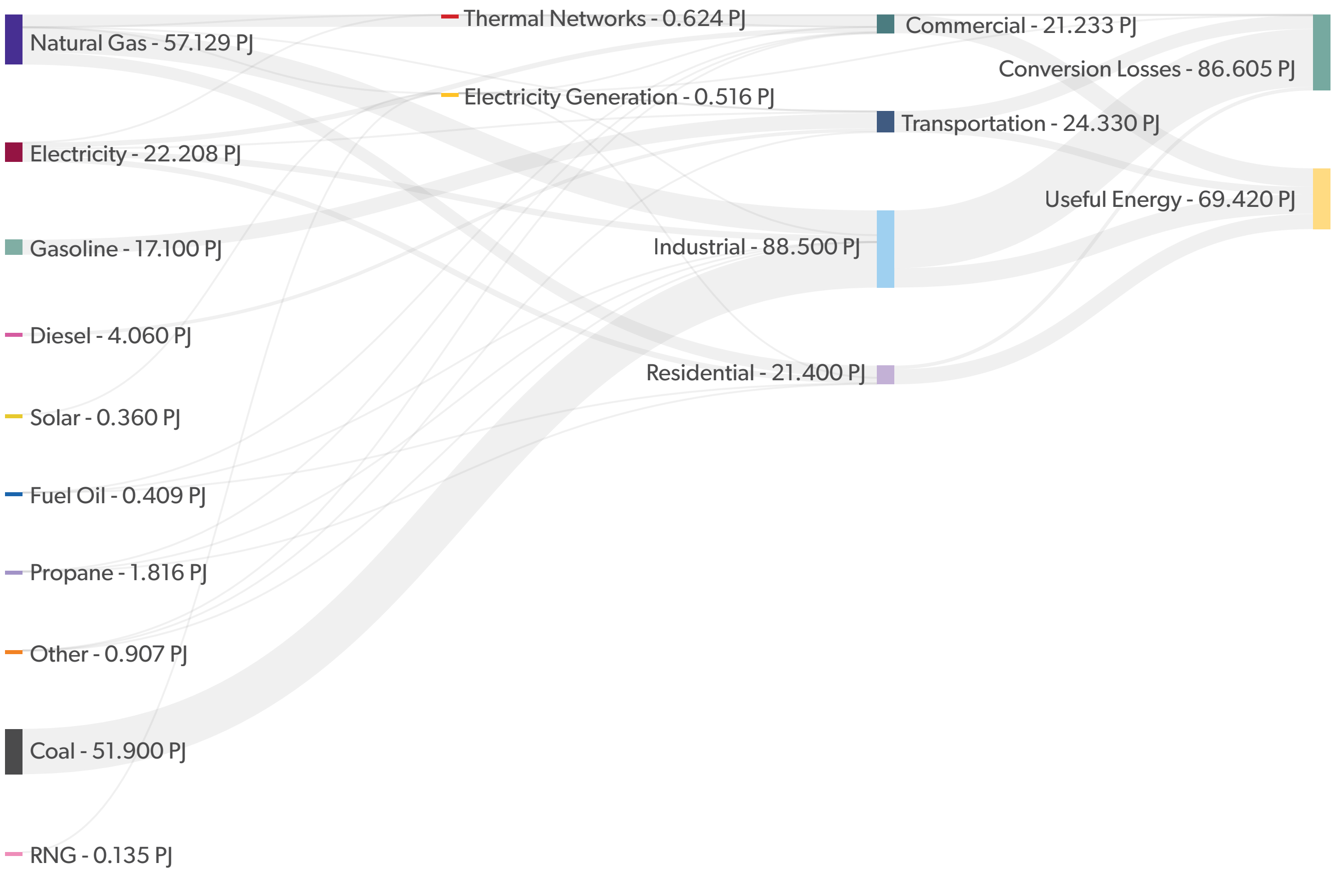


Figure 3. Sankey diagram of energy flows in the BAP, 2050. (The 'Other' category includes emissions mainly from bio-energy.)

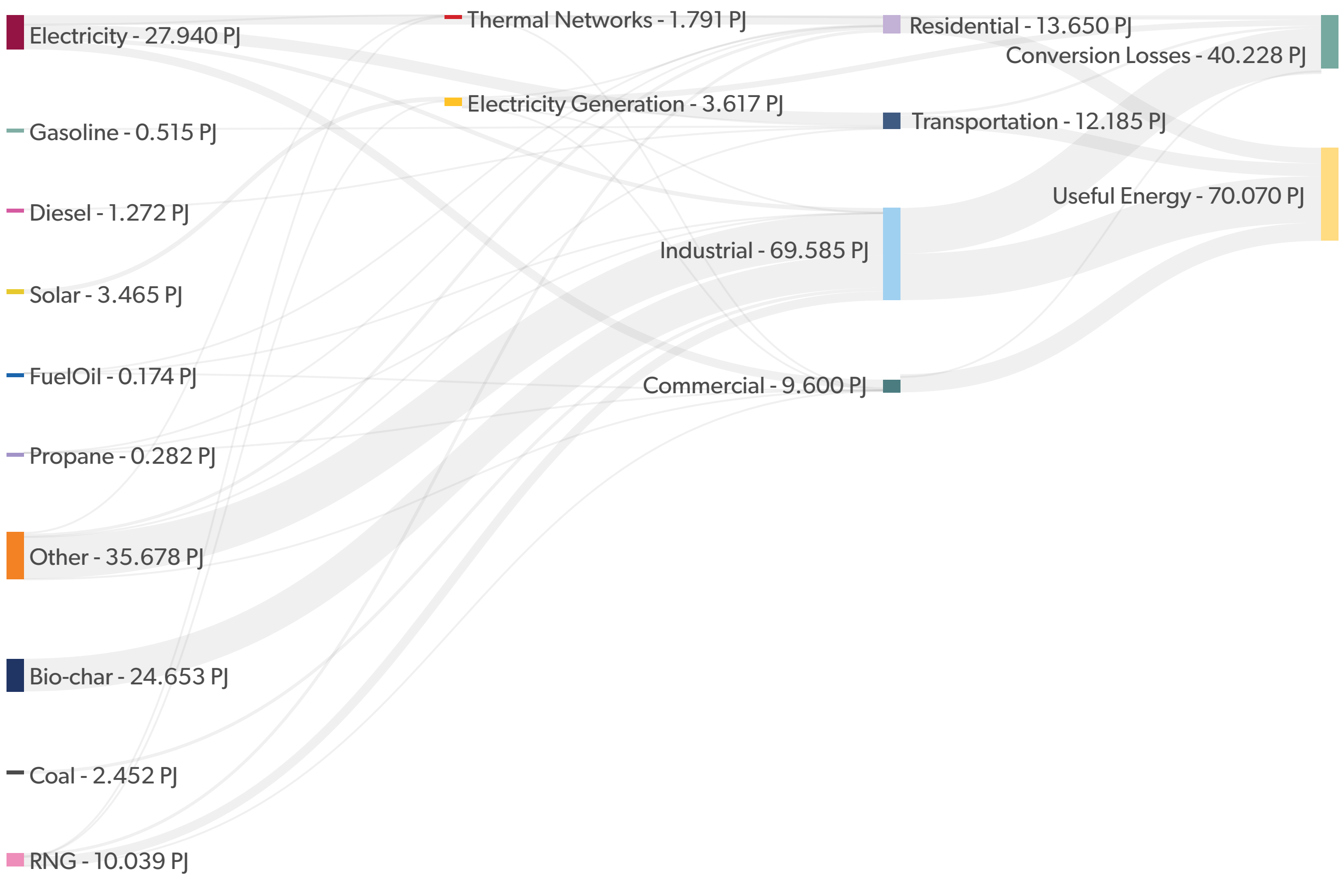


Figure 4. Sankey diagram of energy flows in the NZS, 2050. (The 'Other' category includes emissions mainly from bio-energy.)

The Promise and Risk of Green Hydrogen

Full electrification of heating is a major challenge and will likely create stranded assets for natural gas distributors. The deployment of hydrogen (main contributor to the increase of 'other' in Figure 4 as opposed to Figure 3) and renewable natural gas (RNG) are being explored to limit this impact.

The hydrogen future is constrained by the low efficiencies of manufacturing green hydrogen, which results in electricity generation requirements that are 2-14 times higher than direct electrification. This existing inefficiency risks that committing to hydrogen could lock in requirements for continued fossil fuel production with the promise of carbon capture (grey hydrogen). A recent paper in Nature Climate Change explains:

Betting on the future large-scale availability of hydrogen and e-fuels risks a lock-in of fossil-fuel dependency if their upscaling falls short of expectations. Hydrogen and e-fuels are a potential distraction from the urgent need for an end-use transformation towards wide-scale direct electrification, which is cheaper, more efficient and generally part of well-advanced available technology in many sectors, such as light-duty vehicles or low-temperature heating in buildings and industry.[3]

Despite the risks highlighted above of relying on green hydrogen as a pathway to net zero, green hydrogen will likely be critical in the effort to decarbonize industries such as steel manufacturing, which are otherwise difficult to electrify.

Efficiency First

The NZS electrifies the majority of the most significant energy consuming activities in society: heating and transportation. The way in which electrification is implemented and whether or not this process is accompanied by other actions will influence the extent to which new electric grid capacity is required, the speed at which the grid can be decarbonized, and the overall cost to society of the low-carbon transition. Growth in peak capacity in particular will drive the need for new generating capacity, which will increase the land requirement. The amount of land required can also be mitigated by the technology selected and the policies guiding the deployment of the technology.

Renewable Energy Technologies: Land-Area Requirements

The underlying approach to the NZS is to order the actions according to a priority of 'Reduce, Improve, Switch'. Avoiding energy consumption is the top priority, followed by maximizing energy efficiency improvements, and finally by switching to low-carbon energy sources for the remaining demand. The first two steps can be characterized as generating negawatts. One study calculated that every TWh decrease in annual electric power consumption suggests 7.6–28.7 km^2 of avoided land and for liquid fuel the reduction increases to 27.5–99.3 km^2 of avoided land per TW hr/yr because of the relatively large land-use intensity of biofuels (see Figure 5).[4]

[3] Ueckerdt, F., Bauer, C., Dirnaichner, A. et al. (2021). Potential and risks of hydrogen-based e-fuels in climate change mitigation. Nat. Clim. Change. https://doi.org/10.1038/s41558-021-01032-7

[4] McDonald, R. I., Fargione, J., Kiesecker, J., Miller, W. M., & Powell, J. (2009). Energy sprawl or energy efficiency: climate policy impacts on natural habitat for the United States of America. PloS one, 4(8), e6802.

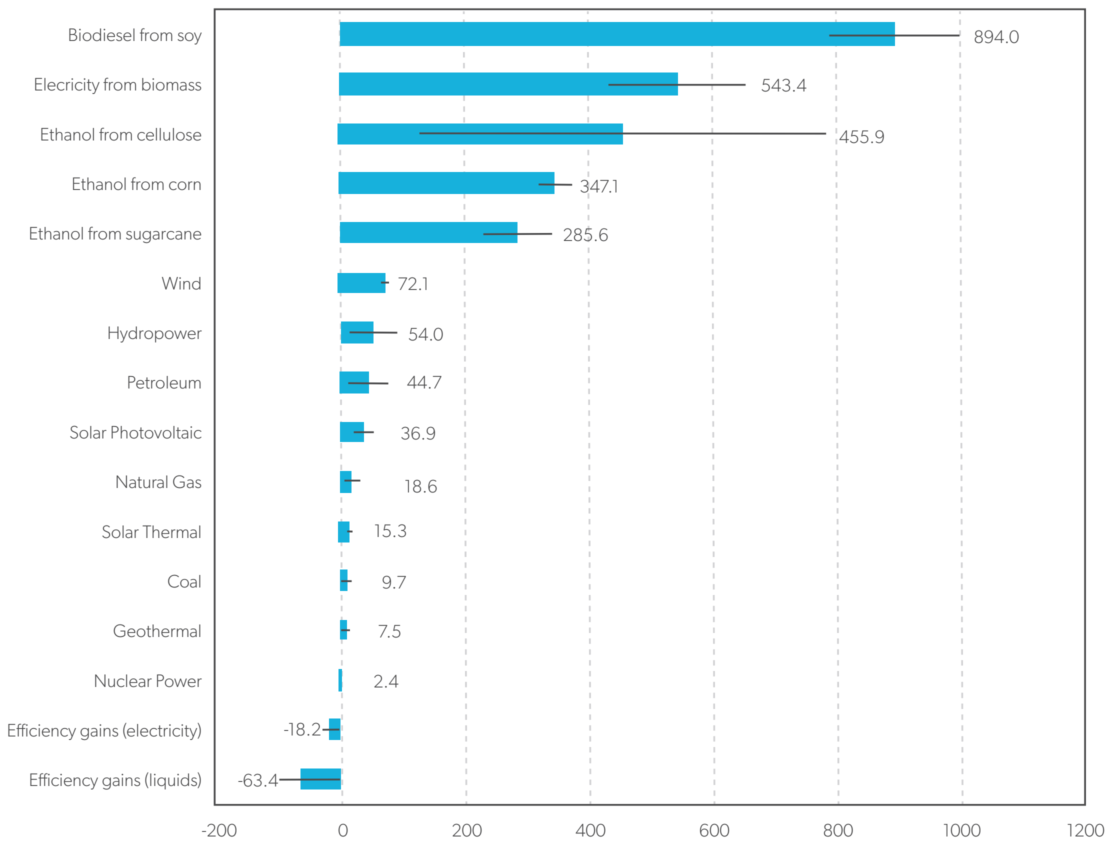


Figure 5. Land required for different sources of energy.[5]

From the perspective of land-use, each kWh of electricity which is saved through efficiency is a kWh that need not be generated and therefore land that need not be used for generation. In an electrified future, each trip shifted from a personal vehicle to transit or walking constitutes an efficiency gain, which reduces the burden on the landscape to provide energy. Efficiency gains can therefore be tied directly to a reduction in land consumption for energy generation.

The NZS switches from fossil fuels to electricity for most end uses, except for industry which becomes reliant on green hydrogen and bio-char. Using the assumptions from the study cited above, it is possible to assess the net impact of the NZS relative to the BAP on land requirements for energy production. Note that these calculations include upstream impacts such as pipelines for oil and gas and are based on US production.

The NZS reduces land for fossil fuel production by a total of 680 km^2 (286 km^2 for natural gas, 206 km^2 for gasoline, 34 km^2 for diesel, 17 km^2 for propane, 4 km^2 for fuel oil and 133 km^2 for coal), see Figure 6. For context, the land area of Hamilton is 1,138 km^2.

An additional 37 km^2 is required for solar generation. Imported electricity varies slightly between the scenarios, due to an increase in electricity demand from 22 to 27 PJ. This is expected to result in an additional 80 km^2 of land use. RNG and biochar are assumed to be sourced from waste streams, avoiding the need for additional land-use. In the case where biochar is produced

[5] Ibid.

via agriculture or from forestry, the land area required is significant. Clean hydrogen for steel manufacturing requires extensive deployment of renewable energy and is assumed to be sourced from hydro in the calculations below. To account for the relative inefficiency of hydrogen production, the land area assumption for hydro was doubled from 54 to 108 km^2/Twh/yr, which is still optimistic. As a result, the renewable energy production to generate the hydrogen requires a land area approximately equal to that of the entire city (1,100 km^2). Most of the land impacts assessed here will not occur within the City boundaries, with the exception being solar generation.

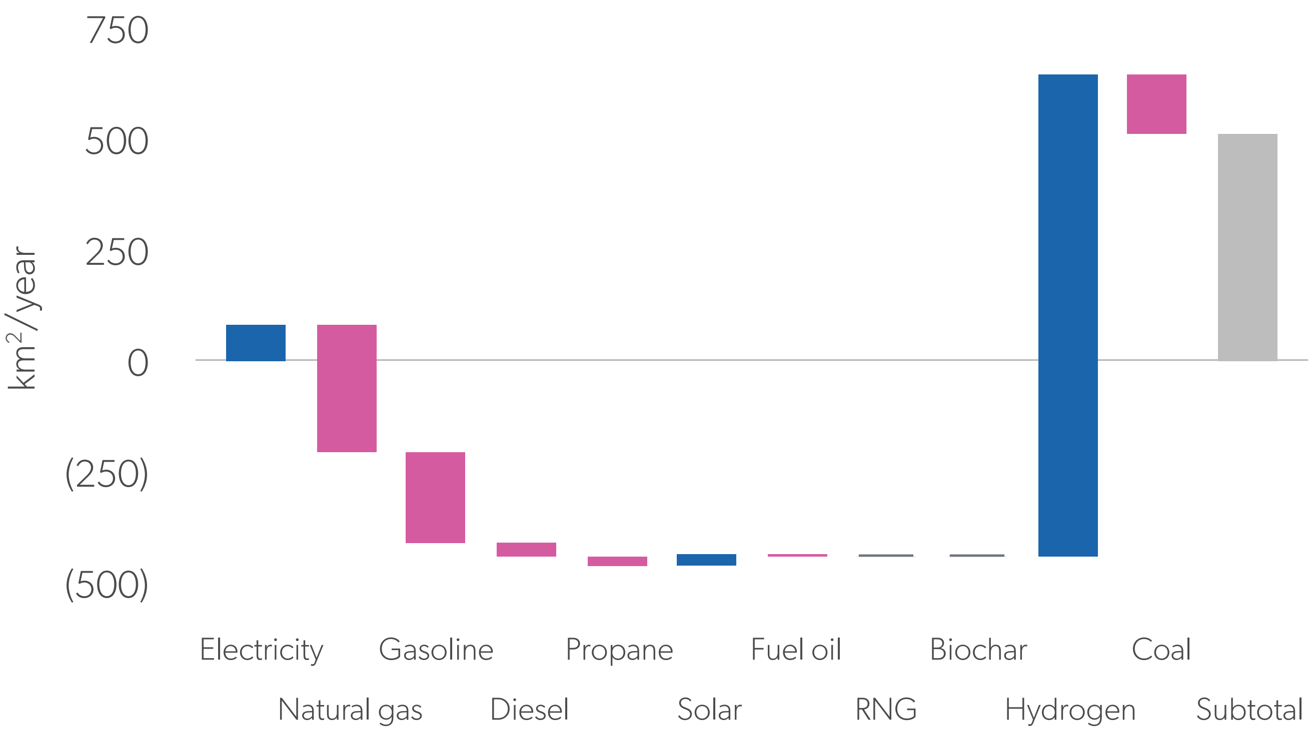


Figure 6. Impact of the NZS on land required for energy relative to the BAP in 2050.

Solar Planning Considerations

As land consumption associated with solar PV is expected to have the largest land-use impact on local lands, the section below provides some strategies for planning for and implementing solar PV within Hamilton.

The NZS will require solar PV installations on somewhere around 3,700 ha or 37 km^2 (including ground mount and rooftop installations). To minimize the land area required, this generation can be located on roofs, on industrial or disturbed sites or in locations with compatible uses.

1. Update Official Plan and Zoning By-law with Renewable Energy Enabling Policies and Regulations

A range of considerations need to be applied to provide certainty to project developers and ensure the best use of land. The following principles are a simplified version of a guide developed for the Hudson Valley.[6]

Prioritize development on previously disturbed areas & existing buildings: The preferred option is to situate renewable energy projects on marginal lands such as degraded or brownfield sites or on existing buildings, as the project can stimulate cleanup of the site, becoming known as a "brightfield", generating additional employment opportunities and ensuring that generation is in proximity to demand. Renewable energy projects can also be sited over parking lots and on the roofs of large buildings. There are 130,000 roofs in Hamilton with 13 million m^2, which can support 1,985 MW of solar capacity.[7] As many rooftops may not be suitable for solar PV mounting based on orientation, access to sun, snow load, and roof capacity, the NZS only models 50% of roof capacity.

Protect ecological resources: Wetlands, forests and other ecological features provide services including wildlife habitat, water treatment and filtration and carbon sinks, which enhance resilience to climate impacts. Areas which should be avoided include wildlife and other critical habitat, including intact and connected wildlife corridors and migratory bird flyways, parks and recreational lands, streams and stream corridors, wetlands and wetland buffer areas, river corridors and floodplains, sensitive geological and hydrogeological formations and contiguous forests.

Protect agricultural lands and promote co-location: The maintenance of agricultural land enables local production of food, as well as maintaining greenspaces and the rural landscape character of the land. Renewable energy installations and transmission and distribution infrastructure should avoid disrupting agricultural land. With careful design, solar facilities can be compatible with some agricultural activities including livestock grazing, beekeeping, cultivation of certain crops, or planting of pollinator-friendly vegetation under and around the panels.

Protect Views: Large-scale installations can transform the landscape. Maintaining specific viewsheds and reducing the impacts on the landscape, including associated infrastructure, is important to maintaining support for the projects. Guidance includes keeping facility components at a low profile, using natural screening and setbacks and locating installations on or within areas of low scenic value. Natural topography and vegetation can keep facilities out of sight from public roads, parks, historic sites and other sensitive viewing areas.

New York State has prepared a comprehensive guidebook on solar, including a model solar energy local law and a solar procurement toolkit.[8] Policies which can be incorporated into a land-use bylaw to protect other uses and activities include:[9]

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[6] Friedrichsen, A. Clean Energy, Green Communities: A Guide to Siting Renewable Energy in the Hudson Valley. Scenic Hudson, Inc., Poughkeepsie, NY. Retrieved from: https://www.bloomfieldct.gov/sites/g/files/vyhlif2831/f/agendas/hudson_valley_guide_to_siting_renewable_energy_sshv-3b_friedrichsen-sh.pdf

[7] Google Environment Insights Explorer (2020). Retrieved from: https://insights.sustainability.google/places/ChIJj3feJ2yYLIgRIQ7f2Fbuais/download

[8] NYSERDA. (2020). New York Solar Guidebook for Local Governments. Retrieved from: www.nyserda.ny.gov/All-Programs/Programs/NY-Sun/Communities-and-Local-Governments/Solar-Guidebook-for-Local-Governments.

[9] Ibid.

- Proper height and setback requirements, to help reduce visual and other potential impacts;
- Minimum or maximum lot size, to control density and meet a community's goals for total renewable energy development, based on the availability of eligible and suitable lands;
- Fencing requirements, including height and type, to reduce impacts to wildlife, promote security, and provide visual screening and noise attenuation;
- Buffer/screening requirements for visual and noise impact mitigation;
- Signage requirements and placement, for security and education;
- Undergrounding of on-site electrical interconnection and distribution lines;
- Vegetation removal/replacement and maintenance requirements, to reduce visual and other impacts of necessary infrastructure; and
- Decommissioning plan requirements, to facilitate the land's eventual return to other uses.

2. The integration of community energy/climate action policy directions into Secondary Plans

Secondary plans can support renewable energy deployment both for greenfield and infill locations. For greenfield locations, secondary plans can ensure roof space and orientation compatible with optimal solar installations, provide land for solar gardens, require EV charging stations and incorporate energy storage. The integration of community energy/climate action policy directions into Secondary Plans can support the development of a neighbourhood level net-zero strategy that incorporates district energy, and broader considerations such as mix of destinations, proximity of destinations, energy performance of buildings, greenspace for carbon sequestration and other aspects.

3. Integrate solar access into urban design guidelines

Urban design influences the availability of roof space for solar deployment and provides assurance that access to sun will be provided as the space develops. The City can require shading analysis for new developments to ensure that the performance of adjacent solar installations is not compromised.

4. Develop an expedited permitting process for solar installations

Consistent with the climate emergency and the NZS, a quick win for the City of Hamilton is to develop an expedited approvals process for solar PV installations. Table 2 describes elements of a permitting process. An additional strategy to incentivize solar installations is to void the fee for permits. The NREL has developed a SolarApp[10] for several American jurisdictions which automates the permitting process and a similar approach could be considered for Hamilton.

[10] See: solarapp.nrel.gov/.

Table 1. Solar PV permitting elements.[11]

TOPIC	BEST PRACTICES
Development permit (rules for placement & aesthetics)	
Approach	Design permit to broadly allow solar PV systems. Provide prescriptive permit exemptions for each zone in the land use bylaw (This is preferable to only exempting residential projects.)
Projection into setbacks	Include specific exemption rules for placement of solar PV systems based on building height and setbacks for each zone, (e.g. residential, commercial, etc.)
Height	Include restrictions limiting height above roof ridge line for permit exemptions.
Ground	Ground-mounted solar systems require development permits although this is dependent upon zoning. For example, acreages should only require a development permit for ground-mounted systems with a footprint above 10 m^2.
Building permit (rules for mounting)	
Exemption for basic flush-mounted systems	Exempt flush-mounted solar PV systems if the following conditions are met: **1.** Maximum weight does not exceed 5 lb/ ft^2 and weight is evenly distributed **2.** Racking is directly attached to roof rafters and trusses and no parts extend above roof height **3.** Pre-engineered and CSA/ULC approved mounting equipment is used
Racking	Where racking is not CSA/ULC approved, the building permit requires professional engineer stamped drawings. Where racking uses ballasts (e.g. gravel or concrete slabs), a building permit is required.
Flat roof	All flat-roof solar PV systems using ballasted racking require a building permit.
Ground-mount	Require a building permit for ground-mount racking attached to a building.
ELECTRICAL PERMIT (RULES FOR ELECTRICAL COMPONENTS & CONNECTION)	
Drawing	Prescribe a single-line diagram template with layout, components & circuit information (e.g. typical templates also require locating all components, how they are connected and operating voltages and current).
Component specifications	Permit applications must specify PV modules, inverters, controllers/ optimizers, combiner boxes, shutdowns, disconnects, and grounding and bonding information.

[11] Municipal Climate Change Action Centre (2019). Solar Toolkit: Best practices for permits, taxes and solar access. Retrieved from: mccac.ca/app/uploads/SolarFriendlyMunicipalities-PermitTaxes.pdf.

ELECTRICAL PERMIT (RULES FOR ELECTRICAL COMPONENTS & CONNECTION)	
Governance & process	
Zone agnostic	Make the permit process the same regardless of the zoning of the property where the solar PV system is installed.
Application	Include a checklist for all required forms and corresponding documentation in the solar PV system application.
	Streamline the permit application and review process for simpler systems to combine development, building and electrical permits into one application.
	Offer online applications, in addition to paper and in-person submissions.
Timing	Aim to approve permits within three business days, or as soon as possible. Aim to schedule inspections within two business days, or as soon as possible. Schedule inspections using a two-hour timing window.
Guidance	Provide a "one-stop shop" website with guidance on how to navigate the permit process. Website should include a description of the process, links to online applications, and contact information for further assistance.
Fees	
Building	Use a flat fee; this is an easy way to partially subsidize solar PV systems.
Electrical	Use a flat fee for residential systems, and a tiered fee schedule with a price cap for all other systems.
Development	Use a flat fee ($400 or less).

5. Coordinate electricity planning with IESO and LDCs

IESO convenes a Hamilton sub-region Technical Working Group with staff from Alectra Utilities, Hydro One Distribution, Hydro One Transmission and IESO. The City of Hamilton should work with the Technical Working Group to align the regional electricity planning with the NZS.

6. Assess potential sites for solar installations

Based on criteria outlined in this memo, and current land planning policy, the City should undertake a study in partnership with local utilities and other key stakeholders, to identify potential sites for ground mount solar installations.

7. Green hydrogen

Despite the fact that producing green hydrogen has significant land use impacts, it may well be critical to certain end use decarbonization in Hamilton, especially industrial end uses. As such, the City should consider supporting efforts to improve green hydrogen's efficient and sustainable production, whether through research or pilot projects.

Appendix F.1: Renewable Energy Technologies: Planning Considerations

In terms of land-use planning policy within the City's jurisdiction, the primary consideration in the NZS is solar and district energy. Unlike non-renewable sources which require expansion as resources are depleted, solar can use the same land for generation on an ongoing basis and can support simultaneous uses such as grazing and arable cropping.

Table 2. Renewable Energy Technologies in the NZS.

TECHNOLOGY	DESCRIPTION[12]	MARKET READINESS	CAPACITY INSTALLED IN HAMILTON'S NZS (MW)		ABATEMENT COST ($/$TCO_2E$)
			2030	2050	
Negawatts	A watt of energy that you have not used through energy conservation or the use of energy-efficient products	Mature	485	1,627	Variable
Passive solar	Passive solar technologies convert sunlight into usable heat and cause air movement for ventilating to heat and cool living spaces without active mechanical or electrical devices.	Mature	n/a	n/a	Not evaluated
Large-scale solar (ground mount)	Photovoltaics (often shortened as PV) converts light (photons) to electricity (voltage). Large scale installations cover an acre of ground or more and are mounted on a support system.	Mature	90	280	($1,254)
Roof-mounted solar	Roof mounted PV systems are installed on houses and non-residential buildings and can vary in size.	Mature	180	425	$597
Wind	Wind is used to produce electricity using the kinetic energy created by air in motion. Commercially available wind turbines have reached 13 MW capacity, with rotor diameters of up to 720 feet.	Mature	No wind capacity was installed within City boundaries in the NZS, instead wind power was included as part of the purchase of renewable energy certificates		$51

[12] Descriptions are adapted from the National Renewable Energy Laboratory (www.nrel.gov/) and US Department of Energy www.energy.gov/).

TECHNOLOGY	DESCRIPTION[12]	MARKET READINESS	CAPACITY INSTALLED IN HAMILTON'S NZS (MW)		ABATEMENT COST ($/$TCO_2E$)
Renewable natural gas	Biogas that has been upgraded for use in place of fossil natural gas. The biogas used to produce RNG comes from a variety of sources, including municipal solid waste landfills, digesters at water resource recovery facilities (wastewater treatment plants), livestock farms, food production facilities and organic waste management operations.	Mature	14.5	26.7	$60

Table 3. Energy carriers

TECHNOLOGY	DESCRIPTION	MARKET READINESS	CAPACITY INSTALLED IN HAMILTON'S NZS		ABATEMENT COST OVER THE PERIOD ($/$TCO_2E$)
			2030	2050	
Green hydrogen	Hydrogen is a secondary source of energy. It stores and transports energy produced from other resources.	In development	4,049,507 MWh	9,551,362 MWh	$816
Air source heat pumps	A heat pump's refrigeration system consists of a compressor and two coils made of copper tubing (one indoors and one outside), which are surrounded by aluminum fins to aid heat transfer. In heating mode, liquid refrigerant in the outside coils extracts heat from the air and evaporates into a gas. The indoor coils release heat from the refrigerant as it condenses back into a liquid. A reversing valve, near the compressor, can change the direction of the refrigerant flow for cooling as well as for defrosting the outdoor coils in winter.	Mature	1,060,428 MWh	2,776,073 MWh	$451

TECHNOLOGY	DESCRIPTION	MARKET READINESS	CAPACITY INSTALLED IN HAMILTON'S NZS		ABATEMENT COST OVER THE PERIOD ($/$TCO_2E$)
Ground source heat pumps	A geothermal heat pump takes advantage of this by exchanging heat with the earth through a ground heat exchanger. The heat exchanger is a system of pipes called a loop, which is buried in the shallow ground near the building. A fluid (usually water or a mixture of water and antifreeze) circulates through the pipes to absorb or relinquish heat within the ground.	Mature	Not evaluated	Not evaluated	Not evaluated
District energy	A mechanism for distributing heating and cooling between multiple buildings, using water. Next generation district energy systems use low temperature water combined with heat pumps and exchange heat and cold between buildings.	Mature	85 MW	85 MW	$192

APPENDIX G: Memo - Impact of GRIDS 2 Scenarios on GHG Emissions and Addendum

October 2021

Contents

City of Hamilton

Impact of GRIDS 2 Scenarios on GHG Emissions

Briefing V.1

October 26, 2021

Disclaimer

The information in this analysis has been compiled to offer an assessment of the GHG emissions for the City of Hamilton. Reasonable skill, care and diligence have been exercised to assess the information acquired during the preparation of this analysis, but no guarantees or warranties are made regarding the accuracy or completeness of this information. This *document, the information it contains and the information and basis on which it relies, are subject to changes that are beyond the control of the author. The information provided by others is believed to be accurate but has not been verified.*

2

Context

This analysis is being undertaken as part of the City of Hamilton's GRIDS 2 / MCR growth management planning exercise to inform the choice of 'How Should Hamilton Grow?' to the year 2051. GRIDS 2 / MCR is examining how the City can accommodate forecasted population and employment growth in the period from 2021 to 2051. The 'How Should Hamilton Grow?' evaluation will evaluate two growth options – the Ambitious Density (AD) scenario which includes an urban boundary expansion of approximately 1,310 ha, while accommodating the majority of the growth in the existing urban boundary; and the No Urban Expansion (NUE) scenario which focuses all of the forecasted growth within the existing urban boundary.

On March 27th, 2019, Hamilton City Council passed a motion stating that the City of Hamilton declared a climate emergency.

As part of this motion, City Council directed Staff to investigate and identify a path for the entire city to achieve net-zero carbon emissions by 2050, including a process for measuring and reporting on progress towards that goal.

Hamilton's Community Energy and Emissions Plan (CEEP) is a major component of the City of Hamilton's strategy for responding to the climate emergency. With the input of local industry, academia, utilities, and local non-profits, this plan aims for Hamilton to achieve net-zero carbon emissions, citywide, by 2050 and become a prosperous, equitable, post-carbon city.

The technical analysis underlying the CEEP evaluated two scenarios to achieve Hamilton's GHG emissions reductions. A Business-As-Planned (BAP) scenario reflects current trends, while a net zero scenario evaluates actions to target net zero emissions by 2050.

In a BAP scenario, Hamilton's 2050 GHG emissions will be far from its net-zero GHG emissions target. In this scenario, by 2050, each Hamiltonian will represent the equivalent of 11.2 tonnes of GHG emissions. As a whole, the City will emit 9.6 Mt CO2e, up from 8.7 Mt CO2e in 2016. The CEEP also plots a pathway to net zero emissions by 2050. In the Net Zero scenario, the city implements ambitious actions in buildings, transportation, energy systems and industry to achieve deep emissions reductions. Each of these actions requires the mobilization of major investments and complex governance and implementation mechanisms.

Land-use policy is an important GHG emissions reduction strategy as it can avoid locking in infrastructure systems and activities that are costly to retrofit or to provide without generating GHG emissions. Conversely, land-use policy can enable cost effective emissions reductions. For example, it is more affordable to provide zero emissions transportation and zero emissions energy to a compact, complete community than to a distributed population. Electric buses can provide a service to more people with shorter routes and lower energy consumption. When destinations are in close proximity, people can walk or cycle. Houses tend to be smaller and share walls, which reduces energy consumption. District energy is more viable when heat loads are concentrated. Land-use policy is also the most cost-effective action a City can take, as it can enable GHG emissions reductions without requiring a direct investment by the City or society.

This analysis considers how the two different land-use scenarios impact patterns of energy consumption and GHG emissions, assuming current technologies and behaviours, by evaluating the impact of the land-use scenarios against the BAP scenario.

Methodology

Modelling Approach

Two land-use scenarios were evaluated for the City of Hamilton in the CityInSight model- Ambitious Density (AD) and No Urban Expansion (NUE). CityInSight is designed to project how the energy flow picture and emissions profile will change in the long term by modelling potential change in the context (e.g. population, development patterns), projecting energy services demand intensities, and projecting the composition of energy system infrastructure, often with stocks. Stock-turnover models enable users to directly address questions about the penetration rates of new technologies over time constrained by assumptions such as new stock, market shares and stock retirements. Examples of outputs of the projections include energy mix, mode split, Vehicle Kilometres Travelled (VKT), energy costs, household energy costs, GHG emissions and others.

The modelling evaluates scenarios that were developed for the City of Hamilton's GRIDS 2 / MCR growth management planning exercise. Both the scenarios evaluated in this analysis are built on the City's Business as Planned (BAP) Scenario used in the Community Energy and Emissions Plan.[1]

In evaluating the scenarios, the following assumptions were applied:

Input data:

- Population, employment, and dwelling unit projections by zone were provided by the City.
- Data on technologies, energy and emissions was derived from the BAP scenario developed for the Community Energy and Emissions Plan.

Assumptions:

- Zonal employment growth is reflective of existing industrial/commercial activity currently taking place within the zone, as attributable to existing floor space attributable to an employment sector within Municipal Property Assessment Corporation (MPAC) data. For example, if employment in a zone is 50% industrial and 50% commercial, new employment will also receive the same share distribution.
- Zones within a modelled "superzone" were aggregated to reflect overall impact at a coarse level due to difference in zone systems used in GRIDS 2 work and the zonal system used in previous CityInSight modelling.
- Transportation modal shares for each zone were held constant across the time period. No additional transit interventions were modelled.
- Actions and assumptions in the BAP scenario are held constant for both of the scenarios.

[1] Additional details on the BAP scenario can be found in this document: https://www.hamilton.ca/sites/default/files/media/browser/2020-12-11/hamilton-baseline-bap-report-dec1-2020.pdf

Method:

- Population, employment, dwelling unit, and non-residential floor space projections, as derived or inferred from the input data, were projected in the CityInSight framework at the zonal level.
- All BAP scenario assumptions and actions were modelled within the timeline to evaluate activity, energy, and emissions impacts of the integrated scenario.

Note that because of the modelling approach and data available, the GHG impact from transportation is likely understated; the City's transportation model found vehicle kilometre travelled (VKT) reductions four times higher than those identified in this analysis. The reduction in vehicular travel will increase the GHG emissions reductions resulting from the NUE scenario over the AD scenario. A future update is planned to address these differences.

GHG Emissions

GHG emissions are lower in the NUE scenario in relation to the AD scenario (Figure 1), but the difference is subtle, illustrated by the closeness of the two curves. Part of the reason that the difference is subtle is because Hamilton's GHG emissions are dominated by industrial emissions (63%) which are not impacted by land-use policy (Figure 2). Transportation emissions account for 19% of the total, while emissions from residential buildings account for 7.6% of the emissions. In order to better illustrate the difference between the two scenarios, the same lines are illustrated against a non-zero y-axis in Figure 3. There is a cumulative reduction of 1 MtCO2e between 2022 and 2050 (Figure 4), which, for scale, is equivalent to 11% of the total annual GHG emissions in 2016.

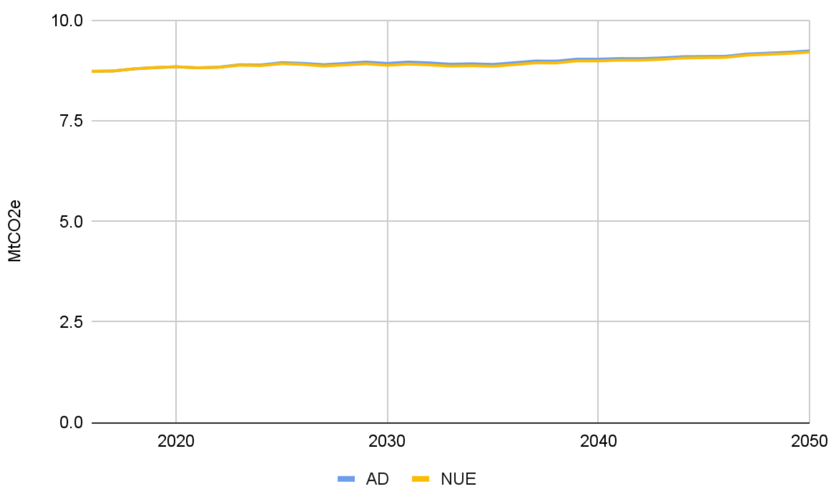

Figure 1: Annual GHG emissions of the AD and NUE scenarios

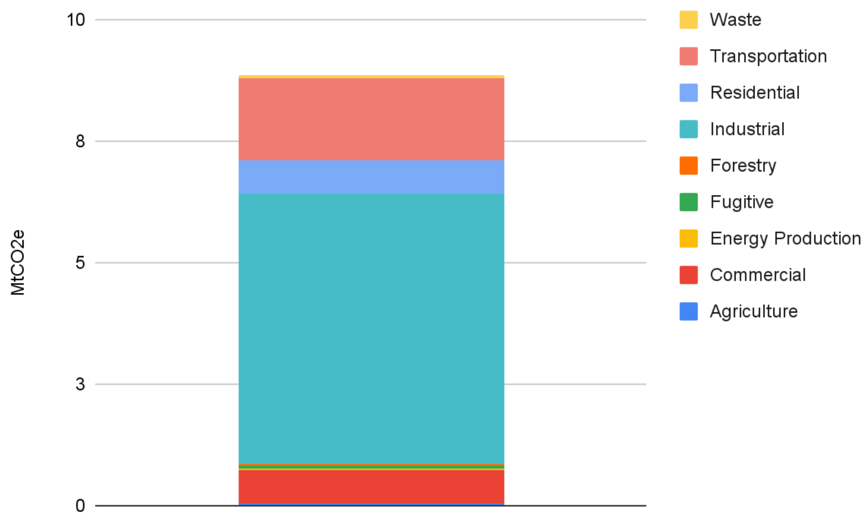

Figure 2: GHG emissions in the City of Hamilton by sector, 2020

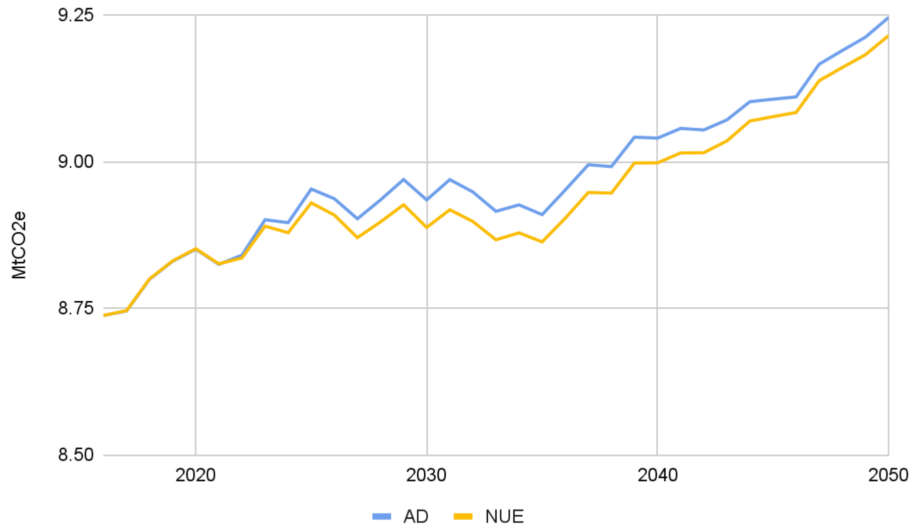

Figure 3: Annual GHG emissions of the AD and NUE scenarios, adjusted y-axis

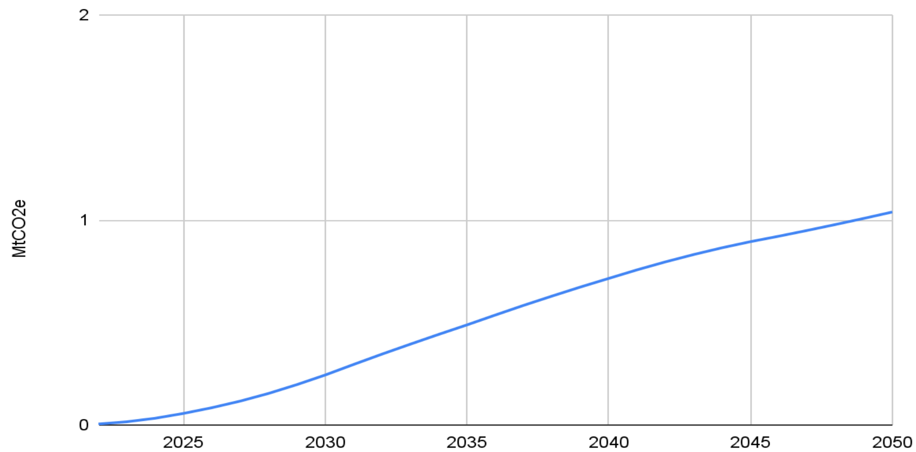

Figure 4: Cumulative emissions reductions of the NUE scenario relative to the AD scenario

While the reduction appears small in the context of the City's total emissions, every tonne of GHG emissions reductions counts in a climate emergency, as each tonne imposes a social and economic cost on society. Further, the incremental cost of achieving these emissions reductions is negligible, since this is a planning decision that doesn't require a direct investment by the municipalities, businesses or households. While there are major economic implications of the scenarios in terms of infrastructure, land costs and other considerations, these are outside of the scope of an analysis of GHG impacts.

Table 1: Summary of GHG Emissions Results

Scenario	Cumulative GHG Emissions (MtCO2e) (2022-2050)	Annual Emissions in 2030 (MtCO2e)	Annual Emissions in 2050 (MtCO2e)
AD	261.3	8.93	9.24
NUE	260.2	8.89	9.21
Reduction over AD	1.0	0.05 (50,000 tCO2e)	0.03 (30,000 tCO2e)
Reduction over AD (%)	0.40%	0.53%	0.33%

To illustrate the drivers of GHG emissions, the differences are illustrated by sector, where negative numbers represent savings in the NUE scenario over the AD scenario. Residential emissions are reduced due to an increased share of more energy efficient apartments in the NUE scenario relative to a greater share of single family homes in the AD scenario. Transportation emissions are reduced as a result of shorter trips. Emissions from sequestration in agriculture, forests and land-use are also decreased due to reduced expansion of the City into greenfield locations.

Assuming the City adopts the CEEP, measures which decarbonise the energy system will reduce the GHG emissions differential between the scenarios, as vehicular travel becomes powered by clean electricity for example. Nevertheless, more energy efficient dwelling types and reduced driving in turn reduce the burden of decarbonising the electrical grid and reduce the need for additional renewable energy generation.

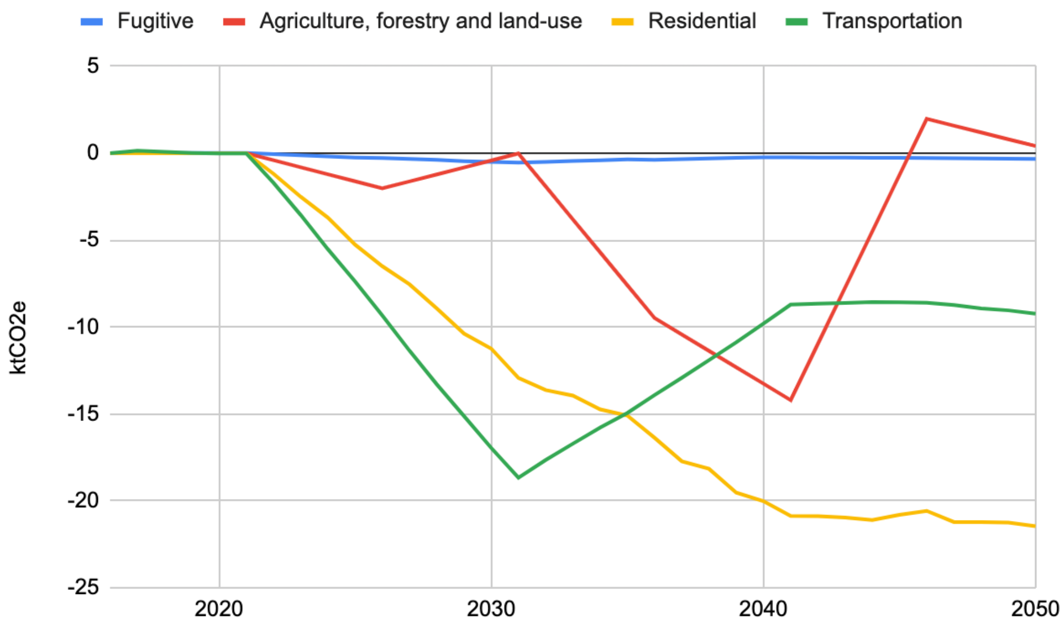

Figure 5: Change in GHG emissions by sector of NUE scenario relative to the AD scenario, (negative emissions equal emissions reductions.

The carbon price places a value on GHG emissions, climbing from $50 per tonne in 2021 to $170 per tonne by 2030. Applying this value to the reduced GHG emissions in the NUE scenario generates an avoided cost of $166 million (undiscounted), or an average of $6 million per year.

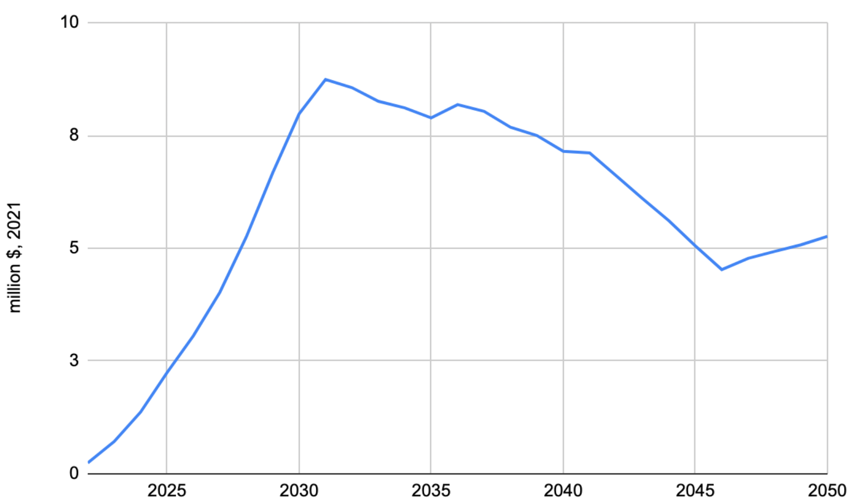

Figure 6: Avoided carbon price expenditure, NUE scenario over the AD scenario, 2022-2050

Table 2: Avoided carbon price expenditures, NUE scenario over the AD scenario

Scenario	Cumulative, 2022-2050 (not discounted, millions, 2021$)	Annual, 2040 (not discounted, millions, 2021$)	Annual, 2050 (not discounted, millions, 2021$)
Reduction over AD	$166	$7	$5.3

Transportation Impacts

In 2020, Hamiltonians drove approximately 4.8 billion kilometres, and by 2040, this climbs to 6.98 billion kilometres. The NUE scenario decreases this total by 100 million or 1.5 percent in 2050 (Figure 7).[2] This reduction results in reduced household travel costs and reduces the burden on the electricity system when the vehicle fleet is electrified.

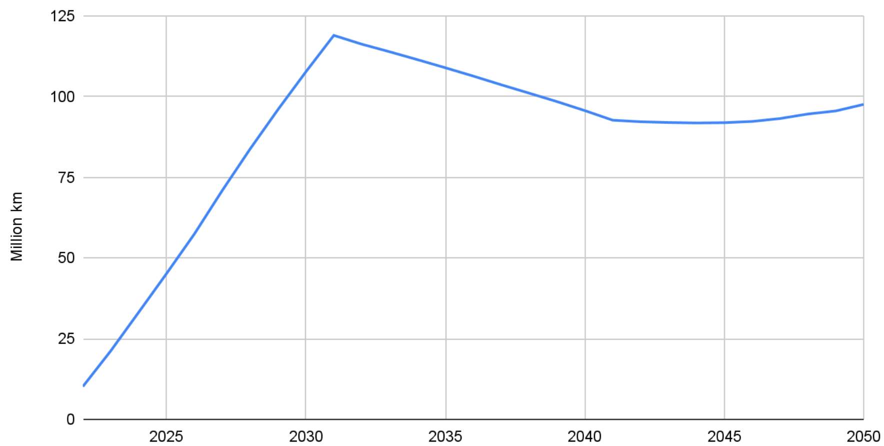

Figure 7: Annual reduction in VKT in the NUE scenario over the AD scenario, 2022-2050

As might be expected there is increased active transportation in the NUE scenario in comparison with the AD scenario. Figure 8 illustrates that there are nearly 2 million kilometres more of walking trips of 2 km length in the NUE scenario, an increase of 30%.

[2] Note that the City's Transportation model identified savings of 400 million kilometres in 2050, or four times the reduction that was identified in this analysis. As a result, this analysis likely understates the GHG reduction from transportation. Additional analysis of the discrepancy in VKTs between the models is being undertaken, and if necessary, an addendum report will be provided which identifies the GHG reduction resulting from the increased GHG savings.

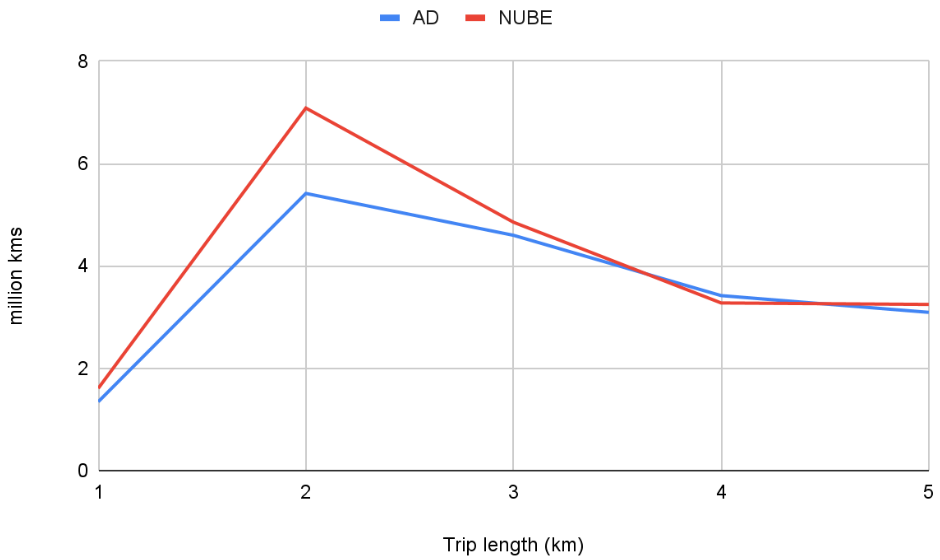

Figure 8: Walking kilometers by trip length, 2050

Energy Impacts

The NUE scenario results in energy savings which climb to nearly 700,000 GJ per year by 2030 (0.7% of total energy consumption in that year). Much of these savings occur in the industrial sector, but Figure 9 illustrates the savings that occur in the residential and transportation sectors, directly benefiting households. The differential in energy consumption in the commercial sector is due to differences in employment rates of growth in the two scenarios as a result of the data sources; by 2050, commercial and industrial floor space are equal in both scenarios. Energy savings result in financial savings. Natural gas costs are approximately $16 per GJ, electricity costs $60 per GJ and gasoline costs $38 per GJ. For illustrative purposes, assuming no increase in gasoline costs, avoided transportation costs total nearly $10 million per year by 2030.

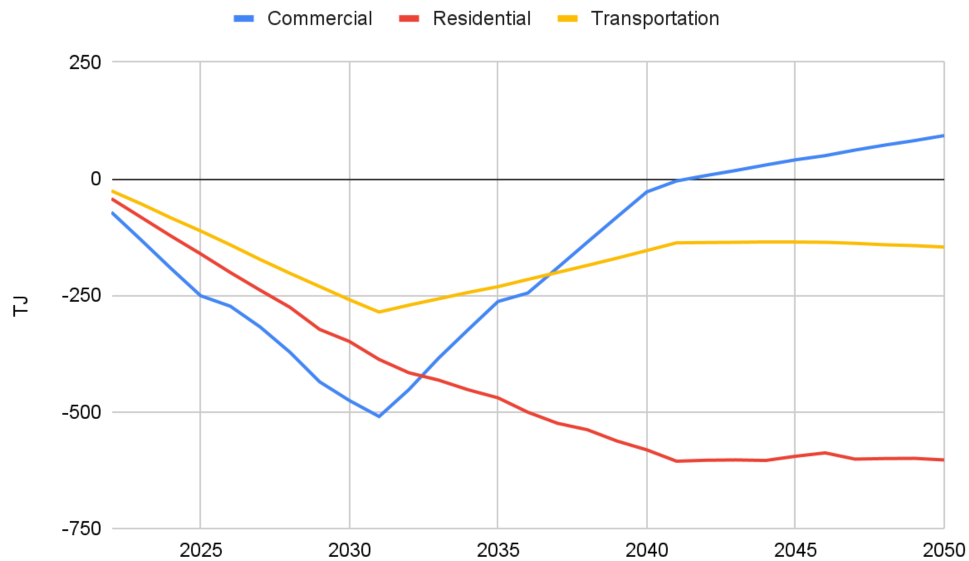

Figure 9: Energy savings by sector, NUE scenario over AD scenario (negative equals energy savings, 1 TJ equals 1,000 GJ), 2022-2050.

Conclusion

As is intuitive, there are GHG emissions reductions that result from concentrating new growth in the urban area; these reductions are primarily the result of reduced vehicular travel and more compact residential buildings. The impact of this change is muted by the interia of the City's existing building stock, travel activity, and industry, the latter of which accounts for 60% of the City's emissions. While the GHG emissions reductions are relatively small, every tonne counts in the context of a net zero target, and in a climate emergency. These reductions are valuable because they are generated without an incremental investment and may enable additional future GHG reductions as measures such as district energy and new forms of public transit can be introduced.

document, the information it contains and the information and basis on which it relies, are subject to changes that are beyond the control of the author. The information provided by others is believed to be accurate but has not been verified.

Addenda – Nov. 17, 2021

Following the completion of this brief, further analysis has been completed to refine the results. First, updated transportation data was provided, specifically modal share projections for internal and external trips for 2051 by zone. Second, interim projections (between 2016 and 2050) were removed to provide better comparability between the two scenarios. Third, commercial and industrial employment distributions were assumed to be the same in both scenarios. These changes had the impact of reducing the cumulative GHG impact (2021-2050) from 1 MtCO2e as described in this brief to 0.5 MtCO2e.

An analysis of the VKT reduction resulting from the NUE scenario narrowed the difference between SSG's analysis and the City's transportation analysis to 100 million annual VKT in 2050. This variance is the result of the modelling treatment of pass-through trips. From a GHG accounting perspective, pass through trips are not counted as part of the City's GHG inventory and are therefore not reflected in the CityInSight model.

This finding provides three insights additional to those described in the briefing:

- *The size of the GHG benefit of the NUE scenario will be influenced by the timing of, and location of, urban expansion.*
- *The sectoral distribution of future employment between the two scenarios will also impact the difference in emissions (these have been held constant in the two scenarios). For example, if one scenario included more employment in low rise office versus high rise office, this will impact the emissions.*
- *There are additional GHG benefits from reduced passthrough trips which do not show up in the CityInSight analysis.*