City of Hamilton

Community Energy Plan

Baseline and Business-As-Planned 2016-2050 Energy and Emissions Report

November 30, 2020

Completed by:

Sustainability Solutions Group

whatIf? Technologies

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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 (CO2e): a measure for describing the global warming potential of a greenhouse gas using the equivalent amount or concentration of carbon dioxide (CO2) as a reference. CO2e is commonly expressed as million metric tonnes of carbon dioxide equivalent (MtCO2e).

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 (tCO2e), 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	**Energy**
1 mtCO2 = 1,000,000 tCO2e 1 ktCO2e = 1,000 tCO2e 1 tCO2e = 1,000 kgCO2e 1 kgCO2e = 1,000 gCO2e	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 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:

I. 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.)

II. 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.

III. 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 CO2e, up from 8.7 Mt CO2e in 2016.

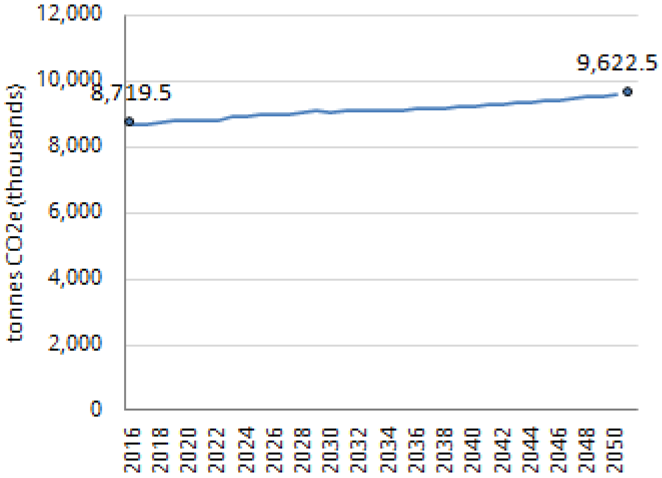

Figure 1: GHG emissions in Hamilton, 2016-2050.

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 ktCO2e 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.

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

Part I: BAP Energy and Emissions, 2016-2050

Demographics

Community Energy and Emissions

Buildings and Industry Sector Energy and Emissions

Transportation Sector Energy and Emissions

Waste Sector Emissions

Agriculture and Sequestration

Looking to the Low-Carbon Scenario

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.

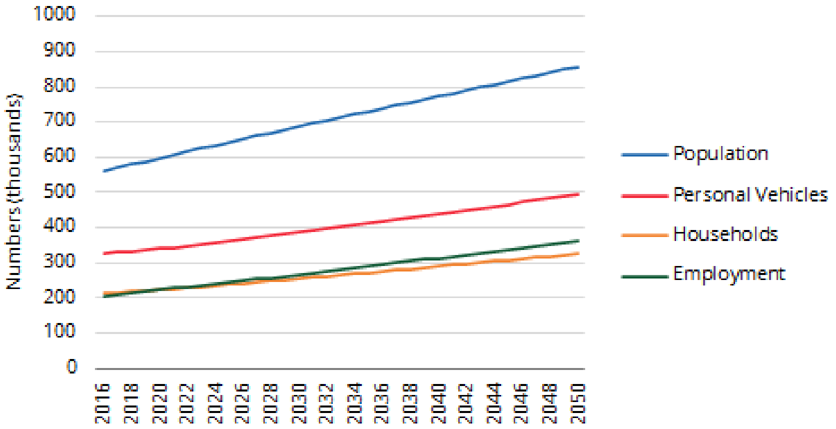

Figure 2: Projected population, personal vehicles, households, and employment 2016-2050.

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).

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.

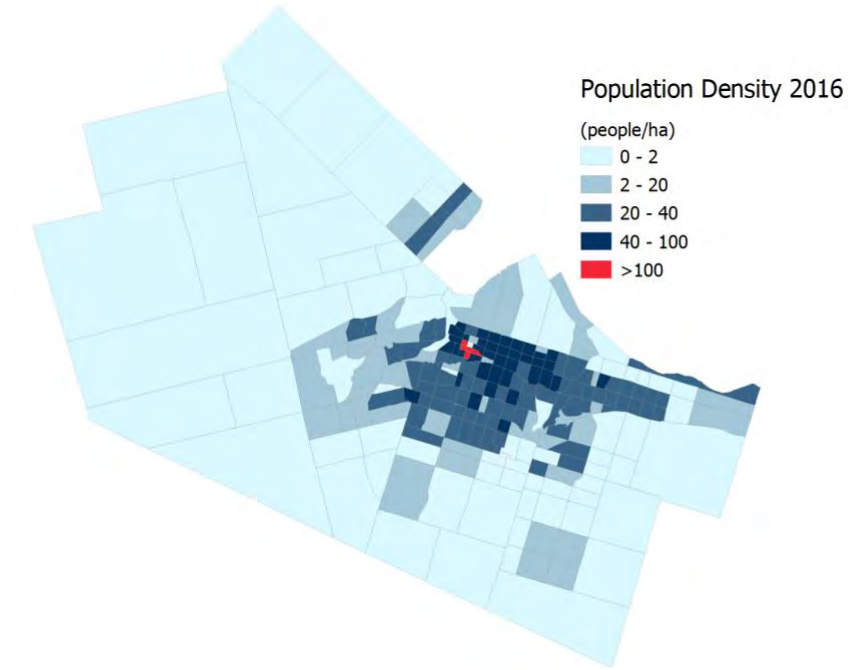

Figure 3: Population density in Hamilton in 2016, by traffic zone.

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 is also anticipated, coinciding with future expansions of the urban boundary, and designated growth areas.

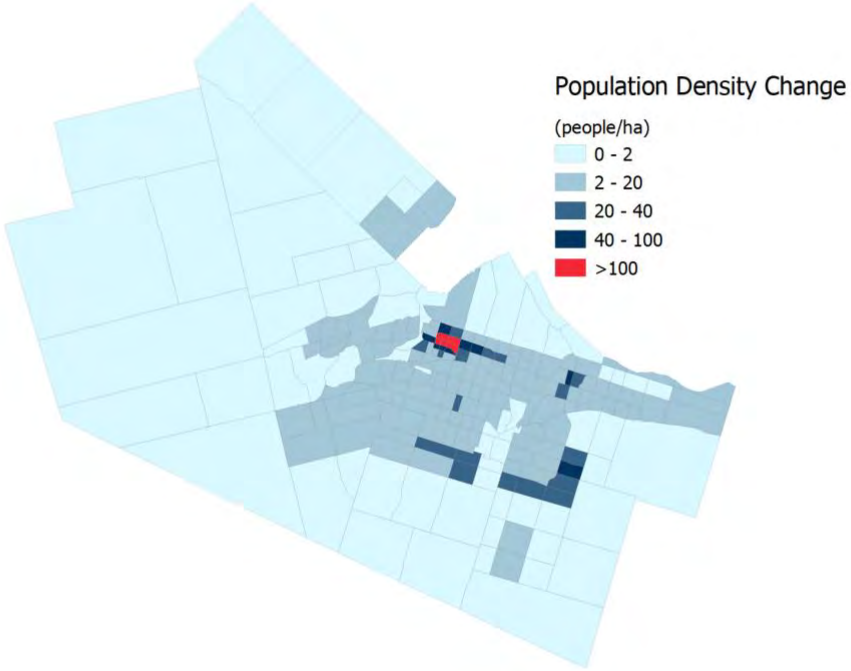

Figure 4: Population density change between 2016 and 2050 in Hamilton, by traffic zone.

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.

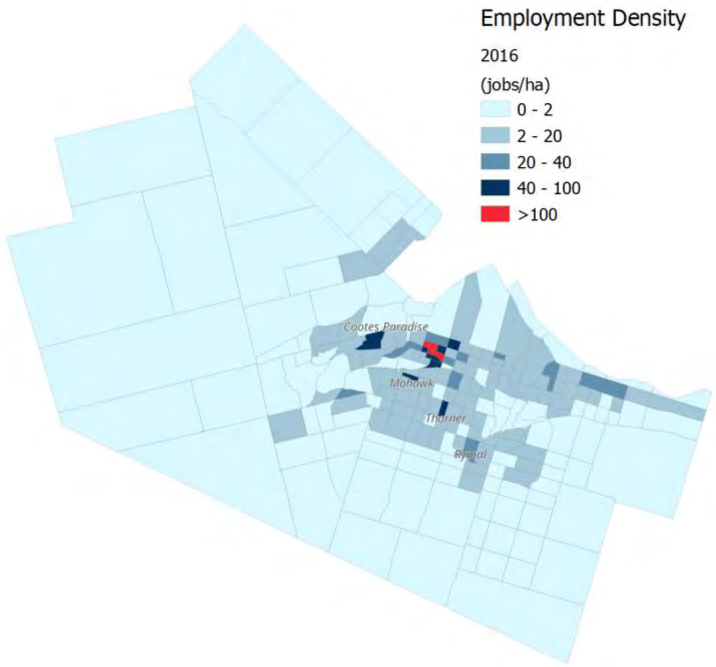

Figure 5: Employment density in Hamilton in 2016, by traffic zone. Cootes Paradise, Mohawk, Thorner, and Rymal neighborhoods are highlighted as employment hubs outside the downtown core.

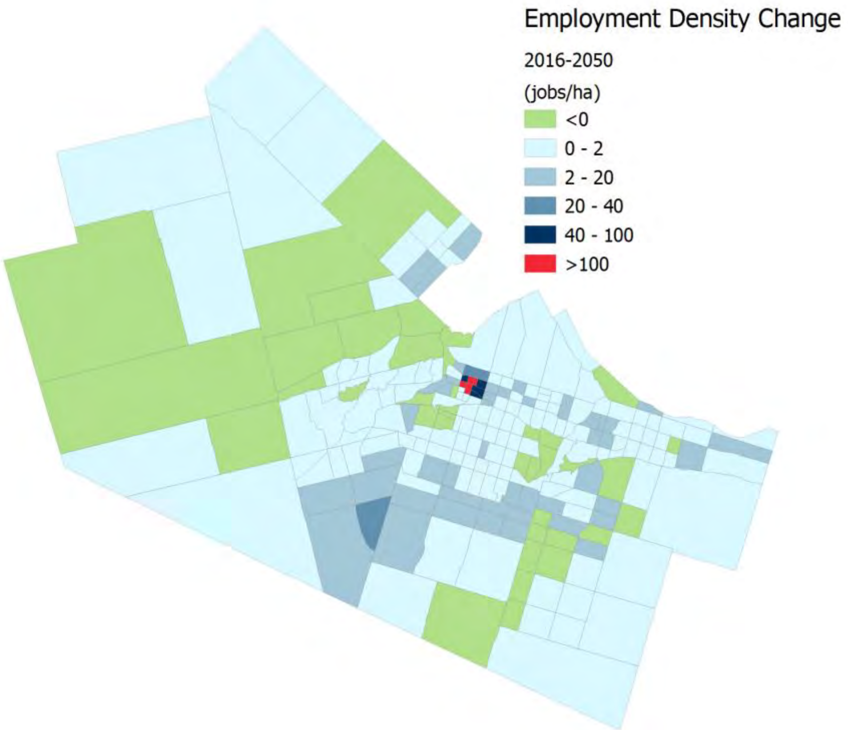

Figure 6: Employment density change in Hamilton, 2016-2050, by traffic zone. (Note: The maximum employment decrease projected for a zone does not exceed -0.32 jobs/ha).

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.

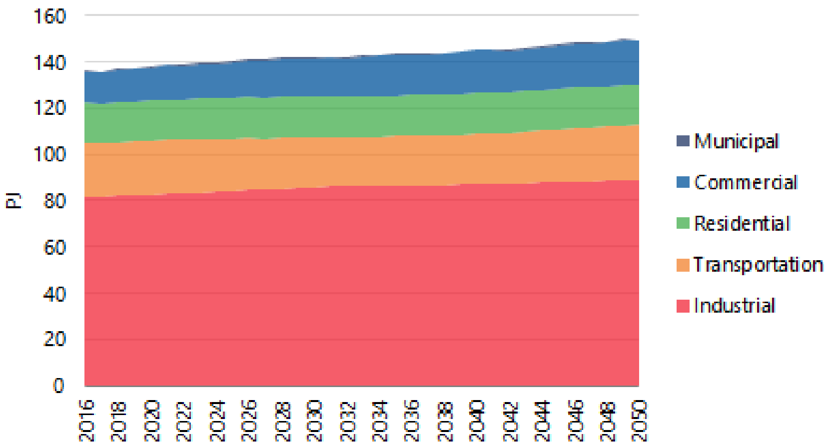

Figure 7: Projected BAP energy consumption (PJ) by sector, 2016-2050.

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.

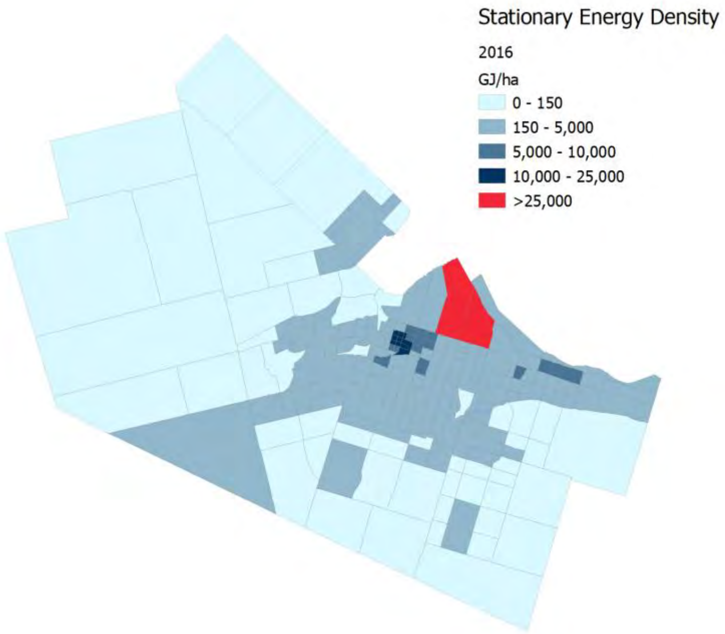

Figure 8: Stationary energy density in Hamilton (GJ/ha) in 2016, by traffic zone.

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.

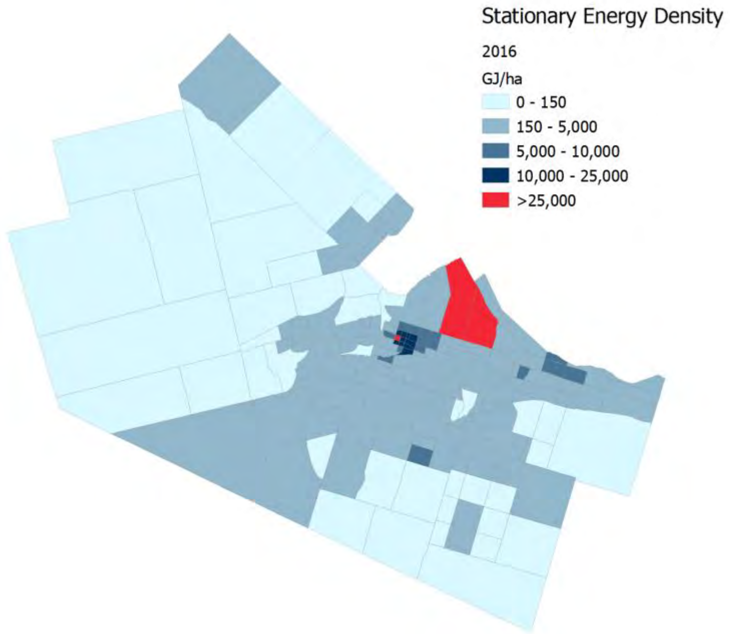

Figure 9: Energy density in Hamilton (TJ/ha) in 2050, by traffic zone.

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

Energy by Fuel

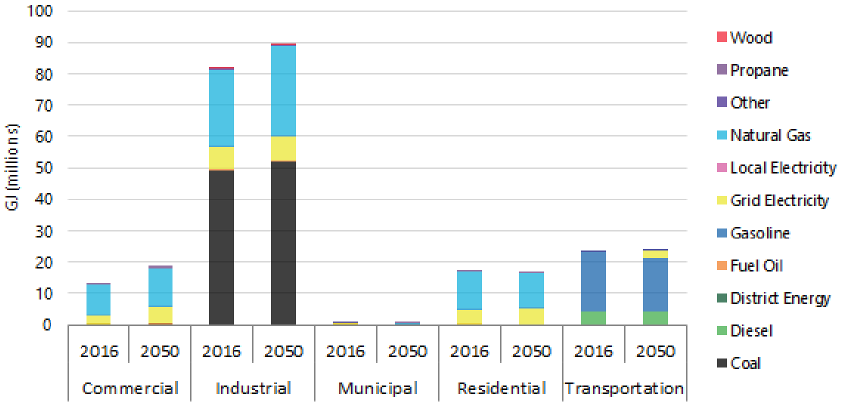

Figure 10: Projected BAP energy consumption (PJ) by sector and fuel, 2016-2050.[2]

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.

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.

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

Per Capita Energy Use

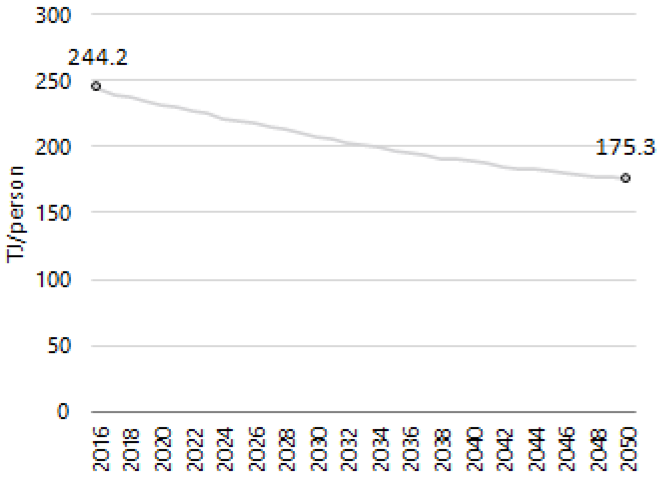

Figure 11: Projected BAP energy per capita (TJ/person), 2016 and 2050.

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.

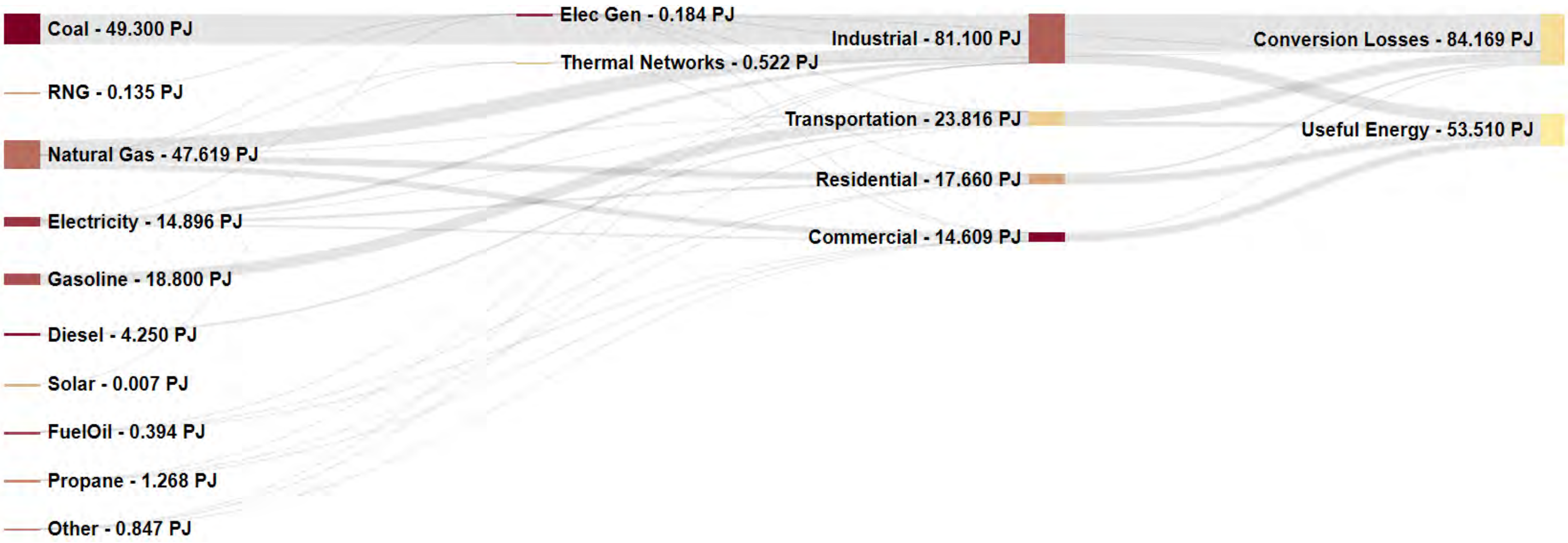

Figure 12. 2016 energy flows and conversions for the city.

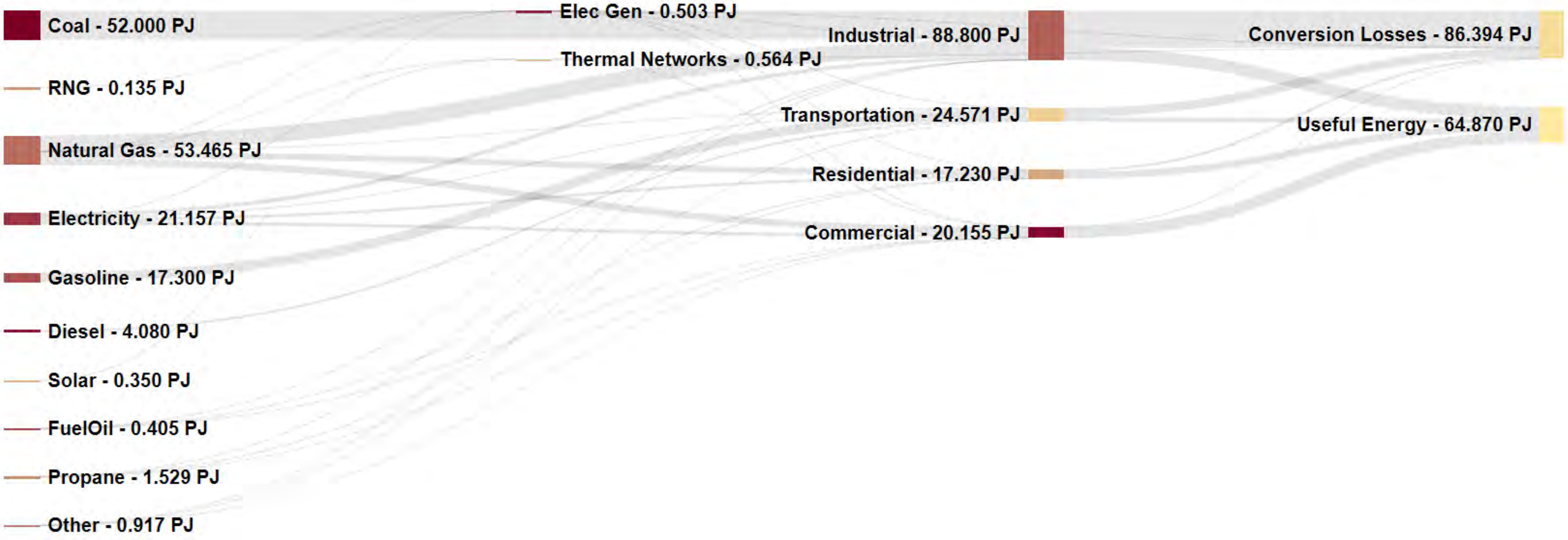

Figure 13. 2050 energy flows and conversions for the city.

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 0.142 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, 557 $ktCO_2e$ 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, 305 $ktCO_2e$ 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 71 $ktCO_2e$ 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.

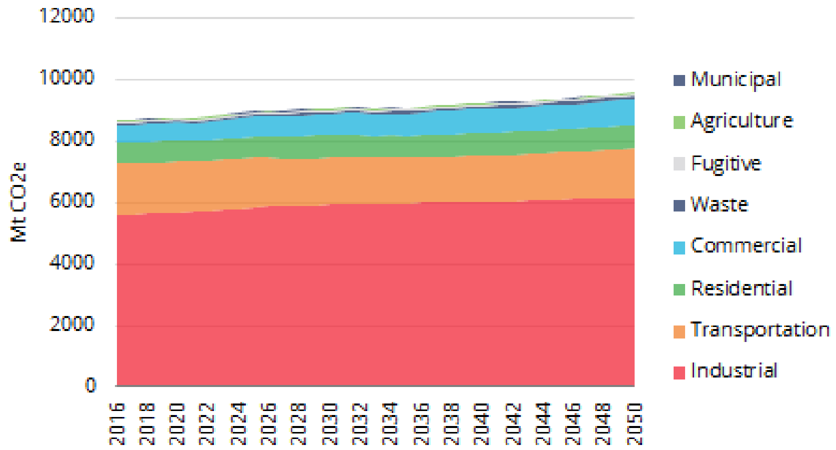

Figure 14: Projected BAP emissions (Mt CO2e) by sector, 2016-2050

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.

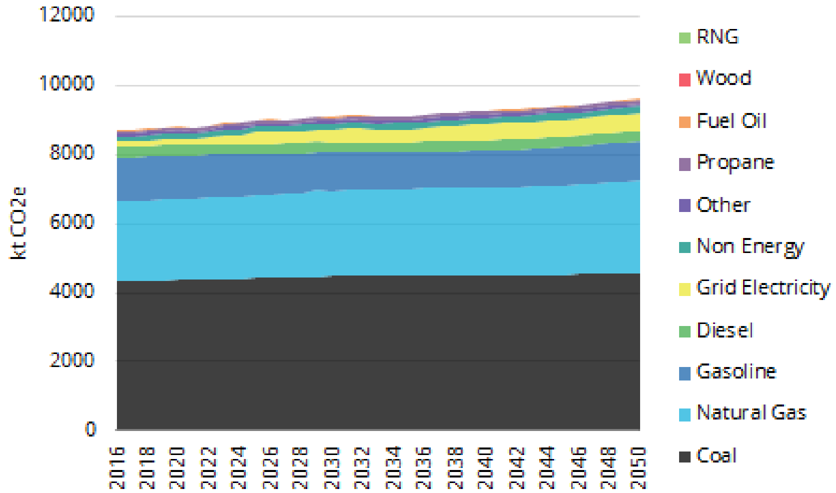

Figure 15: Projected BAP emissions (ktCO2e) by fuel type, 2016-2050.

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 tCO2e/person. Edmonton and Saskatoon'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.

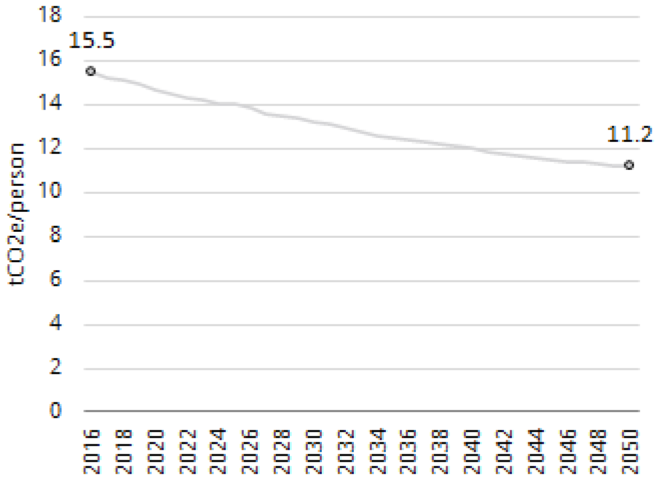

Figure 16: Projected BAP emissions per capita (tCO2e/person), 2016-2050.

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

Community Emissions by Zone, 2050

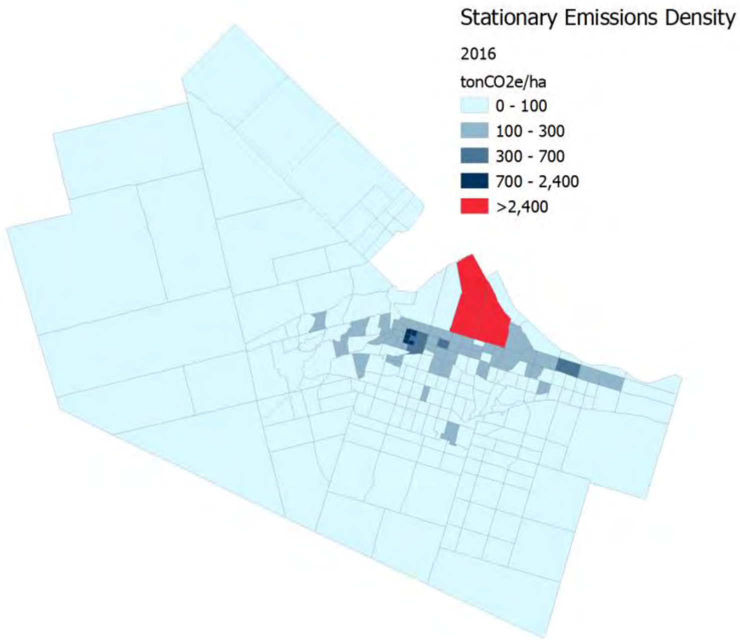

Figure 17: Stationary GHG emissions per hectare, by traffic zone, Hamilton 2016.

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 tCO2e 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.

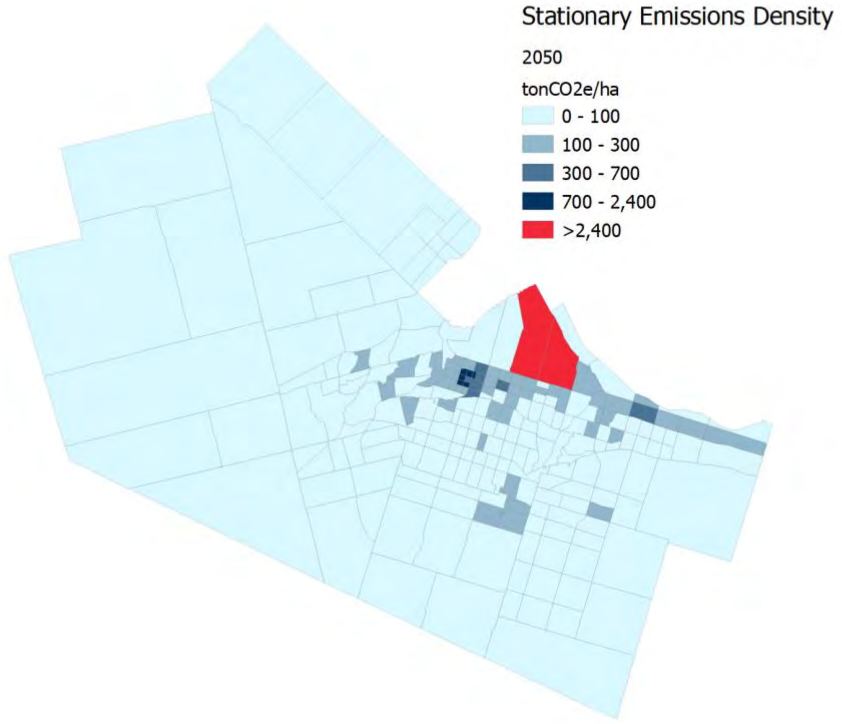

Figure 18: Stationary GHG emissions per hectare, by traffic zone, Hamilton 2050.

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

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.

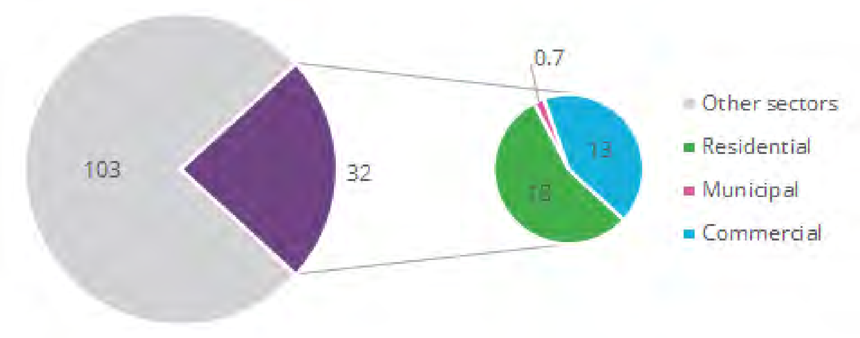

Figure 19: Overall city energy consumption in PJ in 2016. The purple portion represents building sector energy use.

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.

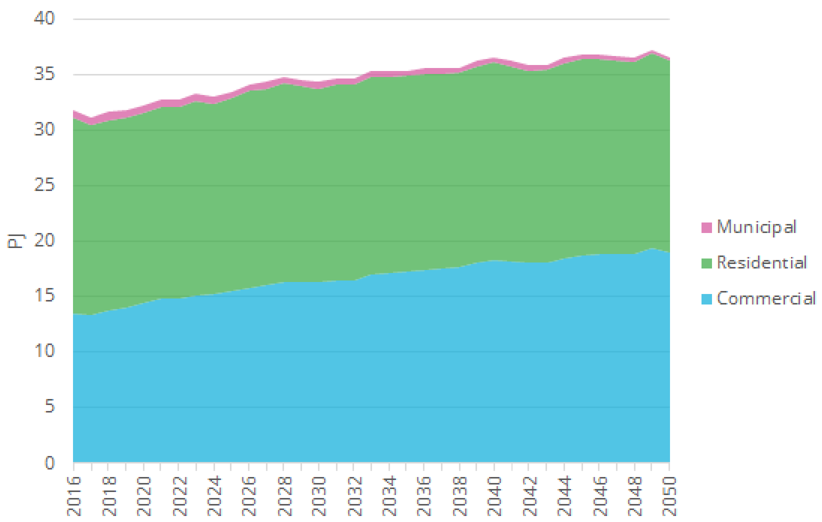

Figure 20: Projected BAP energy consumption for buildings (PJ) by sector, 2016-2050.

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.

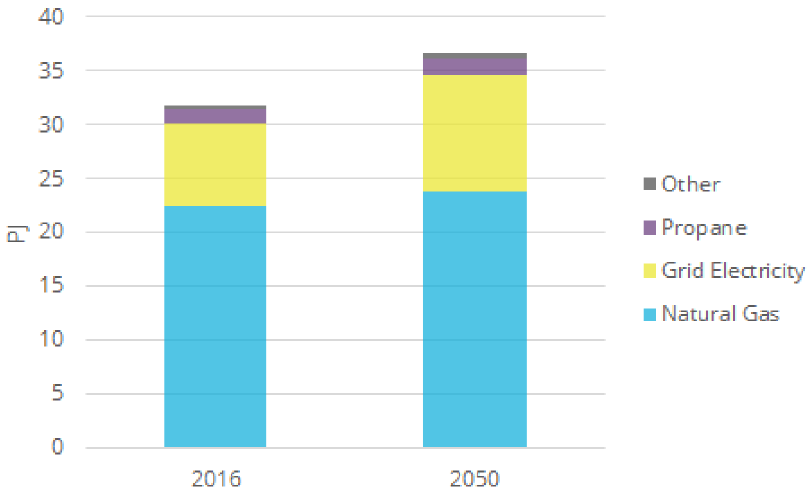

Figure 21: Energy consumption in PJ in 2016 and 2050, by fuel type.[4]

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.

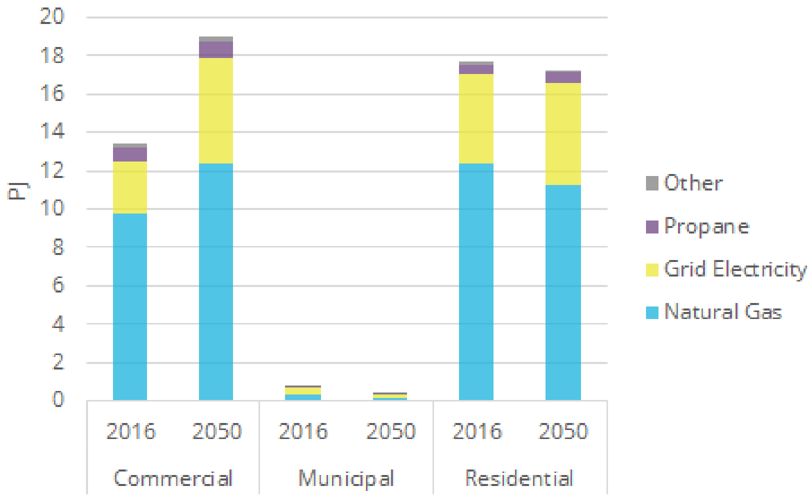

Figure 22: Energy consumption in PJ in 2016 and 2050, by sector and fuel type.[4]

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.

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

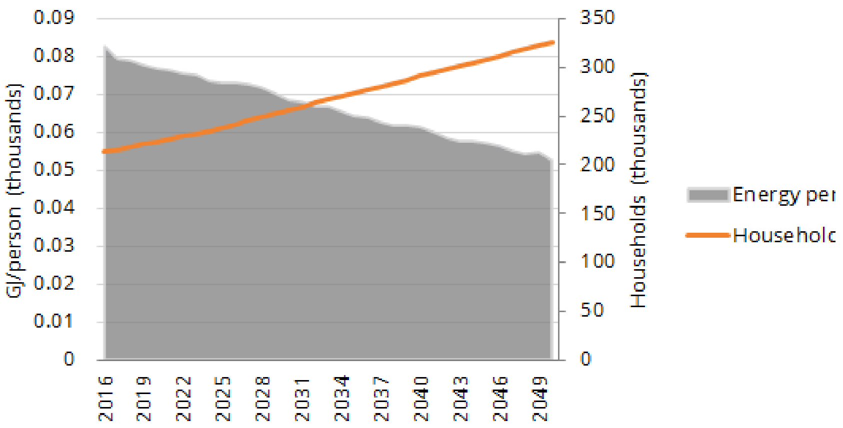


Figure 23: Average household energy intensity (GJ/household) compared with the number of households, 2016-2050.

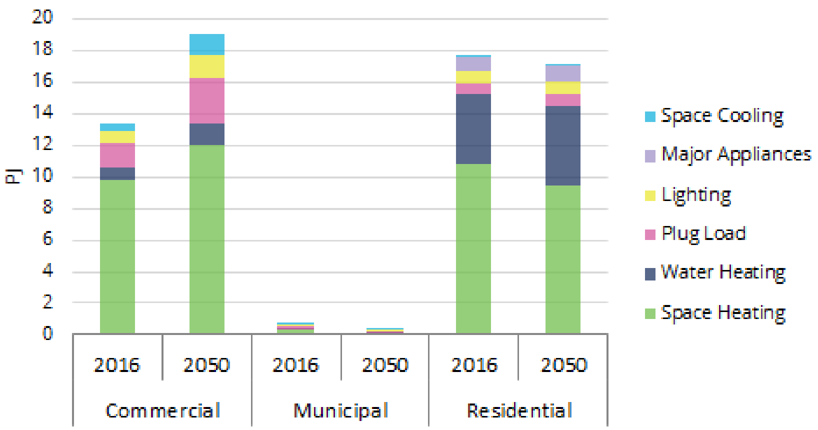


Figure 24: Building energy consumption for 2016 and 2050 (PJ), by end use and sector.

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.

Building Emissions

Similar to energy use trends, GHG emissions from buildings are expected to increase by 29%, from 1.3 MtCO2e in 2016, to 1.6 in 2050. This growth is again driven primarily by the commercial sector, which increases its emissions by 55%, being responsible for 53% of all building emissions in 2050, compared to 44% in 2016.

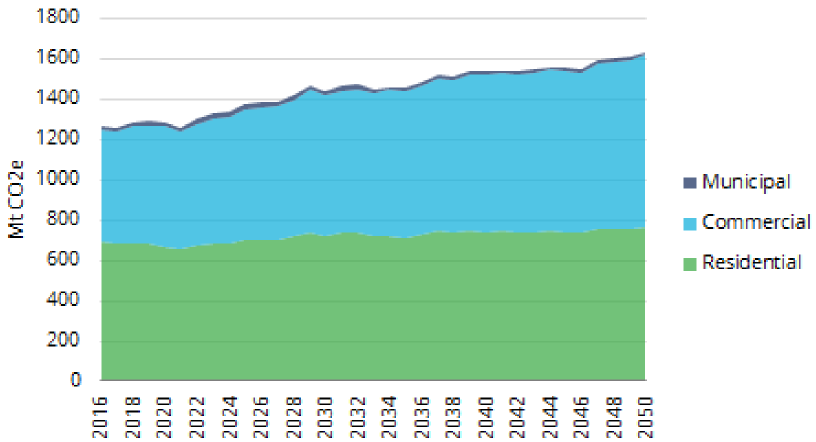


Figure 25: Buildings GHG emissions projection, 2016-2050 (MtCO2e), by sector.

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.

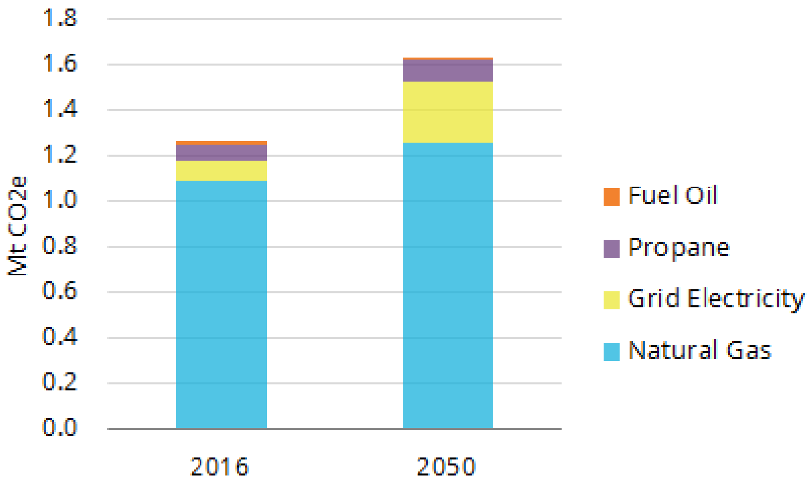


Figure 26: Buildings GHG emissions in 2016 and 2050, by fuel type (Mt CO2e).

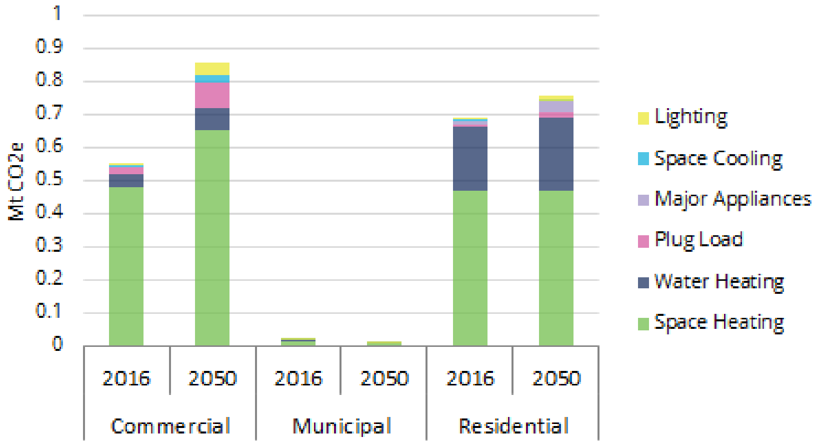


Figure 27: Buildings GHG emissions for 2016 and 2050 (Mt CO2e), by end use and sector.

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.

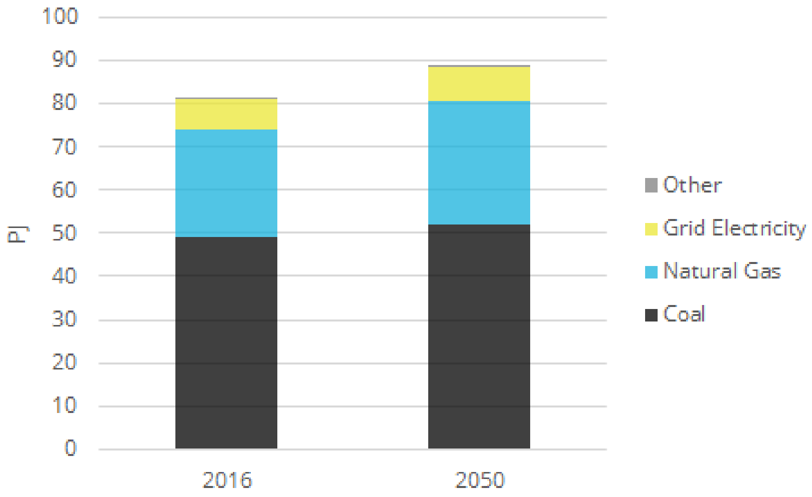
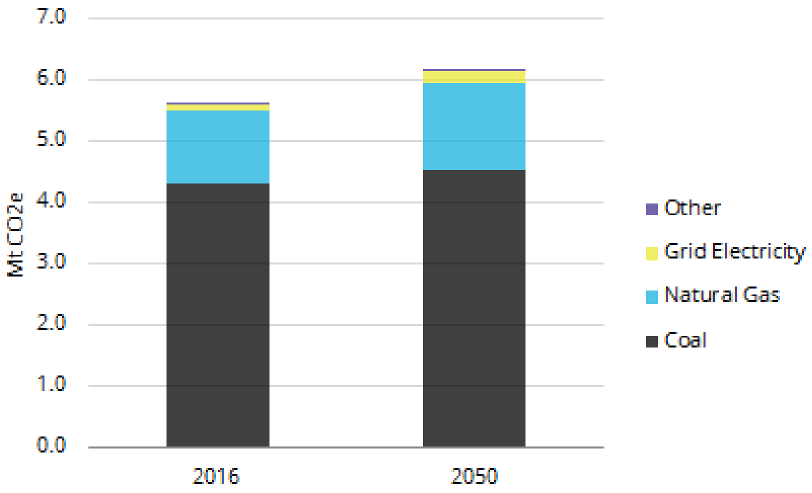


Figure 28: Industrial energy consumption in 2016 and 2050, by fuel type (PJ).[5]

In 2050, industrial process energy use is expected to ramp up 9% with respect to the base year, reaching 89 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 59% of Hamilton's total energy consumption.

Industry Emissions

In the BAP scenario, industry emissions are projected to increase by 10%, going from 5.6 MtCO2e in 2016 to 6.2 MtCO2e 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.



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[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.

Figure 29: Industrial CO2e emissions in 2016 and 2050, by fuel type (MtCO2e).[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.

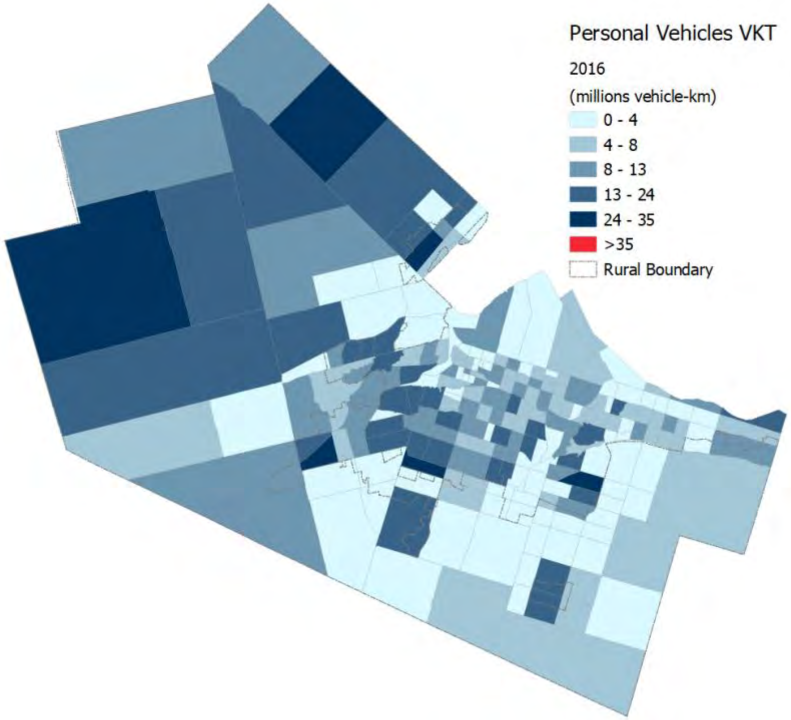

Figure 30: VKT for personal vehicles in Hamilton (millions vehicle-km) in 2016.

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

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[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.

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]

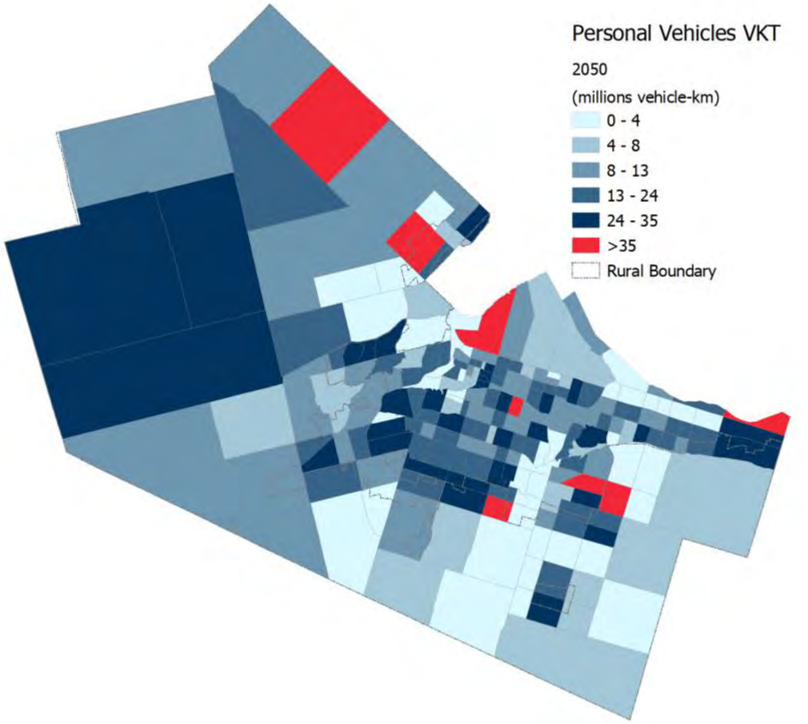

Figure 31: VKT for personal vehicles in Hamilton (millions vehicle-km) in 2050.

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

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[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.

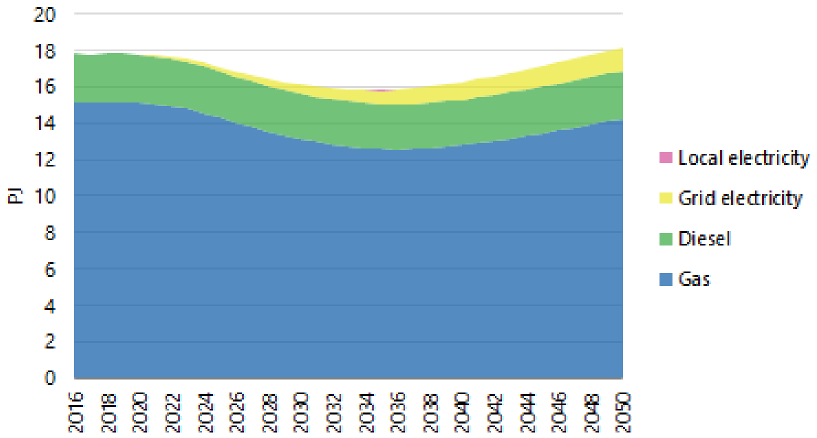

Figure 32: Projected BAP transportation energy use (PJ) by fuel, 2016-2050.[10]

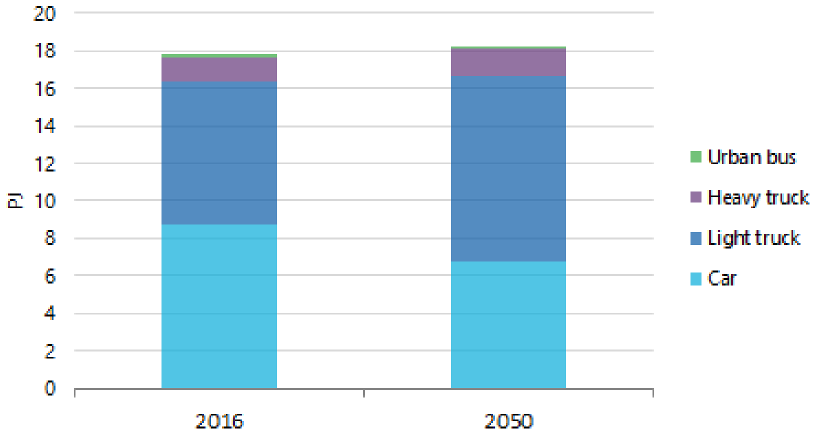

Figure 33: Projected BAP transportation energy use (PJ) by fuel, 2016-2050.

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.

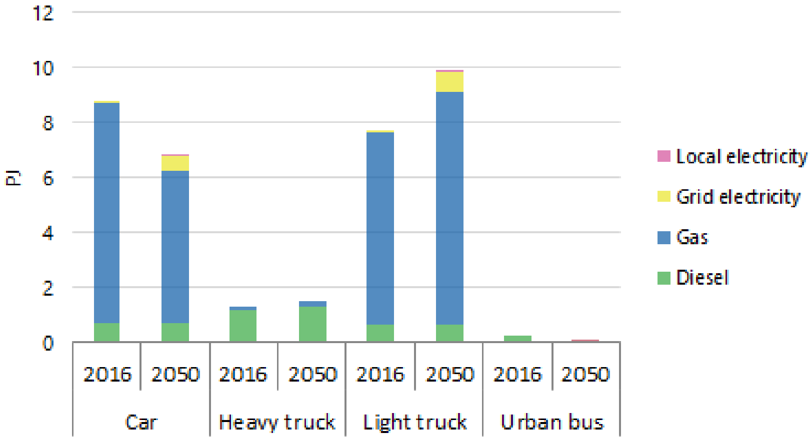

Figure 34: Projected BAP transportation energy use (PJ) by vehicle type and fuel, 2016-2050.

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[10] Note: Here diesel includes marine fuels.

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 (1,681 ktCO2e), and decrease to 17% in 2050 (1,601 ktCO2e). 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 74% of the total arising from gasoline in 2016, 18% from diesel and 5% 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).

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[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.

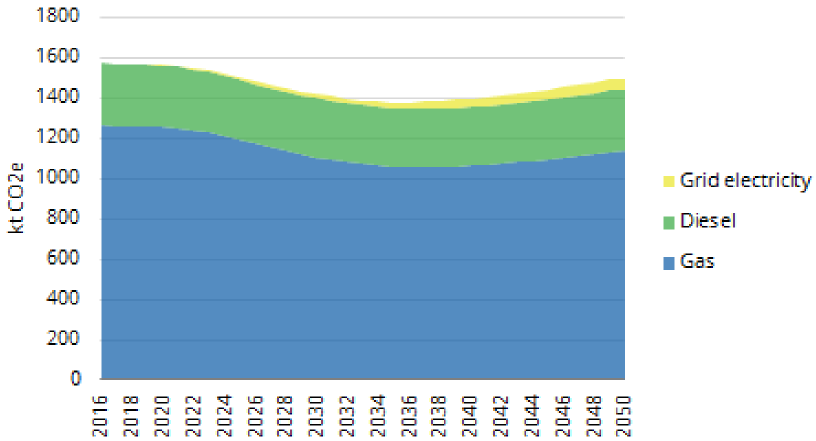

Figure 35: Projected BAP transportation emissions (kt CO2e) by source, 2016-2050.

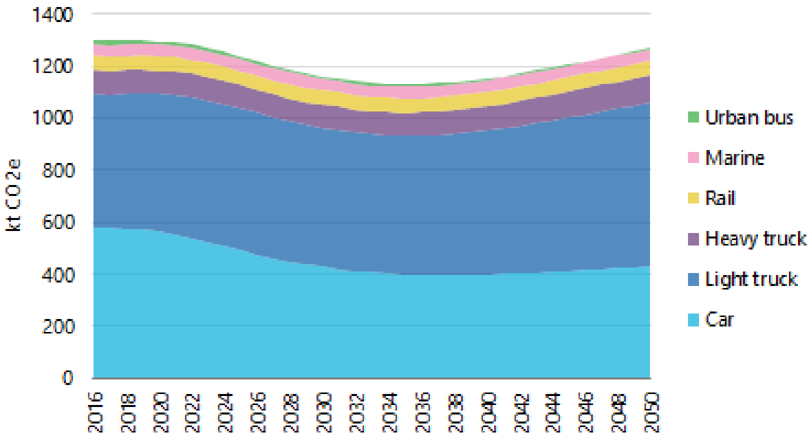

Figure 36: Projected BAP transportation emissions (ktCO2e) by vehicle type, 2016-2050

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$_2$e in 2016 and are projected to increase to 97 ktCO$_2$e 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 ktCO₂e to 7.1 ktCO₂e in 2050.

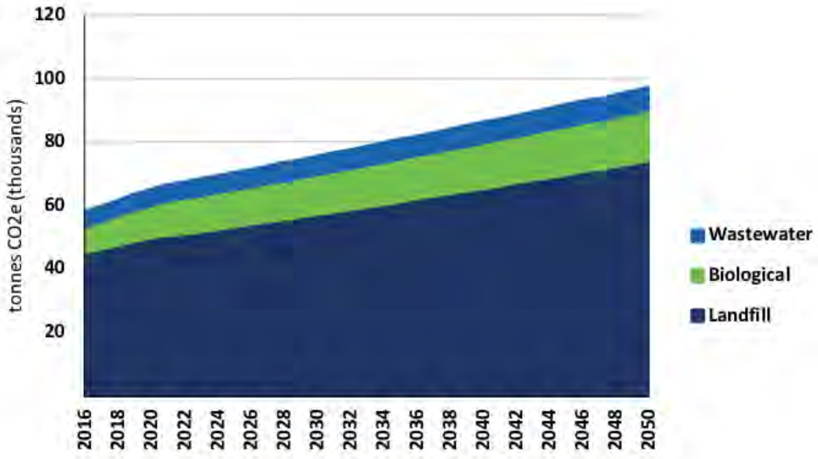

Figure 37: Projected BAP waste GHG emissions (ktCO2e), 2016-2050.

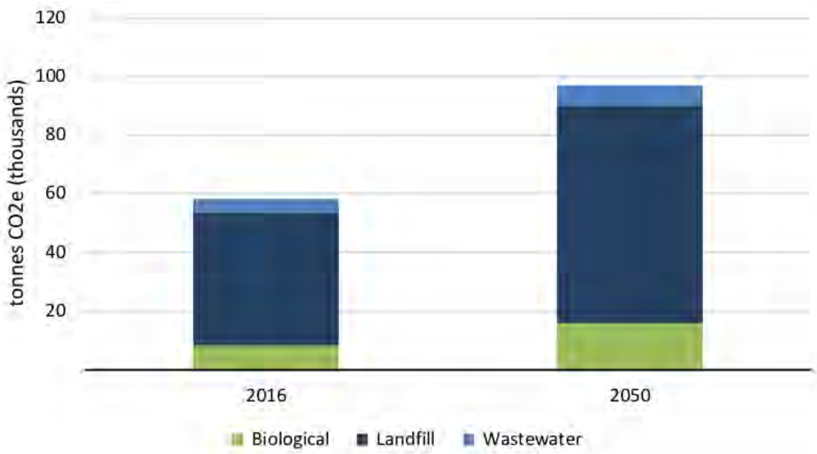

Figure 38: Waste GHG emissions by treatment type (ktCO2e), in 2016 and 2050.

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 ktCO2e, 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 ktCO2e 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 ktCO2e (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**

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[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

In the BAP, Hamilton's largest source of sequestration in 2050 is forested land, with an estimated sequestration of -272 ktCO2e.[13] The second-largest carbon sequestration category are trees in developed areas, sequestering approximately -73 kTCO$_2$e in 2050.

In terms of carbon releases in 2050, the BAP projects a small but steady increase towards tilling, based on historic trend, which results in 23 ktCO$_2$e 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$_2$e.

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.

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

- 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 Energy Plan (CEP).

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.

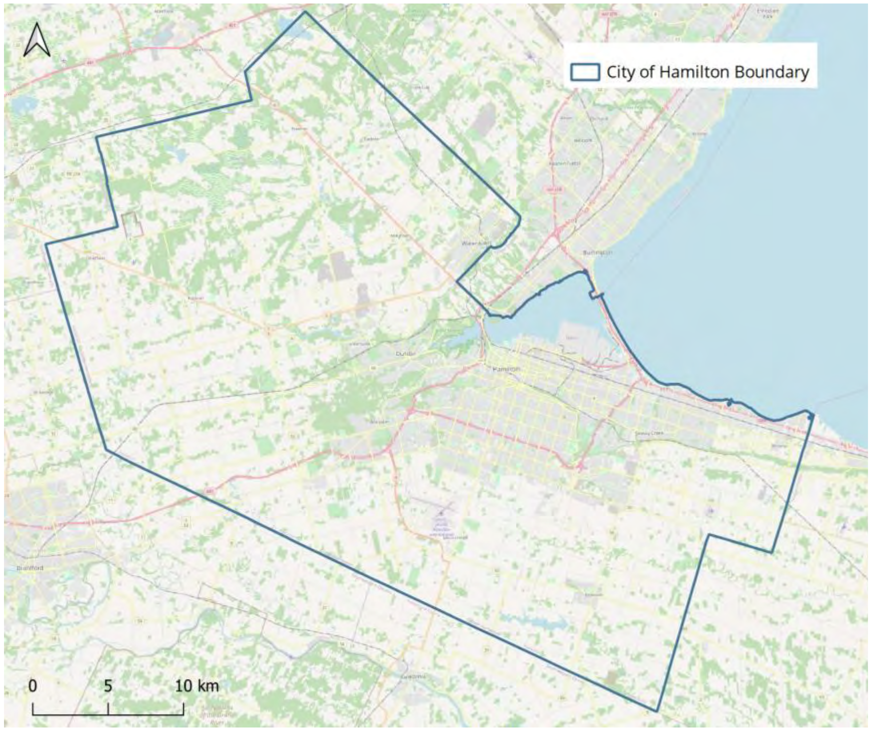


Figure 39: Hamilton geographic boundary.

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 CO2e/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.
Electricity	2016: 50.8 gCO2e/kWh 2050: 83.7 gCO2e/kwh	IESO, Annual Planning Outlook January 2020.

	2016: CO2: 28.9 g/kWh CH4: 0.007 g/kWh N2O: 0.001 g/kWh 2050: CO2: 82.32 g/kWh CH4: 0.02 g/kWh N2O: 0.00 g/kWh	
Gasoline	g/L CO2: 2316 CH4: 0.32 N2O: 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 CO2: 2690.00 CH4: 0.07 N2O: 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 CO2: 2560 CH4: 0.026 N2O: 0.006 Commercial g/L CO2: 2753 CH4: 0.026 N2O: 0.031 Industrial g/L CO2: 2753 CH4: 0.006 N2O: 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
Propane	g/L Transport CO2: 1515.00 CH4: 0.64 N2O: 0.03 Residential CO2: 1515.00 CH4: 0.027	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

	N2O: 0.108 All other sectors CO2: 1515.00 CH4: 0.024 N2O: 0.108	
Agricultural: Livestock	Varies per animal Type Kg CH4/ 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 CH4/tonne solid waste (assuming 75% recovery of landfill methane); 0.050 kg CH4/tonne solid waste not accounting for recovery. Incineration Emissions: CO2 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 gCH4/kg solid organic waste and 0.3 gN20/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	CH4: 0.48 kg CH4/kg BOD N2O: 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. 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.).

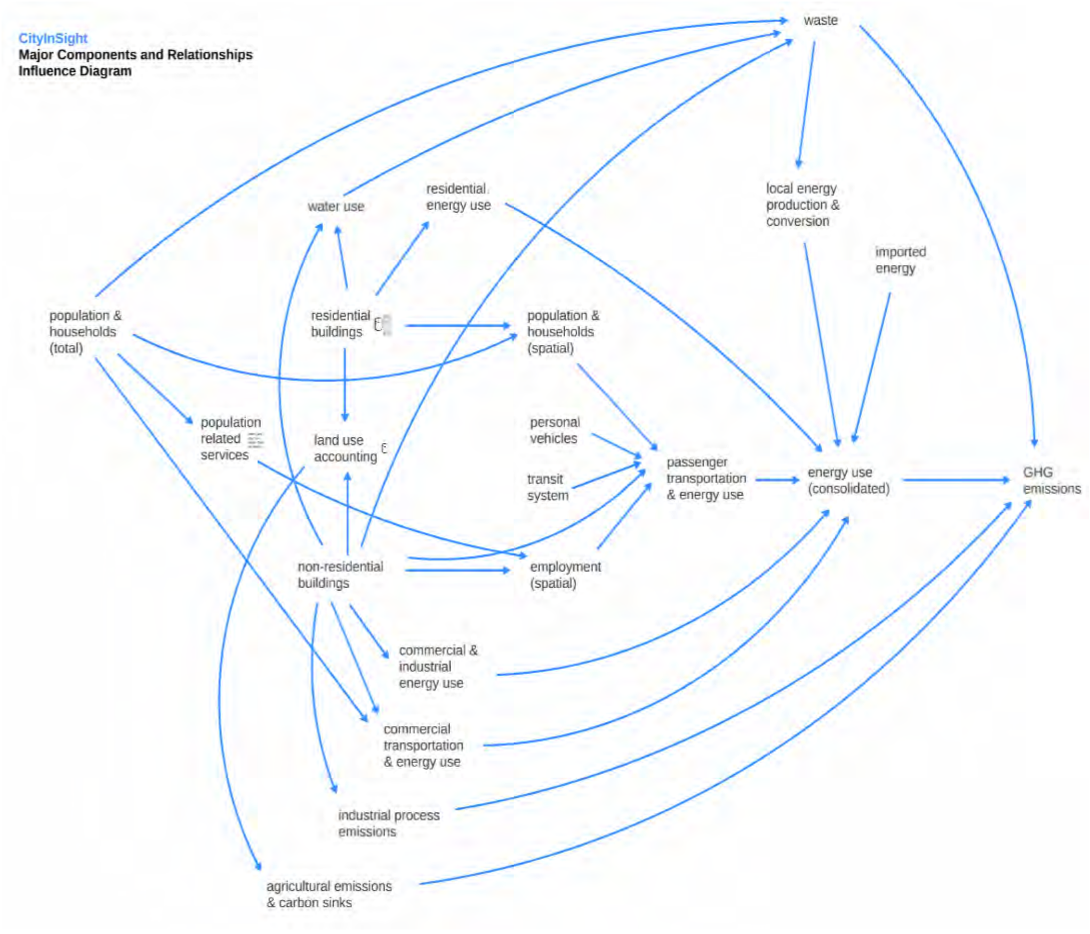
CityInSight incorporates and adapts concepts from the system dynamics approach to complex systems analysis. For any given year within its time horizon, CityInSight traces the flows and transformations of energy from sources through energy currencies (e.g. gasoline, electricity, hydrogen) to end uses (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.
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 but also 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.

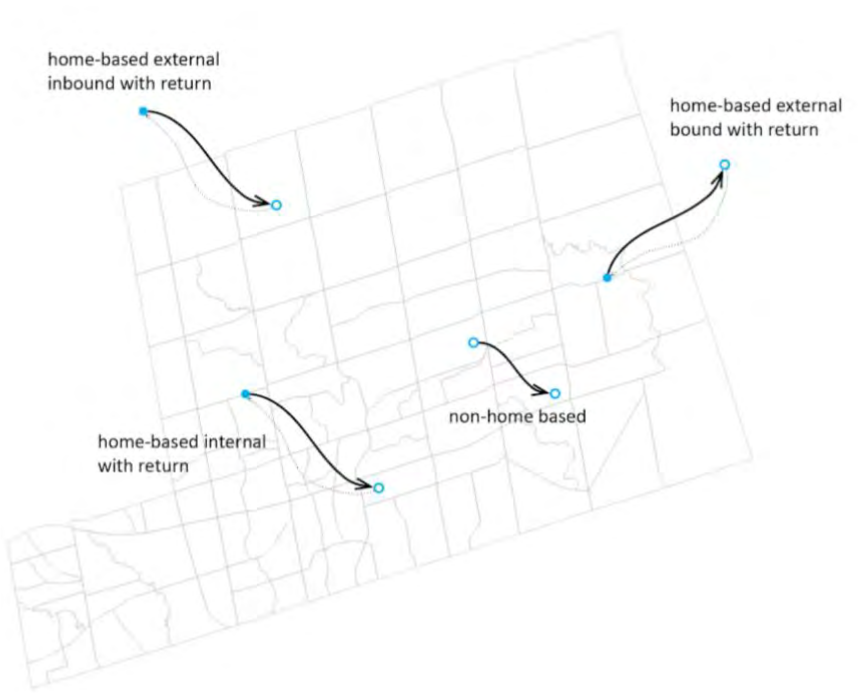
Spatial population and employment

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.

6.2 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 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%
Gasoline	394,323	0%	401,744	0%	2%
Grid Electricity	18,843,170	14%	17,070,310	11%	-9%
Local Electricity	14,824,855	11%	20,956,082	14%	41%
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$_2$e)	2016	2050 (BAP)	% +/- (2016-2050)
Emissions per capita (tCO$_2$e/person)	**15.5**	**11.2**	**-28%**

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

Emissions by sector (tCO$_2$e)	2016	share 2016	2050 (BAP)	share 2050	% +/- (2016-2050)
Agriculture and Livestock (AFOLU)	32,070	0%	32,070	0%	0%
Commercial	554,286	6%	859,121	9%	55%
Energy Production	16,553	0%	19,776	0%	19%
Fugitive[14]	58,178	1%	67,226	1%	16%
Industrial	5,605,924	64%	6,163,004	64%	10%
Municipal	21,475	0%	12,053	0%	-44%
Residential	691,884	8%	761,726	8%	10%
Transportation	1,681,007	19%	1,610,315	17%	-4%
Waste	58,155	1%	97,209	1%	67%
Total	**8,719,532**	**100%**	**9,622,500**	**100%**	**9%**

Emissions by fuel (tCO$_2$e)	2016	share 2016	2050 (BAP)	share 2050	% +/- (2016-2050)
Coal	4,313,227	50%	4,544,853	47%	5%
Diesel	304,161	4%	290,255	3%	-5%
Fuel Oil	28,054	0%	29,140	0%	4%
Gasoline	1,289,410	15%	1,177,009	12%	-9%
Grid Electricity	155,957	2%	513,903	5%	230%
Natural Gas	2,315,179	27%	2,681,579	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	**8,719,531**	**100%**	**9,622,500**	**100%**	**10%**

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[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	554,278	8%	859,113	11%	44%
Industrial	5,605,894	91%	6,162,973	80%	10%
Residential	691,884	11%	761,726	9%	-1%
Municipal	21,475	0%	12,053	0%	-48%
Total	**6,929,368**	**100%**	**7,743,395**	**100%**	**12%**

Buildings emissions (ktCO_2e) by fuel	2016	share 2016	2050 (BAP)	share 2050	% +/- (2016-2050)
Coal	4,313,227	63%	4,544,853	58%	5%

Fuel Oil	28,054	0%	29,140	0%	4%
Grid Electricity	155,956	2%	458,284	6%	194%
Natural Gas	2,298,623	33%	2,661,802	34%	16%
Propane	77,591	1%	101,653	1%	31%
Wood	79	0%	133	0%	69%
Total	**6,929,368**	**100%**	**7,795,866**	**100%**	**13%**

Buildings emissions (tCO_2e) by end use	**2016**	**share 2016**	**2050 (BAP)**	**share 2050**	**% +/- (2016-2050)**
Industrial Processes	5,454,259	79%	6,046,446	78%	11%
Lighting	18,554	0%	61,319	1%	230%
Major Appliances	13,655	0%	28,865	0%	111%
Plug Load	30,694	0%	97,130	1%	216%
Space Cooling	14,034	0%	33,513	0%	139%
Space Heating	1,001,304	15%	1,156,314	15%	15%
Water Heating	341,030	5%	372,279	5%	9%
Total	**6,929,368**	**100%**	**7,743,395**	**100%**	**13%**

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%

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

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	304,161	18%	290,255	18%	-5%
Gas	1,289,410	77%	1,177,009	73%	-9%
Grid electricity	3	0%	55,618	3%	1685297%
Aviation Fuel	87,433	5%	87,433	5%	0%
Total	**1,681,007**	**100%**	**1,610,315**	**100%**	**-4%**
Transportation Emissions (ktCO2e) by vehicle type	**2016**	**share 2016**	**2050 (BAP)**	**share 2050**	**% +/- (2016-2050)**
Car	600,619	36%	442,949	28%	-26%
Heavy truck	94,445	6%	107,398	7%	14%
Light truck	524,967	31%	647,437	40%	23%
Marine	39,454	2%	39,454	2%	0%
Off Road	264,763	16%	222,699	14%	-16%
Rail	50,472	3%	50,472	3%	0%
Urban Bus	18,853	1%	12,472	1%	-34%
Aviation	87,433	5%	87,433	5%	0%
Total	**1,681,007**	**100%**	**1,610,315**	**100%**	**-6%**

Waste Sector

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%**

Land Use

Table 13: Land Use Change Emissions 2021-2050

			(ktCO$_2$e/yr)						
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 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	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.

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

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,	City of Hamilton Corporate Energy Policy (2014); City of Hamilton Corporate Annual Energy Report (2016)	

	retrofits assumed to be implemented linearly)		
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 gCO2e/kWh 2050: 83.7 gCO2e/kwh 2016: CO2: 35.0 g/kWh CH4: 0.001 g/kWh N2O: 0.001 g/kWh 2050: CO2: 82.32 g/kWh CH4: 0.02 g/kWh N2O: 0.00 g/kWh	IESO, Annual Planning Outlook January 2020.	Emissions are expected to increase due to greater reliance on natural gas.
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.	

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 CO2e/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.
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.
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.

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).	Federal government determines the report.	Held constant after 2022 due to political uncertainty. 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 CH4/ 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 CH4 Emissions from Manure Management for Cattle Subcategories	

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 3: GPC Emissions Scope

Reasons for Exclusions	**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**	
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**	

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**	
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

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

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

VI		OTHER SCOPE 3		
VI.1	3	Other Scope 3	**No**	N/A

Appendix 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 1 - 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%