City of Thunder Bay

Community Energy Use and Emissions Plan

Baseline Inventory, Business-As-Planned Scenario and Energy Maps (2016 - 2050)

May 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 if no additional plans, policies, programs, and projects are 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 18ºC, 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 grams, kilograms, or metric tonnes (CO2e), 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.

Fugitive emissions: In this report, fugitive emissions refers to methane gas leaks from the natural gas distribution system.

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 18ºC, requiring heating.

Local electricity: electricity produced within the municipal boundary and sold to the electricity system operator.

Renewable Natural Gas (RNG): Natural gas produced from renewable energy sources, such as organic waste in landfills or at wastewater facilities.

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.

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 ($KtCO_2e$) (a Mt is a thousand kt).

For a sense of scale: *

- An average house uses about 100GJ of energy in a year
- 100 liters of gasoline provides 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

GHG emissions	Energy
1 MtCO2 = 1,000,000 tCO2e	1 PJ = 1,000,000,000 J
1 ktCO2e = 1,000 tCO2e	1 GJ = 1,000,000 J
1 tCO2e = 1,000 kgCO2e	1 MJ = 0.001 GJ
1 kgCO2e = 1,000 gCO2e	1 TJ = 1,000 GJ
	1 PJ = 1,000,000 GJ

Executive Summary

In January 2020, the City of Thunder Bay declared a climate emergency and set an ambitious goal of becoming net-zero by 2050. Thunder Bay is now working with the community to develop a Community Energy and Emissions Plan (CEEP) that will set the path for how to get there.

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

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

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

2. The low-carbon scenario

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

This report summarizes the technical modelling results for the first stage: Baseline & BAP. The BAP scenario aims to reflect current and planned policies and actions for all levels of government.

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 Thunder Bay is the inventory boundary.

The remainder of this report is divided into three parts:

II. BAP Energy & Emissions, 2016-2050, includes the results and analysis of the baseline energy use and GHG emissions inventory for 2016 and the business-as-planned (BAP) scenario to 2050.

II. Sensitivity analysis, discusses the results of a sensitivity analysis undertaken for certain variables identified as having major uncertainties and a significant impact on the BAP model outcomes.

III. The Data, Methods, and Assumptions Manual is referenced throughout this report. The Manual outlines the key assumptions driving the energy use and GHG emissions in the BAP scenario.

Appendices includes all the relevant energy use and emissions data tables referred to throughout the report.

Main Findings

	2016 Baseline	2050 BAP	% change
ENERGY			
Total energy (PJ)	26.25	25.43	-3%
Energy per capita (GJ/cap)	303	266	-11%
EMISSIONS			
Total emissions (MtCO2e)	1.23	1.16	-9%
Emissions per capita (tCO2e/cap)	11	9.4	-15%

In 2016 Thunder Bay's overall energy use was 26 PJ. The largest energy user was the industrial sector, followed by transportation, then residential then the commercial sector.

The primary fuel source for Thunder Bay in 2016 was fossil fuels, primarily natural gas for industrial processes and building heating, followed closely by gasoline and diesel for transportation. Fossils fuels are the primary source (≈95%) of Thunder Bay's 12 Mt (1,228 ktCO2e) of greenhouse gas (GHG) emissions in 2016. The remaining ≈5% are generated by organic waste and animal husbandry.

In 2016, on average, each Thunder Bay resident emitted 11 tonnes of CO2e.

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 energy use and GHG emissions for the city are projected to decrease by 3% and 9% respectively. These reductions are more significant on a per capita basis, as Thunder Bay's population is projected to increase by 15% over that period.

According to the BAP scenario, on average, each Thunder Bay resident is projected to emit 9.4 tonnes of GHGs in 2050. This still leaves a notable gap between projected GHG emissions and the community's target of achieving net-zero carbon emissions by 2050.

Analysis on carbon sequestration was completed for this paper and it was found that a projected 315 ktCO2e will be sequestered annually in 2050, mostly through forested areas in the city.

Table 1: Grand total of GHG emissions for Thunder Bay, 2050.

Sector	GHG Emissions, 2050. ($ktCO_2e$)
'Subtotal' of community-wide emissions	1,161
LULUCF GHG emissions	-351
Emissions from soil management	Not Included in 2050 scope
Grand total	810

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

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

Part I:
Energy & Emissions, 2016-2050

Demographics

Population, Households, Vehicles, and Employment

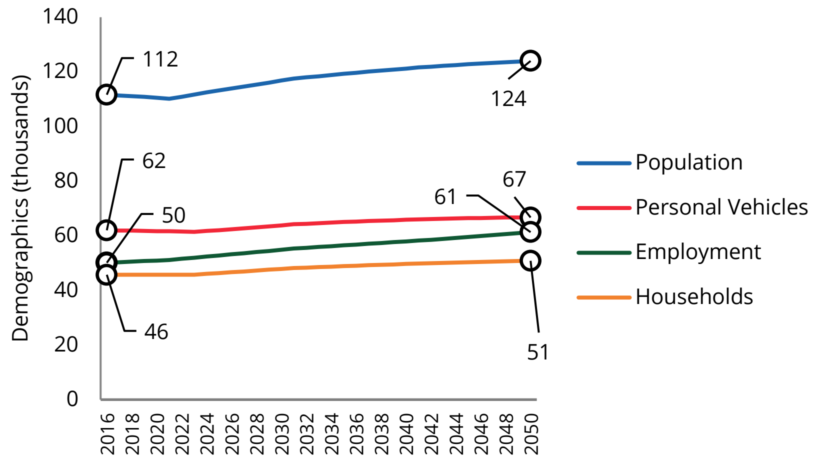

Figure 1: Projected population, households, and employment 2016-2050.

Population size underlies many aspects of the modelling, including building and transportation needs, as well as waste production. Thunder Bay projects a 15% population increase through to 2050, increasing from 107,800 in 2016 to 124,200 in 2051. The City foresees a slightly higher employment growth of 22% during that time period, with the number of jobs increasing from 48,800 in 2016 to 59,700 in 2051.

As Thunder Bay has experienced employment and population decreases in the years leading up to 2016, possible variances in these assumptions have been considered in the Sensitivity Analysis in Part II.

In 2016, there were 45,720 households in Thunder Bay. This increased marginally to 45,721 households by 2019 and is projected to increase to 50,816 by 2050: an 11% increase in residential buildings.

Community Energy

Energy by Sector

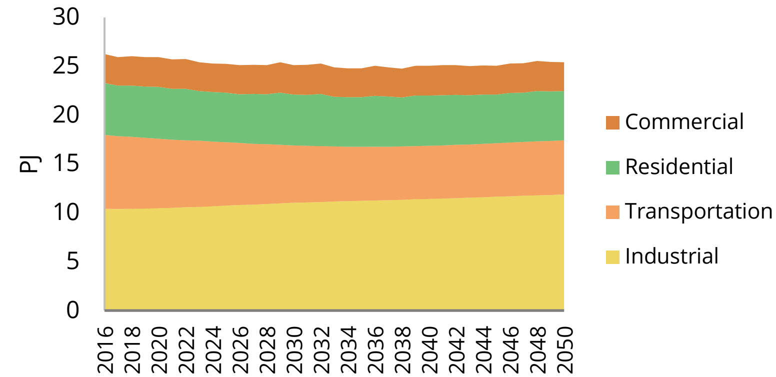

Figure 2: Projected BAP energy consumption (PJ) by sector, 2016-2050.

Community energy consumption for Thunder Bay is projected to decrease slightly from 26 PJ in 2016 to 25 PJ in 2050, a decrease of 3% over the period.

The majority of the reduction in energy consumption is associated with the transportation sector, which is projected to see 27% decline in energy use, specifically from on-road transportation, which includes personal and commercial vehicles. A decrease in energy consumption in this sector occurs through to 2035, due mostly to improved fuel efficiency standards in vehicles, and the incremental uptake of electric vehicles, which also contributes to the small increase in electricity consumption (see Figure 3). This decrease in transportation energy use is mostly offset by the projected 16% increase in industrial energy use, based on the City's estimates of employment growth in that sector.

The slight decrease (5%) in residential energy consumption from 2016 to 2050 is caused by a decrease in heating degree days as a result of a warming climate combined with the improved efficiency of new homes.

This decrease in space heating energy is also seen in the commercial buildings sector but is offset by an increase in cooling degree days and space cooling requirements, as commercial buildings provide larger amounts of space cooling in comparison to residential buildings, which are significantly dominated by space heating demand. Commercial building energy use is projected to stay about constant.

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

Energy by Fuel

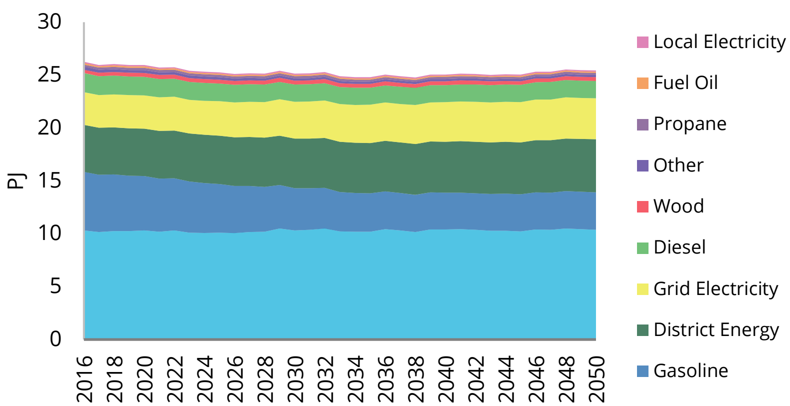

Figure 3: Projected BAP energy consumption (PJ) by fuel, 2016-2050.

The gasoline and diesel reductions seen in Figure 3 reflect the improved efficiency in the transportation sector described above. The small increase in natural gas consumption is due primarily to projected increases in the industrial sector, as its other major use, space heating, sees an overall decline, as described above.

Per Capita Energy Use

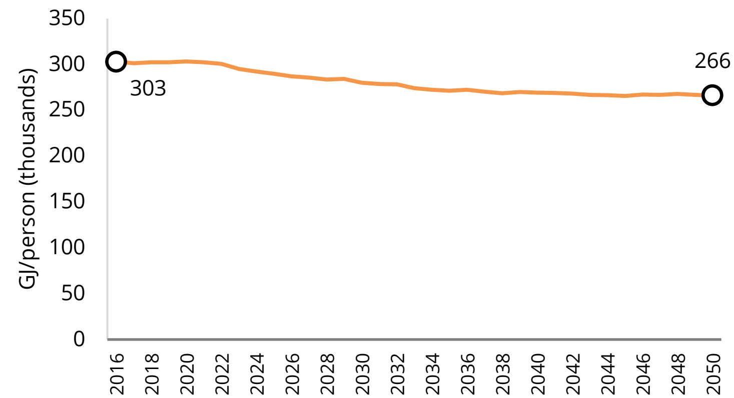

Figure 4: Projected BAP energy per capita (GJ/person), 2016 & 2050.

Per capita, each resident of Thunder Bay is projected to use 11% less energy by 2050. Energy use will fall from 303 GJ/person in 2016 to 266 GJ/person in 2050.

Energy Flow and Conversion

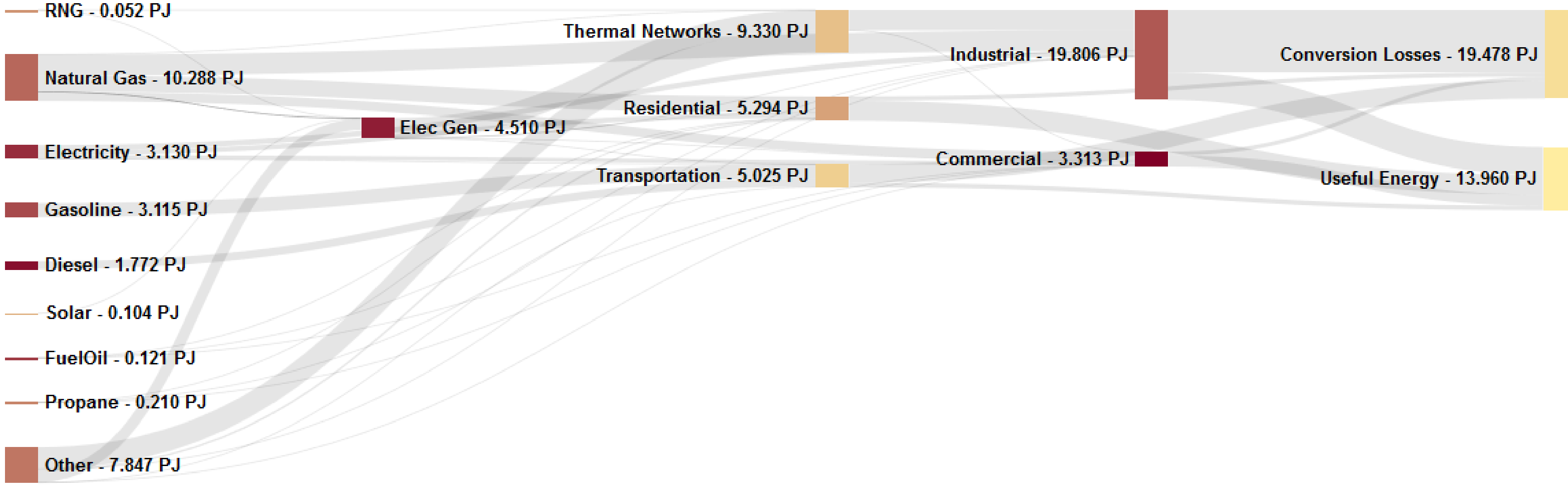

Figure 5: Energy flow, 2050 (BAP).

The Sankey diagrams shown in Figure 6 depicts the energy flow by fuel and sector through Thunder Bay in 2050[1]. Sankey diagrams are particularly useful at identifying opportunities for improved efficiency, as they clearly identify energy waste (i.e. conversion losses).

In 2016, the ratio of useful to non-useful (i.e. wasted) energy was 0.68:1, driven largely by industrial processes that generate waste heat, and by the inherent inefficiency of the internal combustion engine. By 2050, the ratio changes to 0.72:1, as more vehicles are electrified, and new buildings are more efficient.

Local Energy Production

In 2016, Thunder Bay produced just over 4.5 PJ of local energy. A fraction (0.12 PJ) of this amount was produced from solar panel installations ('local electricity' in Figure 3), while the remainder (4.4 PJ) was produced by medium-sized systems, such as the biomass system at Resolute Forest Products' pulp and paper mill, the City's landfill methane gas capture and reuse system, and the Health Sciences Centre's natural gas-powered cogeneration system ('district energy' in Figure 4).

In the BAP, it is assumed that locally generated energy will see a slight increase to just over 5 PJ, primarily due to increased growth of combined heat and power systems by the industrial sector.

[1] RNG= renewable natural gas

Community Energy Consumption by Zone, 2016

Energy Use Intensity

Figure 6 displays Thunder Bay's building energy intensity by traffic zone, or megajoules per m2 of building space. The energy intensity reflects all end uses. This map does not capture transportation energy, as its consumption is mobile and cannot be assigned to a particular zone.

Energy intensity, an indication of energy consumed per square metre of building floorspace, shows large variation across the City. Higher intensities are noticeable in the non-residential inner city, as well as the residential inner city. This indicates of a combination of: Residential energy intensities are higher in the inner city due to older and less efficient housing stock, greater prevalence of mixed-use buildings in the inner city, and greater industrial activity in the inner city.

Residential energy intensities are significantly lower in the outer-city, indicating that despite the homes being larger, they are more efficient.

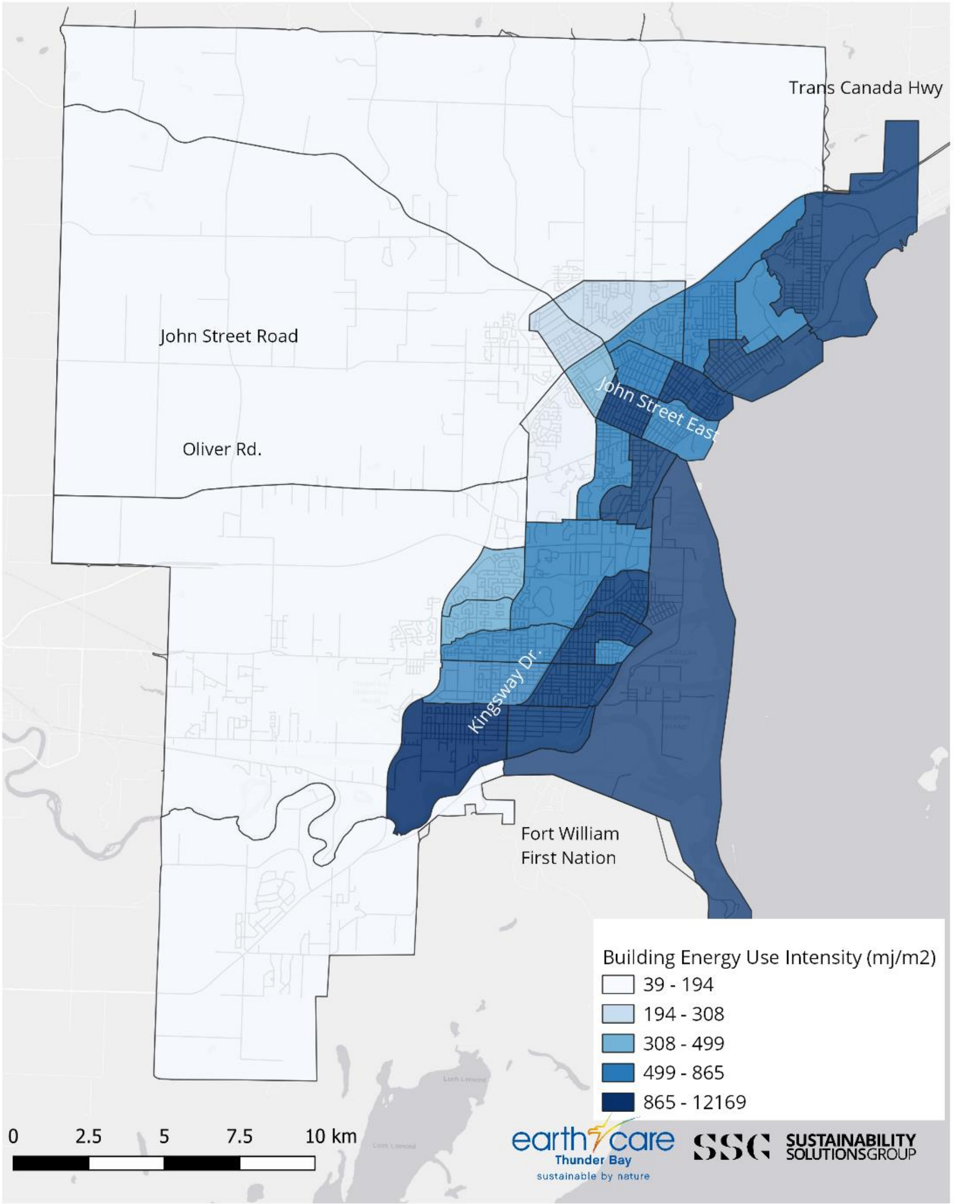

Figure 6: Energy Intensity (mj/m2) per traffic zones, 2016.

Total Energy Consumption

Total energy consumption shows a slightly different pattern for the city in 2050. The outer ring of Thunder Bay shows where development has gone over the past few decades and have often led to larger and detached homes being developed (300-500 TJ per zone). Towards 2050, energy use will increase in the outer areas with any further development in those zones, and as the housing stock begins to age and become less efficient.

The inner-city of Thunder Bay has higher overall consumption due to mixed-use areas, larger commercial developments, greater presence of apartment buildings, and industrial activity.

Industrial energy consumption will increase by approximately 16% whereas the other energy consuming sectors are anticipated to decrease slightly. As will be discussed in the Summary and Key Trends section concluding this paper, high energy consumption for industrial activities will continue to shape the energy profile of the city, especially the inter-city area, towards 2050.

Further maps that profile energy consumption by residential uses and transportation can be found under Appendix 2.

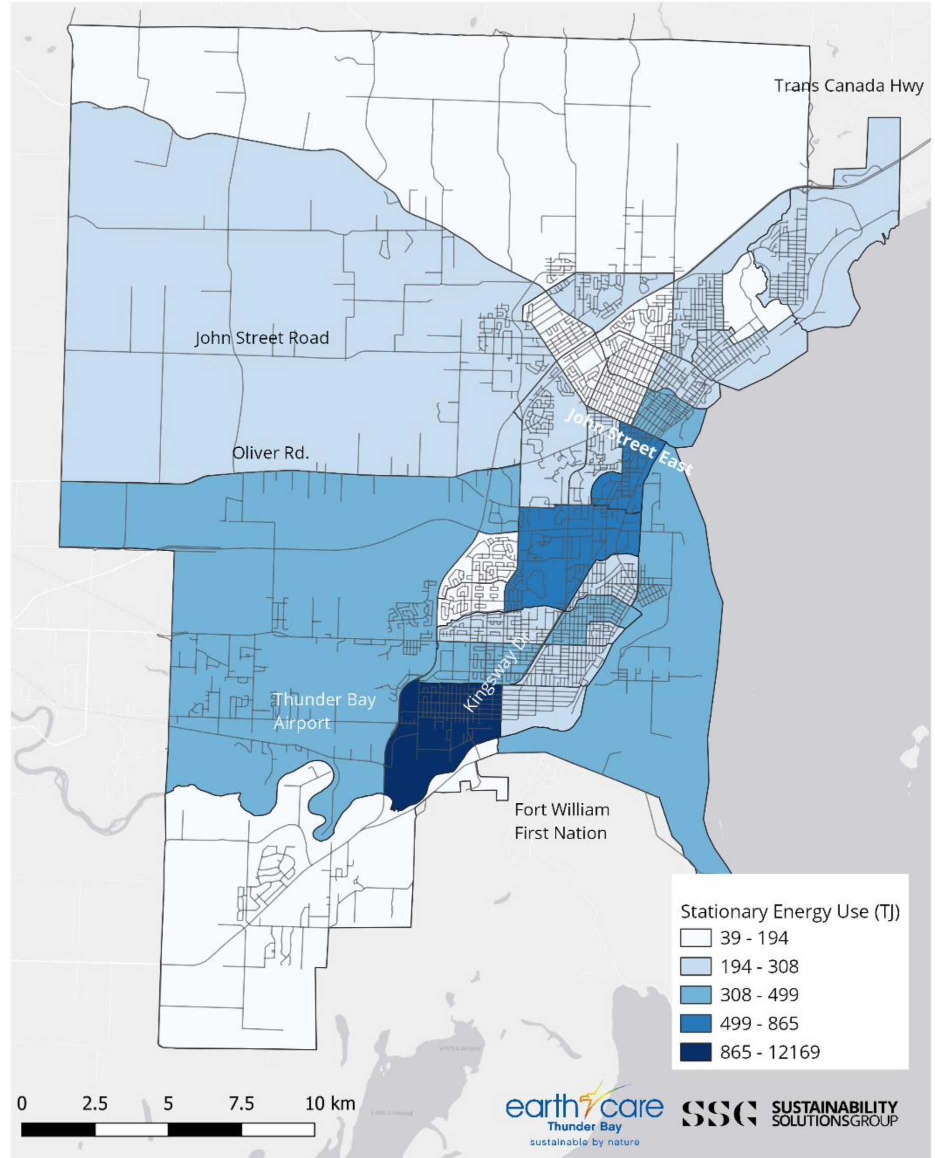

Figure 7: Stationary energy consumption per traffic zones, 2016

Community Emissions

Emissions by Sector

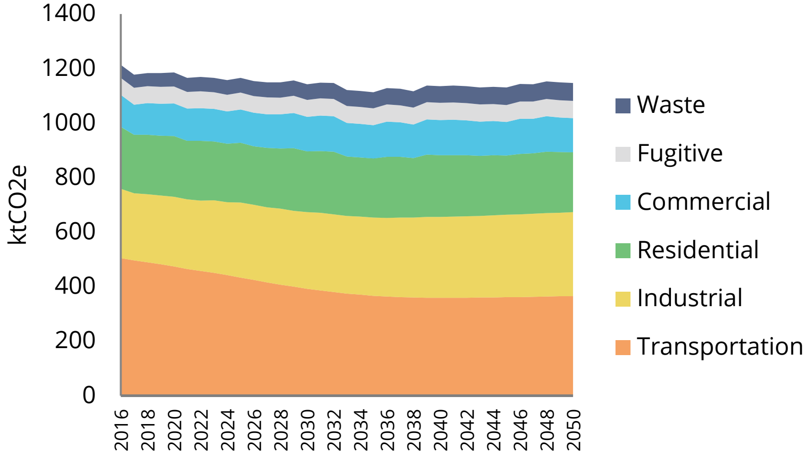

Figure 8: Projected BAP GHG emissions (ktCO2e) by sector, 2016-2050. (Note: Fugitive emissions are natural gas distribution system methane leaks.)

Emissions by Fuel

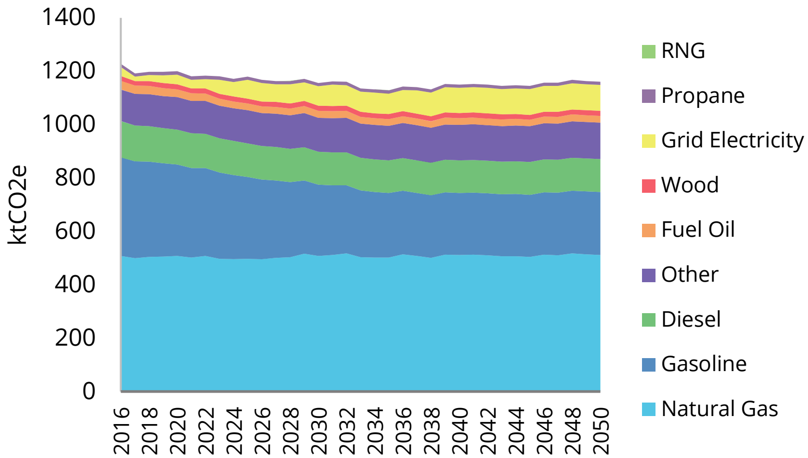

Figure 9: Projected BAP GHG emissions (ktCO2e) by fuel, 2016-2050.

Thunder Bay's emissions are projected to decrease from 1.23 $MtCO_2e$ in 2016 to 1.16 $MtCO_2e$ in 2050, a 9% decrease over that period. The largest decrease in emissions is a result of the reduction in gasoline and diesel use.

Emissions from gasoline and diesel decrease by 36% and 9% respectively from 2016 to 2050, mostly due to improved fuel efficiency standards in on-road vehicles, which result in a steady decline in gasoline and diesel use, as well as an incremental uptake of electric vehicles over the same time period.

Emissions from natural gas stay relatively constant due to projected increases in employment in the industrial sector, which offset reductions in natural gas use for space heating due to projected global warming. Renewable natural gas (RNG) represents the methane captured and re-used at Thunder Bay's wastewater treatment plant and represents less than 1% of community emissions. RNG emissions only reflects the rate of methane loss when combusted. "Other" in Figure 9 represents primarily non-energy related emissions from wastewater, landfill, and 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.

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

Per Capita Emissions

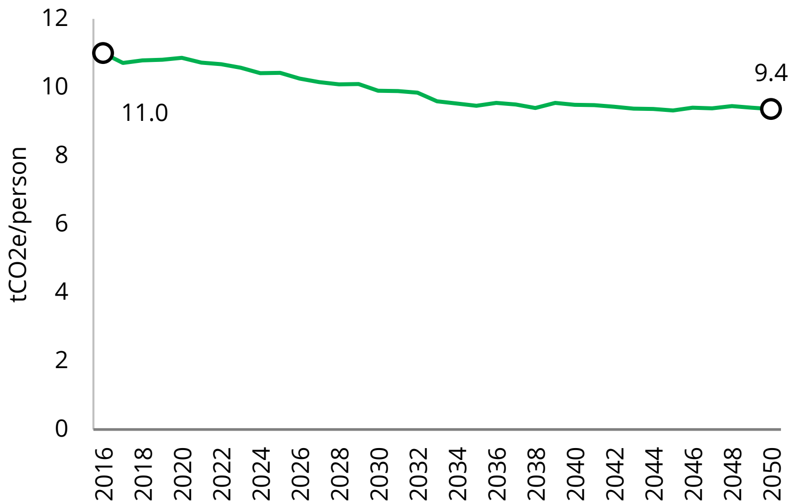

Figure 10: Projected BAP emissions per capita (tCO2e/person), 2016-2050.

Per capita emissions are projected to decrease from 11.0 tCO_2e/person in 2016 to 9.4 tCO_2e/person in 2050, a 15% decrease. For comparison, in 2016 Sudbury's per capita emissions were 7.4 tCO_2e, Saskatoon's were 12 tCO_2e, and Edmonton's were 19.6 tCO_2e/person.

Community Emissions by Zone, 2050

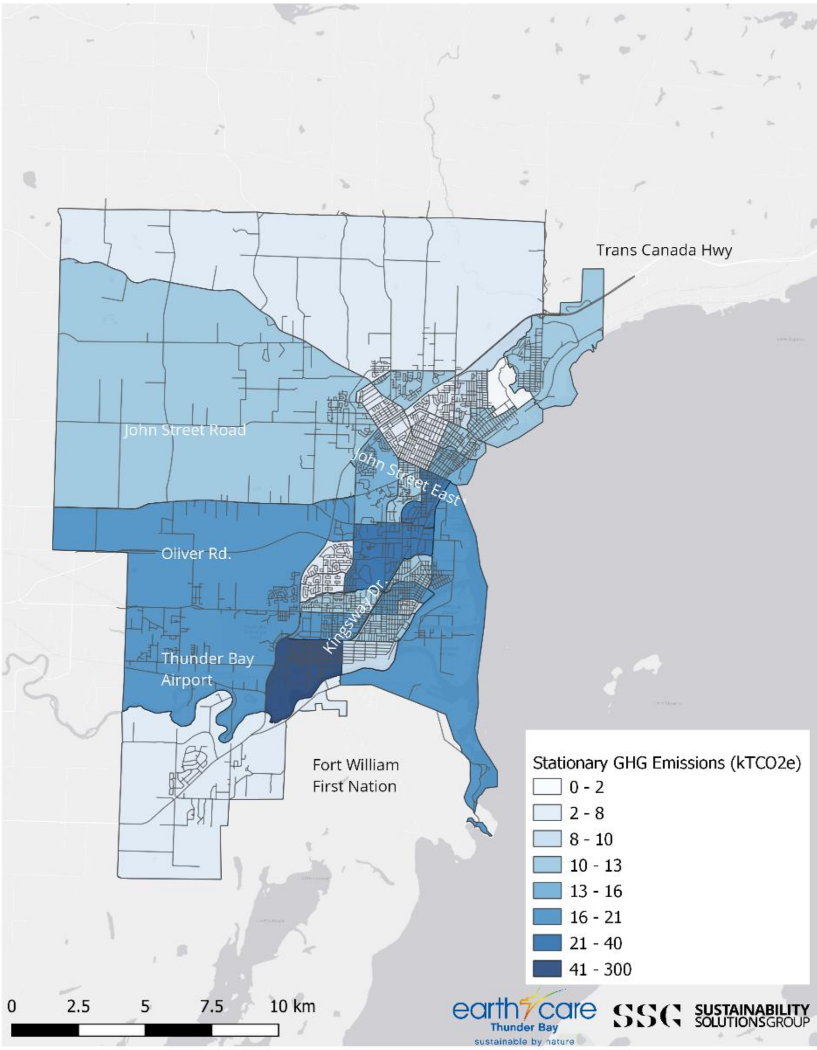

Figure 11: Stationary GHG emissions per traffic zone, Thunder Bay 2050.

Figure 11 illustrates GHG emissions generated in Thunder Bay's traffic zones and highlights how emissions vary in different areas of the city. Total emissions in this context represent stationary sources such as buildings, energy generation, waste, and fugitive sources. Waste and fugitive sources are not displayed on the community energy map (figure 7) because they are by-products of activities rather than emitting activities themselves.

Similar to the community energy map, this map highlights how the GHG emissions in the inner areas compare to the outer areas. Emission levels in inner areas reflect mixed-uses and the large industrial emitters (the dark blue area is home to Resolute Forest Product's energy-intensive pulp and paper mill), while outer areas mostly reflect residential emissions. GHG emissions are anticipated to be larger in the inner areas reaching up to 300 ktCO2e per zone by 2050.

In contrast, emissions are projected to be 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.

(Note: Lake Superior is not emitting directly, but it is highlighted in this map because the traffic zone system used during energy modelling is geographically bounded in this manner.)

Buildings Sector Energy

Buildings Energy by Fuel

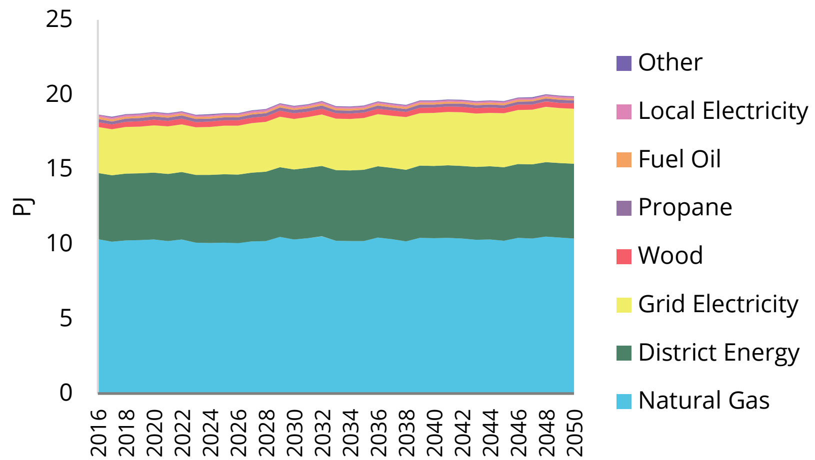

Figure 12: Projected BAP buildings energy use (GJ) by fuel, 2016-2050.

Buildings Energy by End Use

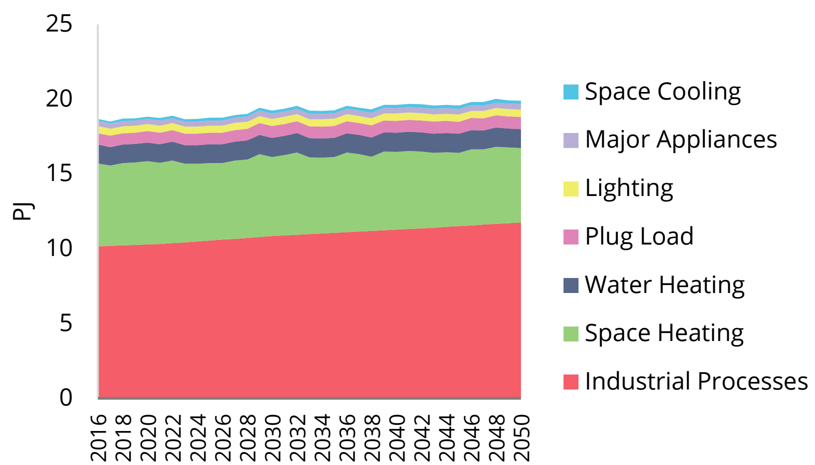

Figure 13: Projected BAP buildings energy use (GJ) by end use, 2016-2050.

Population and employment growth are projected to increase building energy use by about 6% by 2050, from 19 PJ in 2016 to 20 PJ in 2050 (see Figure 12).

Industrial processes represent the largest energy use in 2016, and grow through to 2050, based on projected employment growth in the sector (see Figure 13).

Otherwise, building energy increases are relatively constant, other than a small increase in electricity demand, which increases by 20%, mostly as a result of increasing cooling demand, appliance energy use and plug load. These end uses represent a larger portion of total building energy demand in 2050 (18.5%) compared with 16.5% in 2016 (see Figure 13).

Buildings Energy by Building Type & Fuel

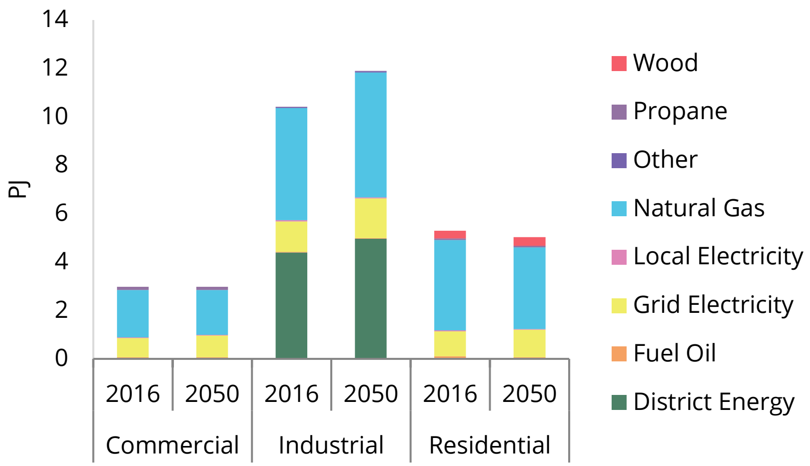

Figure 14: Projected BAP buildings energy use (GJ) by building type and fuel, 2016 & 2050.

Buildings Energy by Building Type & End Use

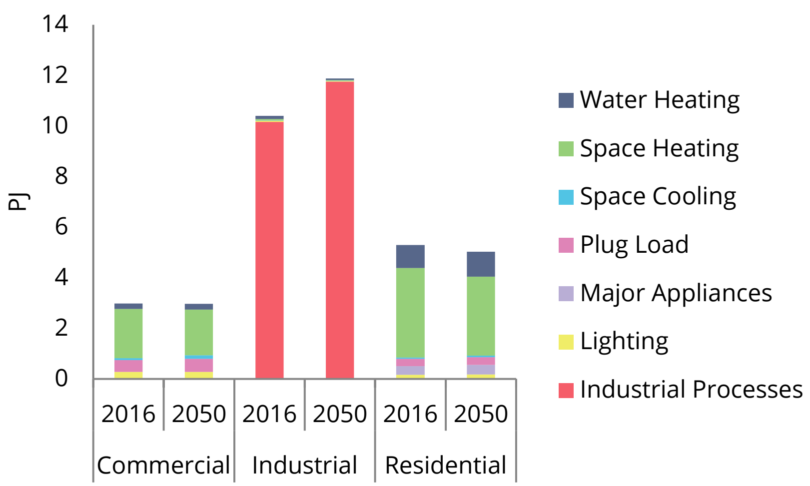

Figure 15: Projected BAP buildings energy use (GJ) by building type and end use, 2016 & 2050.

Energy consumption in the residential sector is projected to decrease by 5% from 2016 to 2050. Due to the projected population growth, the reduction in energy use is projected to be greater per household than total residential energy consumption. Households see a 15% decrease in energy use over the same time period, falling from 116 GJ/household in 2016 to 99 GJ/household in 2050.

Residential energy will decrease due to a combination of:

- increased energy efficiency standards in the Building Code;
- expected energy efficiency improvements for existing buildings; and
- a decrease in space heating requirements with a warming climate, offset slightly by an increase in cooling demand.

In 2016, residential building energy demand was dominated by space heating requirements (67%), followed by water heating (17%). Natural gas accounted for 71% of residential energy demand, followed by electricity (20%), wood (6%), oil (2%), and propane (1%). Natural gas use decreases marginally in the residential sector by 2050, as space heating requirements decline.

Similarly, in 2016, energy demand in commercial buildings is dominated by space heating (65%), though they also have slightly higher demands for plug load, lighting, and space cooling than residential buildings (see Figure 15).

Projected employment growth means that commercial building energy use is projected to stay relatively constant, despite the above-noted increases in building efficiency.

The industrial sector is fueled primarily by natural gas and district energy systems (biomass and natural gas).

Buildings Sector Emissions

Buildings Emissions by Fuel

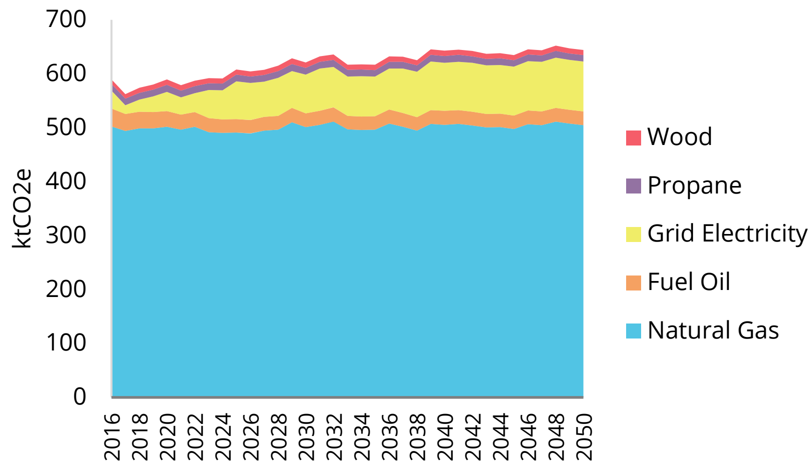

Figure 16: Projected BAP buildings emissions (ktCO2e) by fuel, 2016-2050.

Buildings Emissions by Type & Fuel

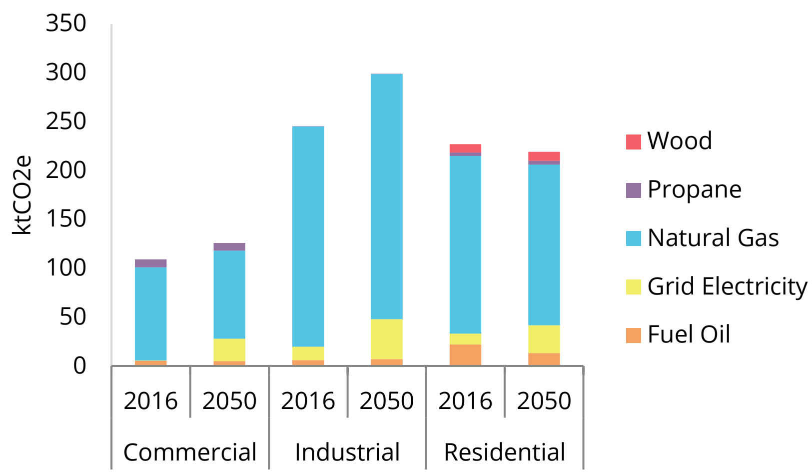

Figure 17: Projected BAP buildings emissions (ktCO2e) by building type and fuel, 2016-2050.

Emissions in the buildings sector increase from 590 ktCO_2e in 2016 to 644 ktCO_2e in 2050, an increase of 9% over the period. Building emissions are dominated by natural gas use, which accounts for 85% of emissions in 2016. By 2050, electricity emissions take on an increasingly larger portion of building emissions, as Ontario's electricity grid is projected to rely more heavily on natural gas.

The continued reliance on natural gas, including in new buildings, and the increase in carbon intensity in the grid results in an increase in building GHG emissions despite a decrease in energy consumption.

Emissions in the industrial sector are projected to increase by 22%, due to an expansion of economic activity (see Figure 17).

Commercial building emissions are also projected to increase by 7%, reflecting growth in employment.

Residential sector building emissions are projected to decrease by about 3.5%.

Buildings Emissions by Building Type & End Use

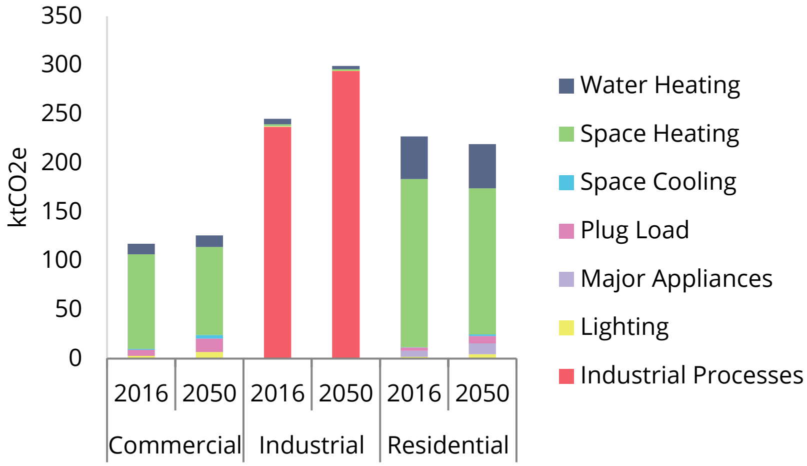

Figure 18: Projected BAP buildings emissions (ktCO2e) by building type and end use, 2016 & 2050.

Emissions from space cooling increase by 200% from 2016 to 2050, but still represent a fraction of total building emissions (about 0.5% in 2016, increasing to about 1% by 2050).

Overall, space heating produces the majority (46%) of GHG emissions for buildings in 2016, followed by industrial processes (40%). By 2050, due to a decrease in heating demand and improved efficiency, combined with growth in the industrial sector, this relationship switches: industrial processes represent 46% of emissions and space heating represents 37%.

Transportation Sector Energy

Transportation Energy by Fuel

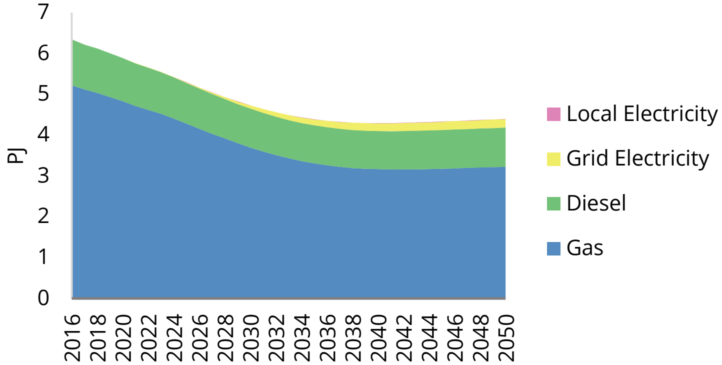

Figure 19: Projected BAP transportation energy use (PJ) by fuel, 2016-2050.

Transportation Energy by Vehicle Type

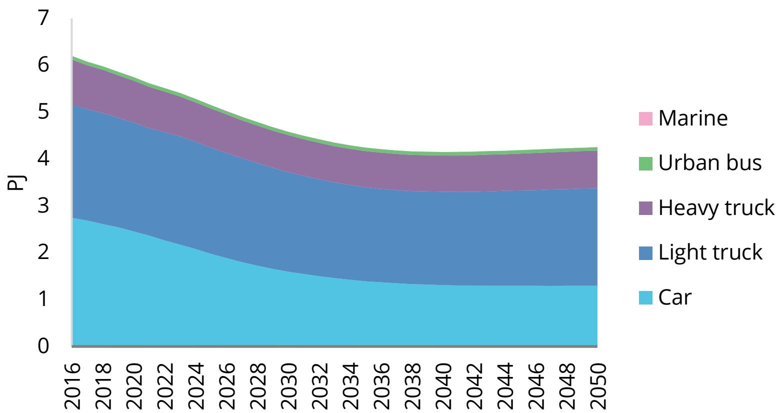

Figure 20: Projected BAP transportation energy use (PJ) by fuel, 2016-2050.

In 2016, approximately 6 PJ of energy was consumed by the transportation sector. Passenger vehicles, including cars and light trucks account for more than 80% of that total. By 2050, overall transportation energy use decreases by 20% to 4 PJ. This mostly reflects an increased uptake of electric vehicles.[2]

Gasoline is the primary fuel source for transportation energy in 2016, accounting for 82% of total energy use, but gasoline is projected to fuel a smaller portion of transportation energy by 2050, accounting for 73% of total energy use. Diesel fuel use will decrease from 18% of total consumption in 2016 to 15% in 2050. Electric vehicles and charging are anticipated to grow by 2050, but electricity is projected to represent only 5% of transport energy consumption.

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 are set to 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 fuel standards for medium- and heavy-duty vehicles.[3]

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

[2] 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.

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

Transportation Energy by Vehicle Type & Fuel

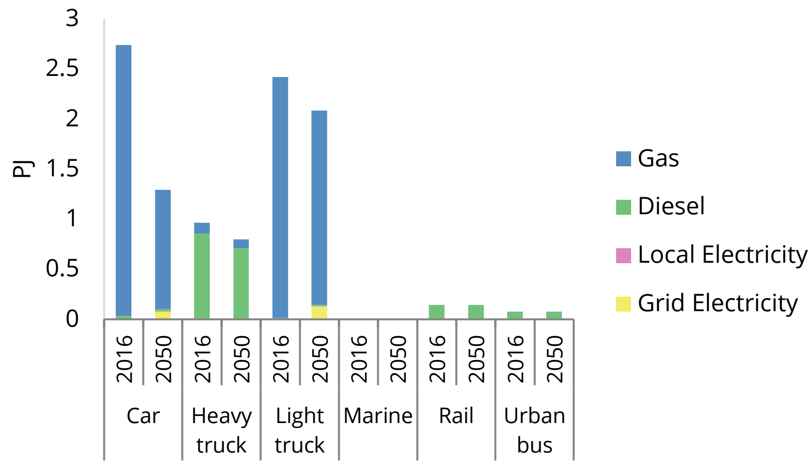

Figure 21: Projected BAP transportation energy use (GJ) by vehicle type and fuel, 2016-2050.

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, and a projected shift away from cars to light trucks, as SUVs become a more popular vehicle.

Heavy vehicles' energy use decreases over time as vehicle efficiency standards through CAFE also increase over time.

Marine consumption from ferries, commercial activities, and fishing vessels was assumed to be constant from 2016 to 2050.

Transportation Sector Emissions

Transportation Emissions by Source

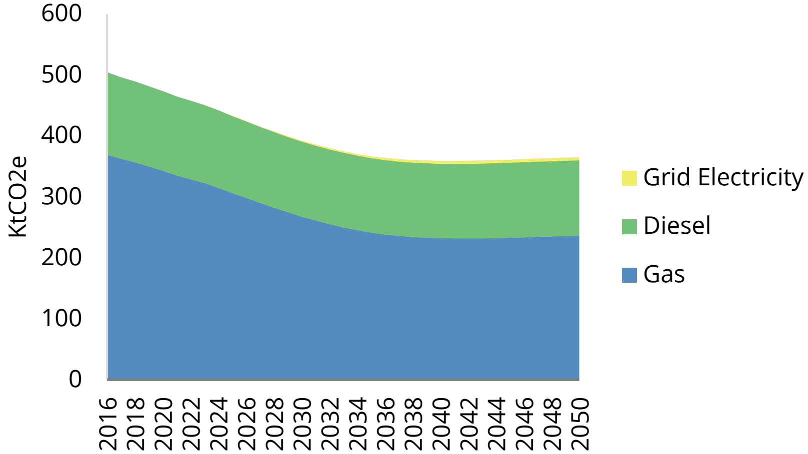

Figure 22: Projected BAP transportation emissions (ktCO2e) by source, 2016-2050.

Transportation Emissions by Vehicle Type

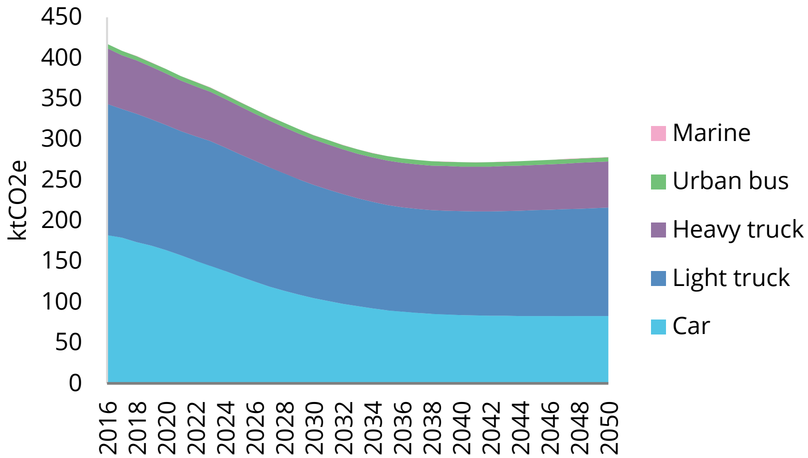

Figure 23: Projected BAP transportation emissions (ktCO2e) by vehicle type, 2016-2050.

Transportation emissions follow a similar trajectory to transportation energy demand, decreasing by 28% between 2016 and 2050. GHG emissions from transportation account for approximately half of the total emissions for Thunder Bay in 2016 (500 ktCO2e) but decrease dramatically to represent 31% in 2050 (365 ktCO2e).

Emissions from gasoline dominate GHG emissions in the transportation sector, with 73% of the total arising from gasoline in 2016. The share of emissions from gasoline decreases over time until it accounts for 65% of transportation emissions in 2050. Gasoline is the primary fuel source for light trucks and cars for the study period. Electric vehicle charging begins to increase towards 2050 but will only represent 1% of transportation GHG emissions reflecting carbon intensity of the electrical grid.

Emissions from all vehicle types either decrease or stay constant between 2016 and 2050.

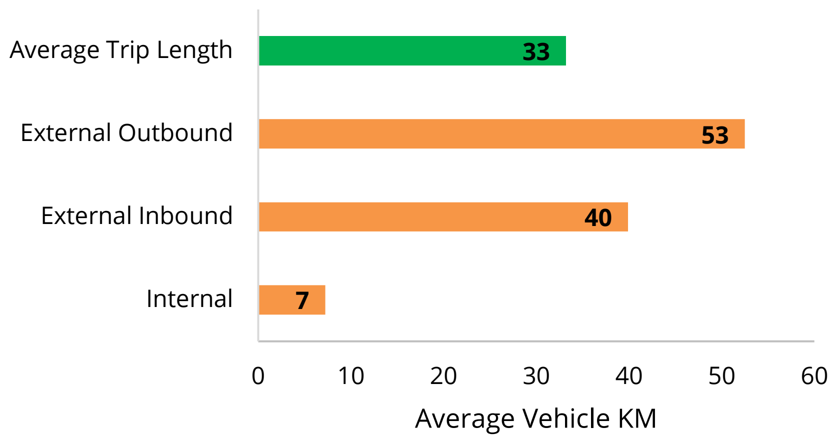

Figure 24: Average PUV VKT

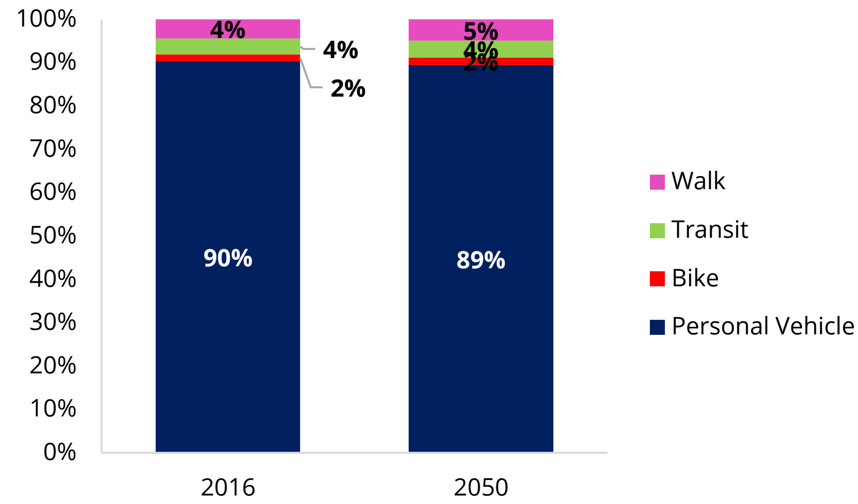

Figure 25: Mode Share in 2016 & 2050

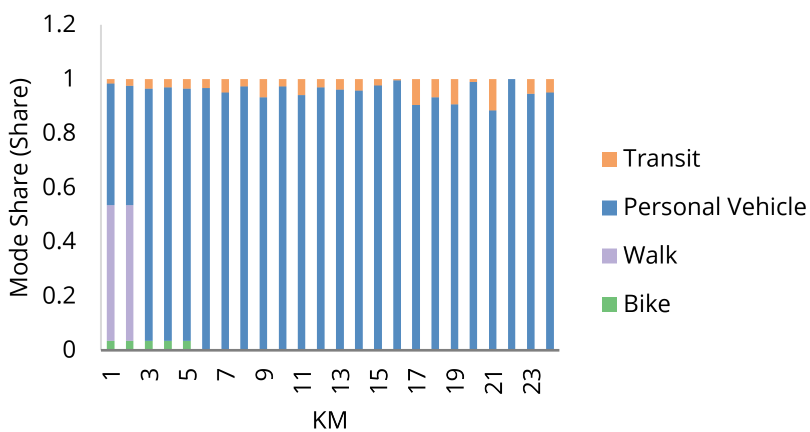

Figure 26: Mode Share by Distance, 2050

The majority of all trips made in Thunder Bay are personal vehicle trips. When considering internal trips (trips that start and end within the city) 90% of trips are completed by vehicle in 2016 and this is projected to stay the same by 2050. Trips that start outside of the city boundary, or end outside the city boundary are nearly entirely done by personal vehicle.

In 2016, 8% of internal trips were made by transit and active transportation. By 2050, active transport will increase slightly due to increased infrastructure and urban design improvements.

The average length of a personal vehicle trip is expected to remain 33km from 2016 to 2050. Despite some improvements to transit, the total amount of vehicle kilometres travelled is not anticipated to decrease towards 2050.

When considering travel types by distance (left), walking and cycling capture up to 50% of trips up to 2km, but their use begins to decline after the 2km mark. Transit captures less than 10% of trips longer than 6km. No significant expansions or improvements to transit are anticipated.

Waste Sector Emissions

Waste Emissions by Type

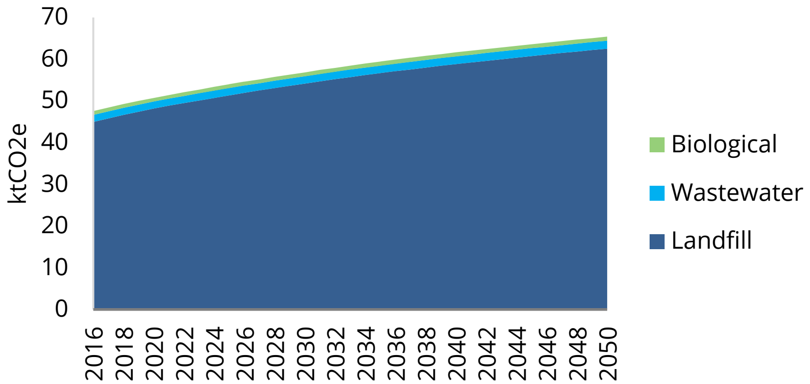

Figure 27: Projected BAP waste emissions (tCO2e), 2016-2050.

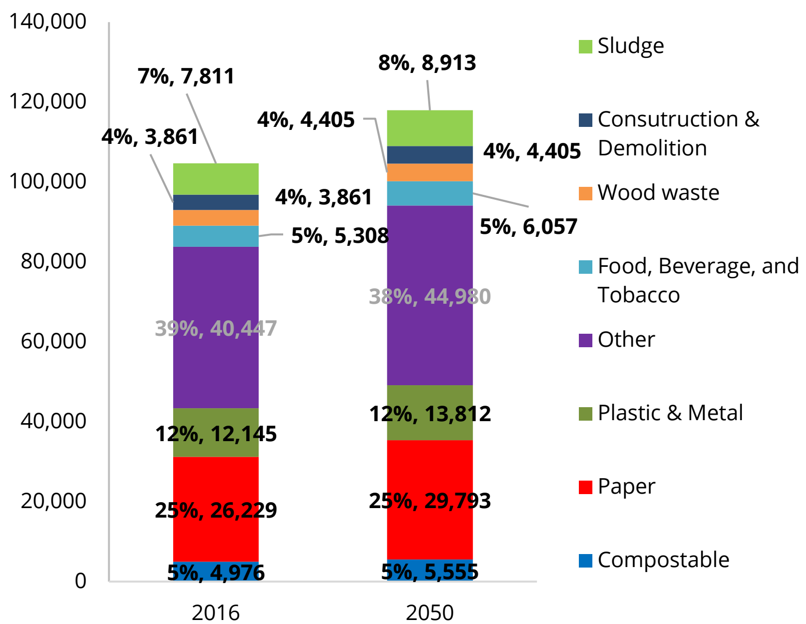

Figure 28: Waste Tonnage by type, 2016 & 2050.

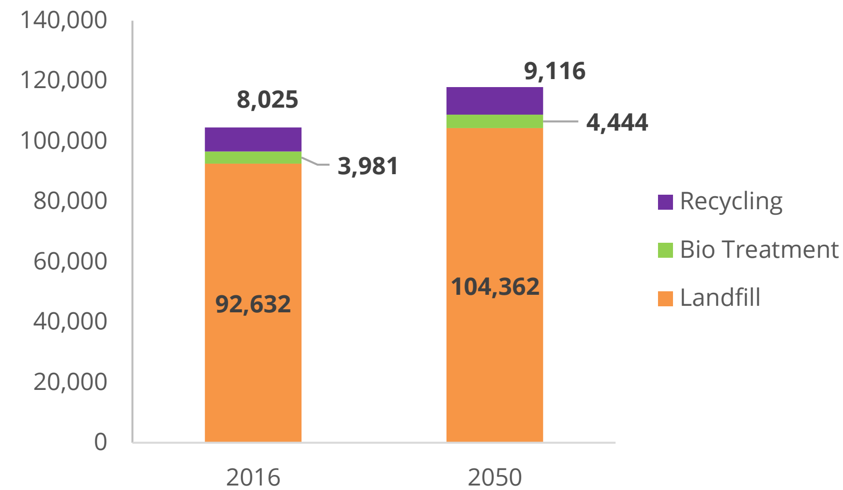

Figure 29: Waste by Treatment Type, 2016 & 2050

In 2016, Thunder Bay produced approximately 104,000 tonnes of solid waste, the majority of which was sent to a landfill. In step with population and employment growth, this number is projected to increase to approximately 120,000 tonnes per year given the current diversion rate.

Waste emissions in Thunder Bay amount to 48 $ktCO_2e$ in 2016 and increase gradually to 65 $ktCO_2e$ by 2050; an increase of approximately 38% 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 organics processing (biological). This is due to the continued addition of waste to landfill, as well as the ongoing decay of existing waste in landfill [that has been added over many years in the past] that continues to produce methane. This is the case despite the City's existing landfill gas capture system.

Wastewater emissions represent approximately 2-3% of the sector's emissions due to the near 100% capture of methane.

The BAP assumes no further reduction in the rates of per capita waste production or improvement in treatment facilities.

Agriculture, Forestry, and Other Land Use (AFOLU)

Thunder Bay has a large land base dedicated to open and forested lands, as well as a small amount of agricultural lands within the city boundary. These lands result in both GHG emissions and carbon sequestration (reduction of GHG emissions). This analysis includes emissions from livestock and land-use change in calculations of community-wide GHG emissions.

For the baseline year, GHG emissions originating from livestock total 8 ktCO2e in 2016, less than 1% of total community emissions.

The number of livestock in Thunder Bay is held constant towards 2050, as a plateau has been reached from 2013 onwards according to Ontario statistics on agricultural activities.[4] As a result, GHG emissions from livestock are projected to remain at 8 ktCO2e towards 2050.

Carbon Sequestration

This section presents estimates of carbon sequestration, or "sink" (removal of carbon from the atmosphere), and emissions (release of carbon into the atmosphere) from land-use practices related to forests, croplands, grasslands, wetlands, and residential areas (urban trees, grass clippings, and food scraps) in Thunder Bay. Changes in land use from 2016 to 2050 will shape carbon release and sequestration.[5]

The land use, land-use change, and forestry (LULUCF) sector results in a net sequestration value of -353 $ktCO_2e$ in 2016, but this decreases to -351 $ktCO_2e$ annually in 2050, as a result of land-use change. The small reduction in sequestration reflects Thunder Bay's planning and policy to reduce outwards expansion, while also protecting and enhancing forested areas. However, it also alludes to the possibility of greater reforestation efforts required.

This estimation of carbon sequestration is held external to community-wide GHG emissions and added to the final total of the city's GHG emissions.

Agriculture and forestry are both a source and a sink for greenhouse gas emissions. Sources of emissions from this sector include deforestation, peatland drainage, livestock, and burning of biomass. Forest preservation, reforestation, and crop management can sequester GHG emissions. 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 fluxes according to changes within and conversions between all land-use types including: forest land, cropland, grassland,

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[4] 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. http://www.omafra.gov.on.ca/english/stats/livestock/index.html

[5] Land-use changes are modelled on 5-year increments starting from 2011, so 2016 would mark the endpoint of the first 5-year increment and the beginning of the next one.

wetlands, and settlements. Definitions of agricultural lands, forested lands, and grasslands provided by the IPCC were compared to Thunder Bay maps and census data for land use.

The largest sequestration category between 2016 and 2051 was forest lands remaining forest lands, with an estimated sequestration of -215 ktCO2e (negative emissions) that holds relatively steady towards 2050. The second-largest carbon sequestration category was settlement areas, remaining settlement areas, and urban trees, with an estimated sequestration of -138 kTCO_2e in 2016 that holds steady towards 2050.

The conversion of forest lands to settlement areas results in a slight increase in GHG emissions from 2021 to 2050, with 2 to 5 ktCO_2e emitted over 5 year increments. Cropland converted to settlement areas, as well as cropland remaining cropland, cause no new GHG emissions in the period between 2016 and 2050.

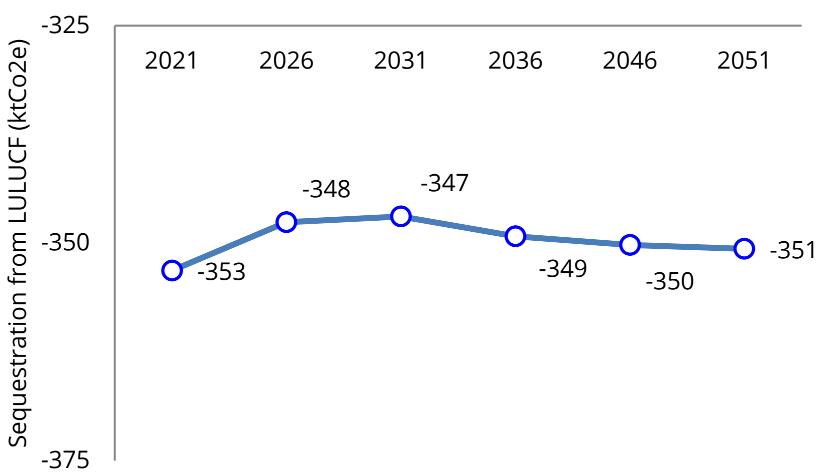


Figure 30: LULUCF and GHG emissions in Thunder Bay, 2016-2050.

Emissions from Soil Carbon Release

GHG emissions from soil management are another dimension of land-use change. Soil produces GHG emissions when nitrogen present in the soil is released as nitrous oxides (N_2O). Such GHG emissions increase when human activities increase soil's nitrogen content. Activities within Thunder Bay that contribute to N_2O emissions from agricultural lands include the use of synthetic and organic fertilizers, the growth of nitrogen-fixing crops, the drainage of organic soil, and irrigation practices on agricultural land.[6]

It is anticipated that the number of GHG emissions from soils will rise because the amount of non-tilled land (land that is not disturbed by fertilization or mechanized measures) is decreasing, while tilled land is increasing.[7]

Two limiting reasons preclude emissions from soil in Thunder Bay's inventory and BAP scenario: Firstly, there is little agricultural land within Thunder Bay's boundary by traditional definitions, so this will not majorly affect the GHG emissions profile of Thunder Bay. Secondly, data quality is fairly limited to accurately make a meaningful projection on these emissions. Due to these factors, GHG emissions from soils will not be included.

Total GHG Emissions with Carbon Sequestration

When considering sequestration value from land use, community GHG emissions decrease between 2016 and 2050 from 1,161 to 810 ktCO_2e. The table below provides the net GHG emissions, when also adding sequestration.

[6] Agriculture Sector Emissions. (n.d.) Environmental Protection Agency. Accessed Here: https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

[7] ibid

Table 2: Grand total of GHG emissions for Thunder Bay, 2050.

Sector	GHG Emissions, 2050. ($ktCO_2e$)
'Subtotal' of community-wide emissions	1,161
LULUCF GHG emissions	-351
Emissions from soil management	Not Included in 2050 scope
Grand total	810

Part 2:

Sensitivity Analysis

The BAP scenario illustrates the projected energy use and GHG emissions for Thunder Bay from 2016 to 2050 based on the assumptions described in the Data, Methods and Assumptions Manual. A sensitivity analysis helps inform the model reader about likely uncertainties and their implications on the model results.

Sensitivity analysis involves adjusting certain selected variables that were considered to have both a high level of uncertainty and a high potential to affect energy use or GHG emissions.

The process used in this sensitivity analysis applies a judgement-based 'one-factor-at-a-time'[8] exploration of variables within a scenario. The results should not be viewed as an evaluation of fully considered alternative futures. Rather, it is an exploration revealing how a selected output (i.e. emissions) responds to changes in selected inputs (e.g. number of residential units).

Variables and Results

Several variables were identified for sensitivity analysis in the BAP. The assumptions and impact on each variable are described in Table 7 under Appendix 1 and depicted in Figures 32 and 33. The impact on each variable, expressed in GJ for energy and $ktCO_2e$ for emissions, shows the absolute difference on the variable relative to the BAP in 2050.

Discussion: Energy Sensitivity Analysis

The following assumptions were identified for analysis in relation to their impact on the BAP's overall energy use: (1) population, (2) employment, (3) the uptake of electric vehicles, (4) vehicle kilometres travelled, and (5) heating and cooling degree days.

If population or employment were to decline or increase (as compared to the assumed increase in the BAP), it naturally follows that energy consumption would decrease or increase. Each individual and each job requires a certain amount of energy. However, the relative size of the decrease or increase in energy consumption are not the same. This difference is due to the fact that new residential and non-residential buildings and vehicles would be incrementally more efficient and use less energy compared with existing buildings and vehicles that would be 'turned off' in a declining population or employment scenario.

In this sensitivity analysis, we applied high- and low-case population and employment projections provided by the City. The high-case projection is larger than the low-case decrease, which offsets the important difference in efficiency and fuel use noted above.

The high-case population projection results in a 1.3% increase in overall energy consumption, while the low-case population projection results in a 1.1% decrease. The low-case employment projection results in a 3.1% decrease in energy consumption, whereas the high-case results in a 3.4% increase in energy consumption.

Both the uptake rate of electric vehicles (EVs) and the number of projected vehicle kilometres travelled (VKT) were also tested for their

[8] One-factor-at-a-time (OFAT or OAT) involves changing only one variable at a time to see what effect it has on the output. The process generally involves changing one input variable while keeping others at their baseline (nominal) values, then returning the variable to its nominal value, and repeating for each of the other inputs in the same way. Sensitivity is then measured by monitoring changes in the output.

impact on overall energy use. A 50% increase in assumed EV uptake (from 14% of new sales by 2050, to 28% by 2050) would result in a 1% reduction in overall energy consumption. A 50% decrease in assumed EV uptake (down to 7% by 2050) would result in a 0.5% increase in overall energy consumption. The reason for increased efficiency with greater EV uptake is due to the fact that electric vehicles are more efficient than traditional combustion engines.

In terms of VKT, a 25% increase would result in a 2.6% increase in overall energy consumption. A 25% decrease in VKT uptake would result in a 2.6% decrease in overall energy consumption.

Finally, future weather predictions, specifically heating and cooling degree days (HDD and CDD), are a significant driver of projected energy use in buildings. In the BAP, HDD are predicted to decrease and CDD are projected to increase, according to the business-as-planned warming scenario. If HDD and CDD instead remained constant, it would result in a 1.9% increase in overall energy consumption. A more aggressive warming scenario (an additional 10% decrease in HDD and 10% increase in CDD) would result in a 2% decrease in overall energy consumption, since cooling requires less energy use than heating.

GHG Sensitivity Analysis

The same variables were assessed for sensitivity in relation to their impact on GHG emissions, with the addition of the methane emissions factor.

Similar to energy, assumptions for population and employment have a significant impact on the BAP GHG emissions trajectory. As noted above, the buildings and vehicles associated with a growth scenario are likely to be more efficient than the buildings and vehicles 'turned off' in a decline scenario. However, the projection for emissions in the high-case projection is larger than the decrease in the low-case projection, which offsets the inverse relationship described above. As such, the emissions in a higher population growth scenario would increase by 1.9% compared with a decrease of only 1.7% in a declining scenario. The emissions in an employment growth scenario would increase by 3.6 % compared with a decrease of 3.3% in a declining scenario. In both cases, the emissions impacts are larger than the equivalent energy use impact. This is due to the fact that fossil fuels are projected to make up a larger share of Thunder Bay's energy use by 2050 in the BAP.

Assumed electric vehicle (EV) uptake and vehicle kilometers traveled (VKT) were also considered in the sensitivity analysis for their impact on BAP GHG emissions. If we decrease the assumed EV uptake by 50%, BAP emissions increase by 1.3% and, if the EV uptake increases by 50%, projected emissions decrease by 2.5%. The relatively small impact here is due to the fact that new sales in any given year only represent a small fraction of the overall vehicle stock.

If we decrease the VKT by 25%, BAP emissions decrease by 4.5% and, if we increase VKT by 25%, projected emissions increase by 4.5%. In both cases the impact is larger on GHG emissions than for energy because transportation fuels are so carbon-intensive.

Future weather predictions, especially HDD, are a major driver of predicted emissions in buildings, as building heating is primarily provided via fossil fuels. In the BAP, HDD are predicted to decrease and CDD are projected to increase according to the applied warming scenario. If HDD and CDD were instead to remain constant, it would result in a 2.8% increase in overall emissions. A more aggressive warming scenario (an additional 10% decrease in HDD and 10% increase in CDD) would result in a 3% reduction in overall emissions. Warming weather serves to temper building emissions.

The methane emissions factor (i.e. the calculation used to convert a tonne of methane emissions into an equivalent tonne of carbon dioxide) has the single most significant impact on overall GHG emissions for Thunder Bay. The methane emissions factor applied in the model is the current standard emissions reporting regimes; however, the most recent science indicates the actual methane emissions factor should be much more aggressive due to its increased global warming potential in the critical short term.[9] Decision-makers should keep this in mind as they consider how to address the main drivers of methane emissions in Thunder Bay, namely: 1) the uncontrolled decay of organic waste, and 2) leaks from the natural gas distribution system.

[9] Table 8.7, Chapter 8, Anthropogenic and Natural Radiative Forcing, Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

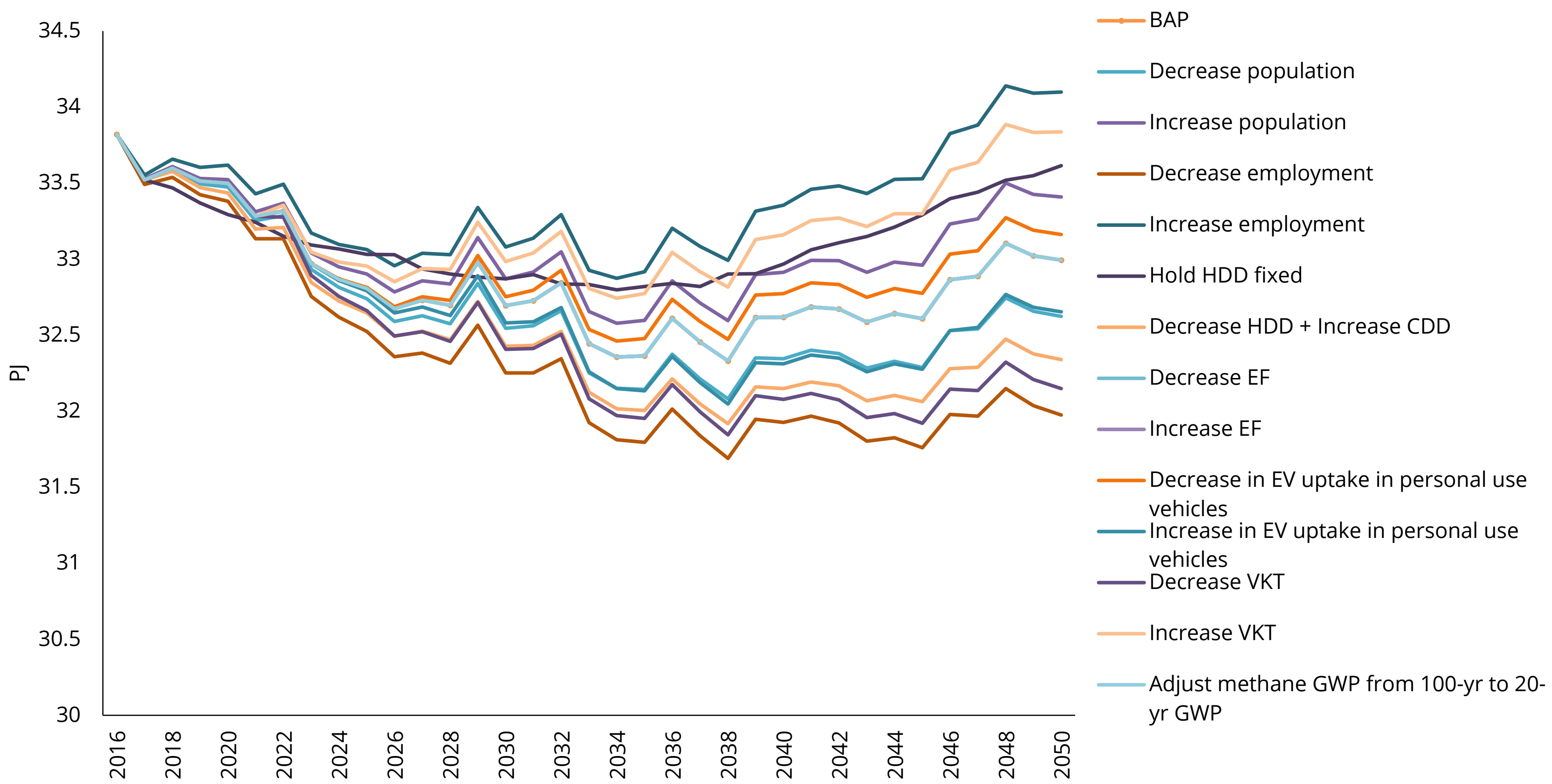


Figure 31: BAP energy sensitivity, 2016-2050.

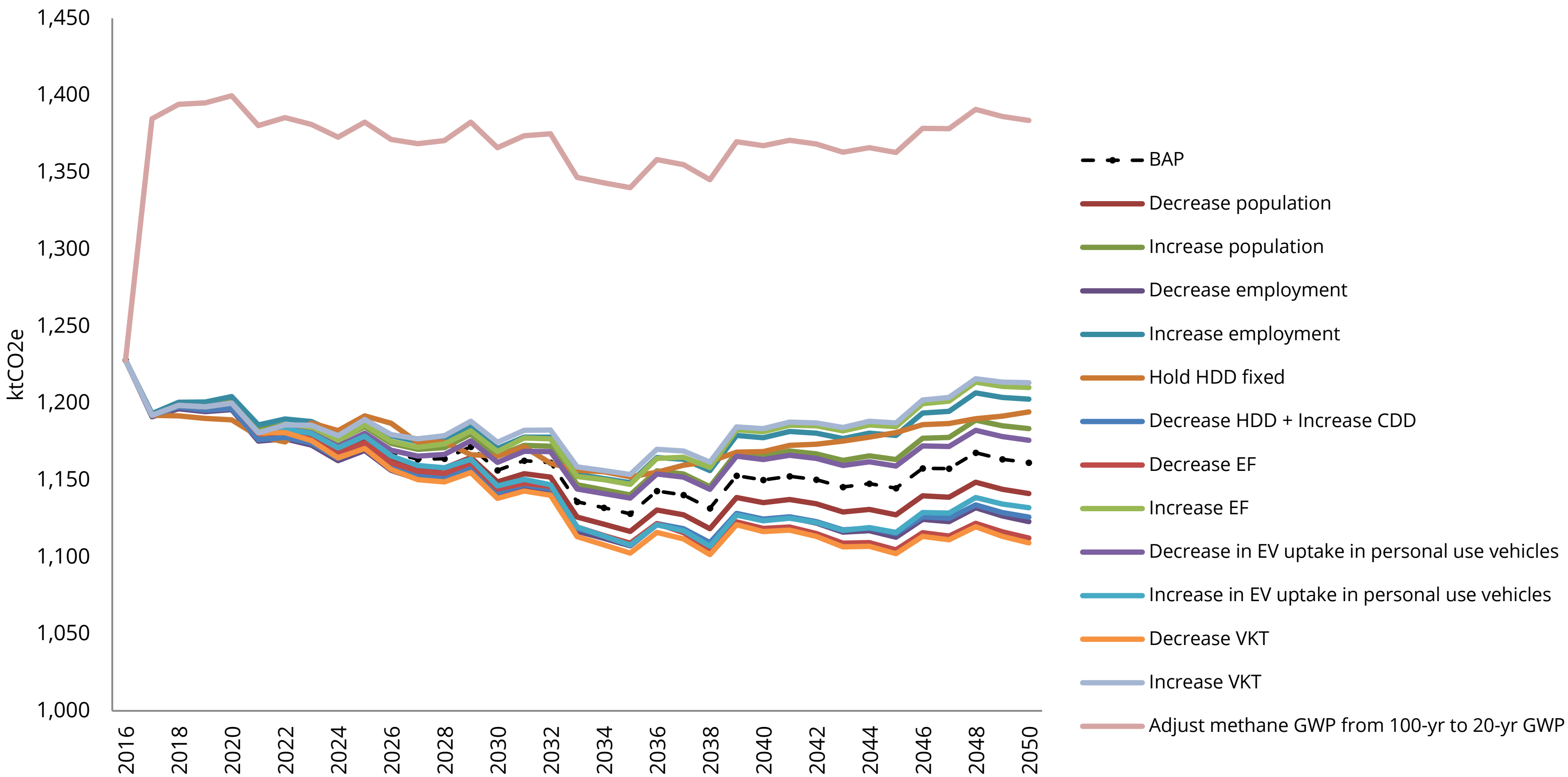


Figure 32: BAP emissions sensitivity, 2016-2050.

Summary & Key Trends

Under the Business as Planned Scenario, Thunder Bay's GHG emissions are projected to decline slightly from approximately 1,200 $ktCO_2e$ to 1,160 $ktCO_2e$ by 2050, a -5% reduction. With carbon sequestration added, total emissions are reduced to approximately 810 $ktCO_2e$. Following the historic development pattern of the region, the transportation, industrial, then residential sectors are the dominant consumers of energy and thereby the largest emitters of GHGs.

Thunder Bay has ambitiously adopted a Net-Zero GHG emissions target, thereby making 810 $ktCO_2e$ the gap that needs to be closed in the year 2050. Thunder Bay will chart the course to reach this target through the development of the CEEP which will complement efforts made through the Official Plan and Sustainability Plan.

The next 30 years are critical for emissions reductions, and this is especially important given the need to reduce cumulative GHG emissions by 2050 and to also follow through with the climate declaration made by the city in January 2020. Actions and their timing will be explored through the exploration of low-carbon scenario modelling in the next phase of the project.

Key Trends

The analysis completed in the Business-As-Planned scenario reveals the following key trends to consider during the development of the Community Energy and Emissions Plan.

- The current carbon intensity of the provincial electrical grid is low but is less certain in the upcoming years. This creates a major emissions reduction opportunity for fuel switching from carbon intensive fuels to electricity, particularly from natural gas in the buildings sector, and gasoline and diesel in the transportation sector, and for vehicles (private and transit) away from carbon intensive gasoline to increasingly cleaner electricity.
- Significant efforts to fuel switch to electricity will require new generation capacity with renewables to ensure that the emissions factor for electricity continues to decline.
- Retrofitting the existing building stock will be critical as the residential sector is the third largest consumer of energy in the city.
- New building standards will need to be progressively more stringent to flatten the curve of energy demand for residential and non-residential buildings.
- Industrial energy consumption and GHG emissions represent the second largest sector in Thunder Bay. The reliance on fossil fuels, namely natural gas needs to be mitigated through process improvements, recommissioning efforts, and fuel switching.
- Transport energy and emissions decline towards 2050, but mostly as a reflection of increased electric vehicle take-up. Overall vehicle trip lengths are not projected to decline; and personal vehicle trips will continue to be the dominant travel method for the growing population.
- Vehicular mode share for external trips is ≈90% (internal), and ≈100% external; efforts to shift this mode share are critical as transportation will remain the largest emitter as a sector by 2050.
- Out of all fuel sources, natural gas is the most significant source of emissions; this creates an emissions reduction opportunity for fuel switching to electricity for space heating in commercial and residential buildings.
- Existing buildings (pre-2011) have a major impact on GHG emissions; the incremental effect of high efficiency new buildings is small but decreases the upward pressure of an

increasing population on the GHG curve. An ambitious retrofit program will be critical.

- With current solid waste generation and diversion rates, emissions from waste will continue to grow with a growing population. Actions to decrease waste generation, increase diversion, to recover additional energy from waste [that is otherwise not being used and represents a lost opportunity] will be critical to reducing emissions in this sector.

Part 3: Data, Methods, and Assumptions Manual

1. Summary

The Data, Methods and Assumptions (DMA) manual has been created for Thunder Bay 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 Thunder Bay boundary. The inventory will also serve the decision-making needs of Thunder Bay, 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 & 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 33.

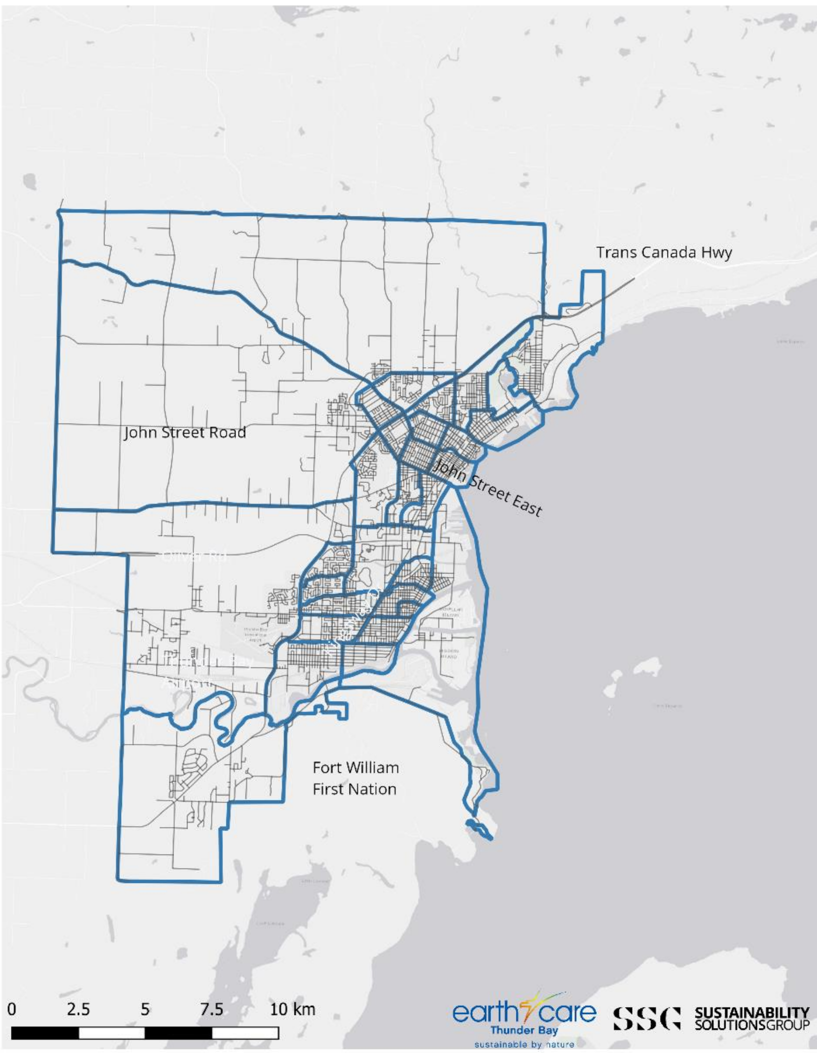


Figure 33: Thunder Bay geographic boundary.

3.2 Time Frame of Assessment

The time frame for assessment of Thunder Bay 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 & 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:

$$\boldsymbol{Energy}_{city} = \boldsymbol{Energy}_{transport} + \boldsymbol{Energy}_{buildings} + \boldsymbol{Energy}_{wastegen}$$

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:

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

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. Refer to the Appendix for a list of GHG emission sources by Scope that are included.

Table 3: 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 Factors

In order to compile a baseline of emissions within Thunder Bay, 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 sources.

Table 4: Emissions Factors for Thunder Bay Baseline and Future Scenarios

Category	Description	Comment
Natural gas	49 kg CO_2e/GJ	Environment and Climate Change Canada. National Inventory Report 1990-2015: Greenhouse Gas Sources and Sinks in Canada. Part 2. Tables A6-1 and A6-2, Emission Factors for Natural Gas.
Electricity	2016: 50.8 gCO_2e/kWh 2050: 83.7 gCO_2e/kwh 2016: CO_2: 28.9 g/kWh CH_4: 0.007 g/kWh N_2O: 0.001 g/kWh 2050: CO_2: 82.32 g/kWh CH_4: 0.02 g/kWh N_2O: 0.00 g/kWh	IESO, Annual Planning Outlook January 2020.
Gasoline	g/L CO_2: 2316 CH_4: 0.32 N_2O: 0.66	Environment and Climate Change Canada. National Inventory Report 1990-2015: Greenhouse Gas Sources and Sinks in Canada. Part 2. Table A6–12 Emission Factors for Energy Mobile Combustion Sources
Diesel	g/L CO_2: 2690.00 CH_4: 0.07	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

	N2O: 0.21	
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 N2O: 0.108 All other sectors CO2: 1515.00 CH4: 0.024 N2O: 0.108	Environment and Climate Change Canada. National Inventory Report 1990-2015: Greenhouse Gas Sources and Sinks in Canada. Part 2. Table A6–3 Emission Factors for Natural Gas Liquids Table A6–12 Emission Factors for Energy Mobile Combustion Sources

Agricultural: Livestock	Varies per animal Type Kg 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 70% 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.	There is methane capture at the landfill in Thunder Bay. 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 38-10-0032-01: 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

5. Modelling

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

5.1 About CityInSight

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

Energy and GHG emissions are derived from a series of connected stock and flow models, evolving on the basis of current and future geographic and technology decisions/assumptions (e.g. EV penetration rates). The model accounts for physical flows (i.e. energy use, new vehicles by technology, vehicle kilometres travelled) as determined by stocks (buildings, vehicles, heating equipment, etc.).

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

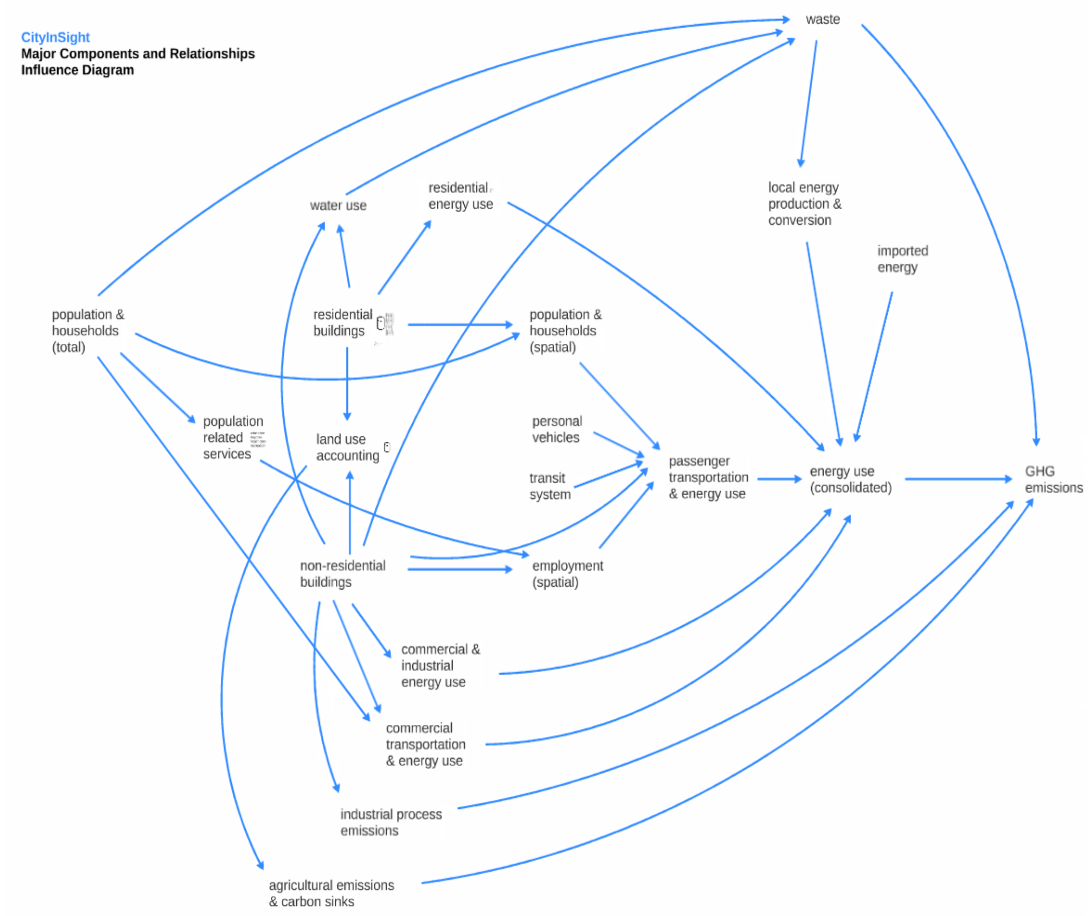
Table 5: Characteristics of CityInSight.

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.

5.2 Model Structure

Figure 34: 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 34. 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.

5.3 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).

5.4 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 Thunder Bay 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.

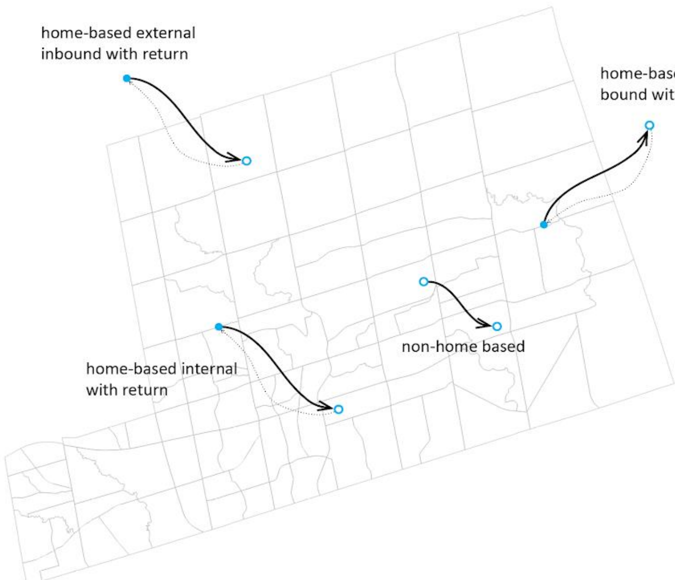
Spatial population and employment

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 Thunder Bay’s boundary) are accounted for, as well as half of the trips that terminate or originate within the City's boundary. This approach allows Thunder Bay to better understand its impact on the peripheries.

Figure 34. 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 Thunder Bay 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 Thunder Bay.

Agricultural and land based emissions are calculated as change of activities, uses, and land over time. For the baseline, no major change was assumed for the period between 2015 and 2016. In the BAP and in future scenarios, land that is predominantly forested or agriculturally based 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

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.

5.5 Data and Assumptions

A detailed table is available in Appendix 3 showing the data used and assumptions made to develop the BAP scenario for Thunder Bay. A separate breakdown of how the inventory complies with the GHG protocol can be found under Appendix 4.

6. 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.

6.1 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 & 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. (see Appendix)

6.2 Low Carbon Scenario

Using the business as usual 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 net zero 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 Net-Zero;
8. Develop marginal abatement curve for 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.

7. 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, & Sivakumar, 2012).

> **> Approach:** Each of the variables will be increased by 10-20% 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 6: Community energy consumption tabulated results, 2016 & 2050 (BAU).

Energy by sector (PJ)	2016	share 2016	2050 (BAU)	share 2050	% +/ 2016-2050
Commercial	3	11%	3	12%	-0.1%
Industrial	10	40%	12	47%	14%
Residential	5	20%	5	20%	-5%
Transportation	8	29%	6	22%	-27%
Total	**26**	**100%**	**25**	**100%**	**-3%**
Energy by fuel (PJ)	**2016**	**share 2016**	**2050 (BAU)**	**share 2050**	**% +/ 2016-2050**
Diesel	2	7%	2	6%	-9%
District Energy	4	17%	5	20%	13%
Fuel Oil	0.2	1%	0.1	0%	-25%
Gasoline	6	21%	4	14%	-36%
Grid Electricity	3	12%	4	15%	26%
Local Electricity	0.1	0%	0.1	0%	0%
Natural Gas	10	39%	10	41%	1%
Other	0.3	1%	0.2	1%	-28%
Propane	0.2	1%	0.2	1%	-2%
Wood	**0.3**	**1%**	**0.4**	**1%**	**10%**
Energy per capita (GJ/cap)	**303**		**266**		**-12%**

Community Emissions

Table 7: Per capita emissions, 2016 and 2050 (BAU).

Emissions by sector (tCO_2e)	2016	2050 (BAU)	% +/- (2016-2050)
Emissions per capita (tCO_2e/person)	**11**	**9**	**-15%**

Table 8: Community emissions tabulated results, 2016 & 2050 (BAU).

Emissions by sector ($ktCO_2e$)	2016	share 2016	2050 (BAU)	share 2050	% +/- (2016-2050)
Agriculture &	8	1%	8	1%	1%
Commercial	117	10%	126	11%	7%
Energy Production	6	0%	6	1%	0%
Fugitive[10]	63	5%	63	5%	1%
Industrial	254	21%	308	27%	21%
Residential	227	19%	219	19%	-4%
Transportation	505	41%	365	31%	-28%
Waste	48	4%	65	6%	38%
Total	**1,228**	**100%**	**1,161**	**100%**	**-5%**

Emissions by fuel ($ktCO_2e$)	2016	share 2016	2050 (BAU)	share 2050	% +/- (2016-2050)
Diesel	136	11%	124	11%	-9%
Electricity	33	3%	25	2%	-25%
Fugitive	369	30%	236	20%	-36%
Fuel Oil	33	3%	98	8%	193%
Gasoline	508	41%	511	44%	1%
Natural Gas	118	10%	137	12%	15%
Propane	12	1%	12	1%	-2%
Waste	0	0%	0	0%	0%
Wood	17	1%	18	2%	5%
Total	**1,228**	**100%**	**1,161**	**100%**	**-5%**

10 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 9: Buildings sector energy tabulated results, 2016 & 2050 (BAU).

Buildings energy (PJ) by building	2016	share 2016	2050 (BAU)	share	% +/- (2016-2050)
Commercial	3	16%	7	33%	0%
Industrial	10	56%	12	60%	14%
Residential	5	28%	5	25%	-5%
Total	**19**	**100%**	**20**	**100%**	**6%**

Buildings energy (PJ) by fuel	2016	share 2016	2050 (BAU)	share 2050	% +/- (2016-2050)
District Energy	4	24%	5	25%	13%
Fuel Oil	0	1%	0	1%	-25%
Grid Electricity	3	17%	4	18%	19%
Local Electricity	0.1	1%	0.1	1%	-5%
Natural Gas	10	55%	10	52%	1%
Other	0	0%	0	0%	14%
Propane	0.2	1%	0.2	1%	-2%
Wood	0.3	2%	0.4	2%	10%
Total	**19**	**100%**	**20**	**100%**	**6%**

Buildings energy (PJ) by end use	2016	share 2016	2050 (BAU)	share 2050	% +/- (2016-2050)
Industrial Manufacturing	10	54%	12	59%	16%
Lighting	0.5	3%	0.5	2%	0%
Major Appliances	0	2%	0	2%	12%
Plug Load	1	4%	1	4%	7%
Space Cooling	0.1	1%	0.2	1%	57%
Space Heating	6	30%	5	25%	-10%
Water Heating	1	7%	1	6%	2%
Total	**19**	**100%**	**20**	**100%**	**6%**

Table 10: Buildings sector emissions tabulated results, 2016 & 2050 (BAU).

Buildings emissions ($ktCO_2e$)	2016	share 2016	2050 (BAU)	share 2050	% +/- (2016-2050)
Commercial	109	19%	126	20%	15%
Industrial	245	42%	299	46%	22%
Residential	227	39%	219	34%	-4%
Total	**590**		**644**		**9%**

Buildings emissions ($ktCO_2e$) by fuel	2016	share 2016	2050 (BAU)	share 2050	% +/- (2016-2050)

Fuel Oil	33	6%	25	4%	-25%
Grid Electricity	33	6%	93	14%	178%
Natural Gas	502	85%	505	78%	1%
Propane	12	2%	12	2%	-2%
Wood	8	1%	9	1%	10%
Total	**590**	**100%**	**644**	**100%**	**9%**
Buildings emissions (ktCO$_2$e) by end use	**2016**	**share 2016**	**2050 (BAU)**	**share 2050**	**% +/- (2016-2050)**
Industrial Manufacturing	237	40%	294	46%	24%
Lighting	5	1%	12	2%	135%
Major Appliances	6	1%	11	2%	75%
Plug Load	9	2%	21	3%	126%
Space Cooling	2	0%	5	1%	211%
Space Heating	270	46%	241	37%	-11%
Water Heating	60	10%	60	9%	1%
Total	**590**	**100%**	**644**	**100%**	**9%**

Transportation Sector

Table 11: Transportation sector energy tabulated results, 2016 & 2050 (BAU).

Transportation energy (PJ) by fuel	2016	share 2016	2050 (BAU)	share 2050	% +/- (2016-2050)
Grid Electricity	0	0%	0.2	5%	187900%
Local Electricity	0	0%	0.01	0%	149243%
Diesel	1	18%	1	22%	-15%
Gas	5	82%	3	73%	-38%
Total	**6**	**100%**	**4**	**100%**	**-31%**
Transportation energy (PJ) by vehicle type	**2016**	**share 2016**	**2050 (BAU)**	**share 2050**	**% +/- (2016-2050)**
Car	3	43%	1	29%	-53%
Heavy truck	1	15%	1	18%	-17%
Light truck	2	38%	2	47%	-14%
Marine	0	0%	0	0%	0%
Rail	0	2%	0	3%	0%
Urban bus	0	1%	0	2%	0%
Total	**6**	**100%**	**4**	**100%**	**-31%**

Table 12: Transportation Emissions, tabulated results, 2016 & 2050 (BAU).

Transportation Emissions ($ktCO_2e$) by fuel	2016	share 2016	2050 (BAU)	share 2050	% +/- (2016-2050)
Grid Electricity	0	0%	5	1%	437746%
Diesel	136	27%	124	34%	-9%
Gasoline	369	73%	236	65%	-36%
Total	**505**	**100%**	**365**	**100%**	**-28%**
Transportation Emissions (ktCO2e) by vehicle type	**2016**	**share 2016**	**2050 (BAU)**	**share 2050**	**% +/- (2016-2050)**
Car	182	36%	83	23%	-55%
Heavy truck	68	14%	57	16%	-17%
Light truck	161	32%	133	36%	-17%
Marine	0	0%	0	0%	0%
Off Road	76	15%	76	21%	0%
Rail	11	2%	11	3%	0%
Urban bus	5	1%	5	1%	0%
Total	**505**	**100%**	**365**	**100%**	**-28%**

Waste Sector

Table 13: Waste Sector Emissions, 2016 & 2050

Waste Emissions ($ktCO_2e$) by fuel	2016	share 2016	2050 (BAU)	share 2050	% +/- (2016-2050)
Biological	1	2%	1	2%	12%
Landfill	45	95%	63	96%	39%
Wastewater	2	4%	2	3%	12%
Total	**48**	**100%**	**65**	**100%**	**38%**

Land Use

Table 14: Land Use Change Emissions 2021-2050

LULUCF Category	Subcategory	(t/ha/yr)	(ktCO$_2$e/yr)						
			2021	2026	2031	2036	2041	2046	2051
A. Forest land	1. Forest land remaining forest land	-7.92	-215	-215	-215	-215	-215	-215	-215
B. Cropland	1. Cropland remaining cropland	0.08	0	0	0	0	0	0	0
E. Settlements	1. Settlements remaining settlements	-5.76	-138	-138	-138	-138	-138	-138	-138
E. Settlements	2.1 Forest land converted to settlements	274.48	0	5	6	3	3	2	2
E. Settlements	2.2 Cropland converted to settlements	54.08	0	0	0	0	0	0	0
	Total		**-353**	**-348**	**-347**	**-349**	**-350**	**-350**	**-351**

Table 15: Tabulated Summaries of Sensitivities

		RESULTS			
		ENERGY Impact: relative to BAP in 2050		EMISSIONS Impact: relative to BAP in 2050	
		[+/-] GJ	[+/-] %	[+/-] tonnes CO2e	[+/-] %
Variable	Modeling assumption	BAP energy 2050 =33.0 million GJ		BAP emissions 2050 = 1.2 Mt CO2e	
Demographics					
Decrease population	Exhibit 6L City of Thunder Bay Low Case Projection	-370,400	-1.1%	-19,900	-1.7%
Increase population	Exhibit 6H City of Thunder Bay High Case Projection	415,500	1.3%	22,200	1.9%
Employment					
Decrease employment	Exhibit 6L City of Thunder Bay Low Case Projection		-3.1%		-3.3%
Increase employment	Exhibit 6H City of Thunder Bay High Case Projection		3.4%		3.6%
Heating degree days (HDD)					
Hold HDD fixed	Keep number of heating degree days fixed at baseline value.	621,800	1.9%	33,000	2.8%
Decrease HDD + increase CDD	Incrementally decrease number of heating degree days so that, by 2050, there are 10% less HDD compared with BAP. Incrementally increase number of cooling degree days so that, by 2050, there are 10% more CDD compared with BAP.	-654,200	-2.0%	-35,200	-3.0%
Grid electricity emissions factor (EF)					

Decrease EF	Decrease EF to 40g CO2e/kWh in 2050 (50% decrease compared with BAP 80g CO2e/kWh in 2050).	0	0.0%	-49,000	-4.2%
Increase EF	Increase EF to 120g CO2e/kWh in 2050 (50% increase compared with BAP 80 g CO2e/kWh in 2050).	0	0.0%	49,000	4.2%
Electric vehicle (EV) adoption					
Decrease in EV uptake in personal use vehicles	Apply low EV scenario. This implies EV makes up 7% (instead of 14%) of new sales in 2030.	169,700	0.5%	14,600	1.3%
Increase in EV uptake in personal use vehicles	Apply high EV scenario. This implies EV makes up 28% (instead of 14%) of new sales in 2030.	-339,200	-1.0%	-29,300	-2.5%
Vehicle kilometres travelled (VKT)					
Decrease VKT	Gradual decrease in passenger vehicle VKT by 25% in 2050.	-844,500	-2.6%	-52,000	-4.5%
Increase VKT	Gradual increase in passenger vehicle VKT by 25% in 2050.	844,500	2.6%	52,000	4.5%
Methane					
Adjust methane global warming potential (GWP) from 100-yr (used in BAP) to 20-yr GWP	Adjust EF for CH4 to: GWP20 CH4 (with ccfb) = 86	0	0.0%	222,400	19.2%

Appendix 2: Additional Energy Maps

The map below indicated residential energy use in Thunder Bay measured in Terajoules. The deep blue section reveals where higher consumption takes place. This characterizes zones where new development that is more likely to feature larger and single detached houses has occurred further along Oliver and John Street Road in western Thunder Bay. The inner city consumption pattern is a better indicator for higher densities.

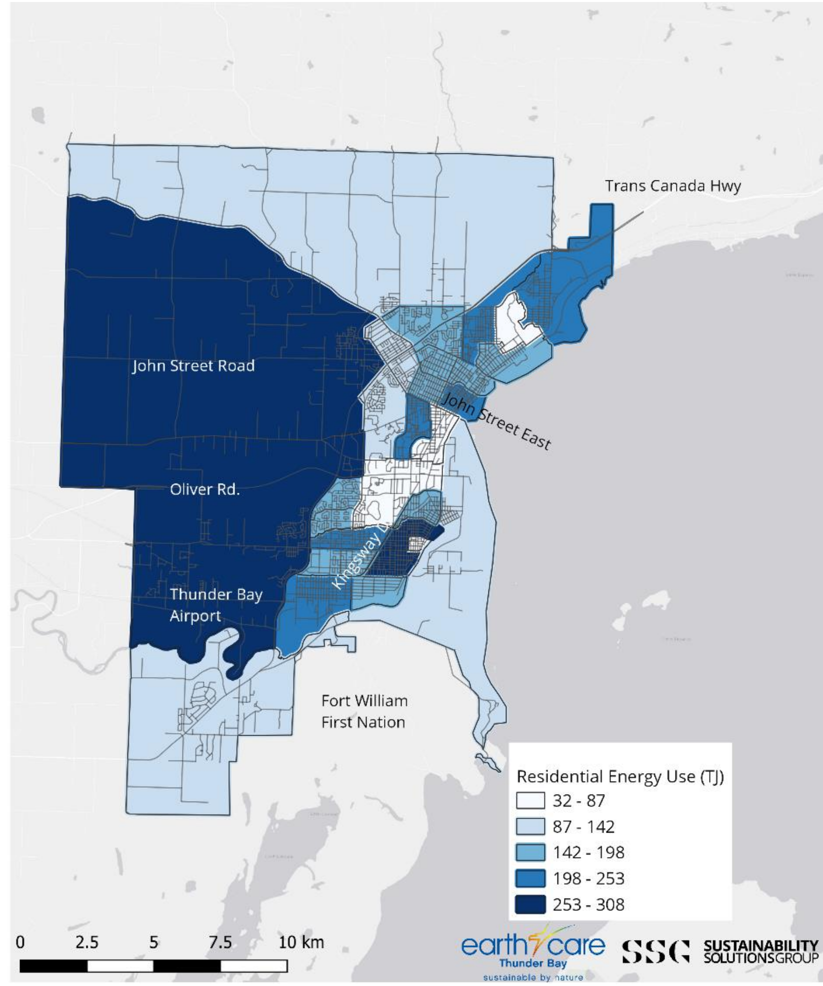


Figure 35: Residential Energy Use, 2050

Building heating demand is represented in Figure 36. Measured at a MJ of heating per m2, this map is indicative of higher heating demand at a zone level. Generally speaking demand that exceeds 140 MJ/m2 is a good threshold to apply a District Energy Heating system. This map indicates that the inner city would remain the best candidate to apply a District Energy system.

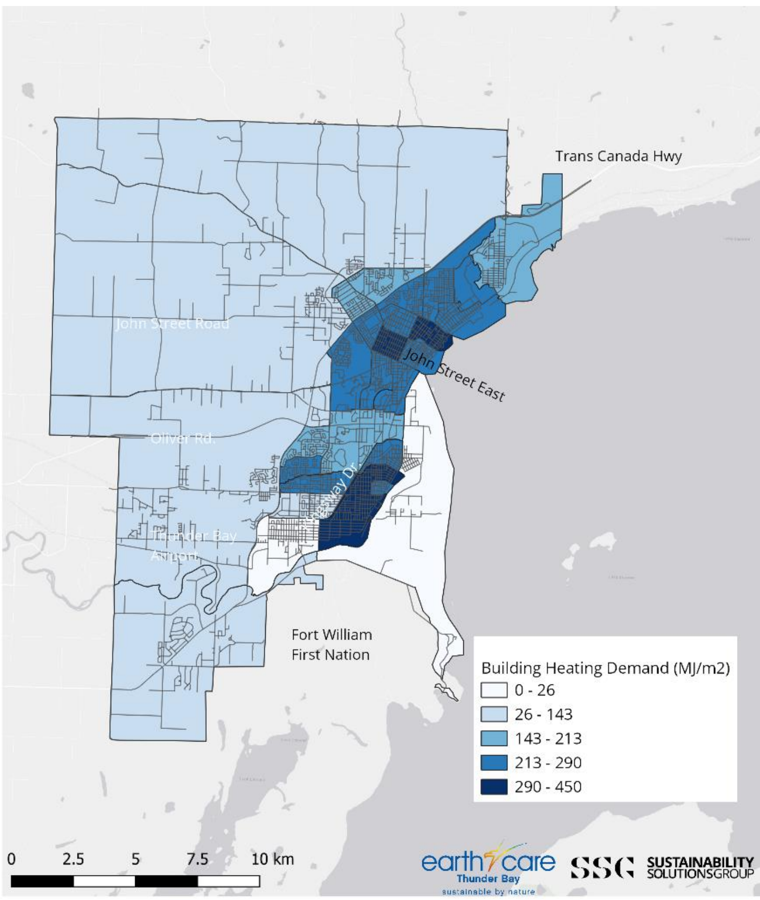


Figure 36: Building Heating Demand, 2050

Transportation energy use at the zone level is represented under figure 37. This map points to greater energy demand consumed in outer areas of the city. Northern Thunder Bay is sparsely populated and therefore represents less consumption but will likely be highest at a per capita level. The inner city is more likely to take on more of the approximate 10% of active transport and transit mode share.

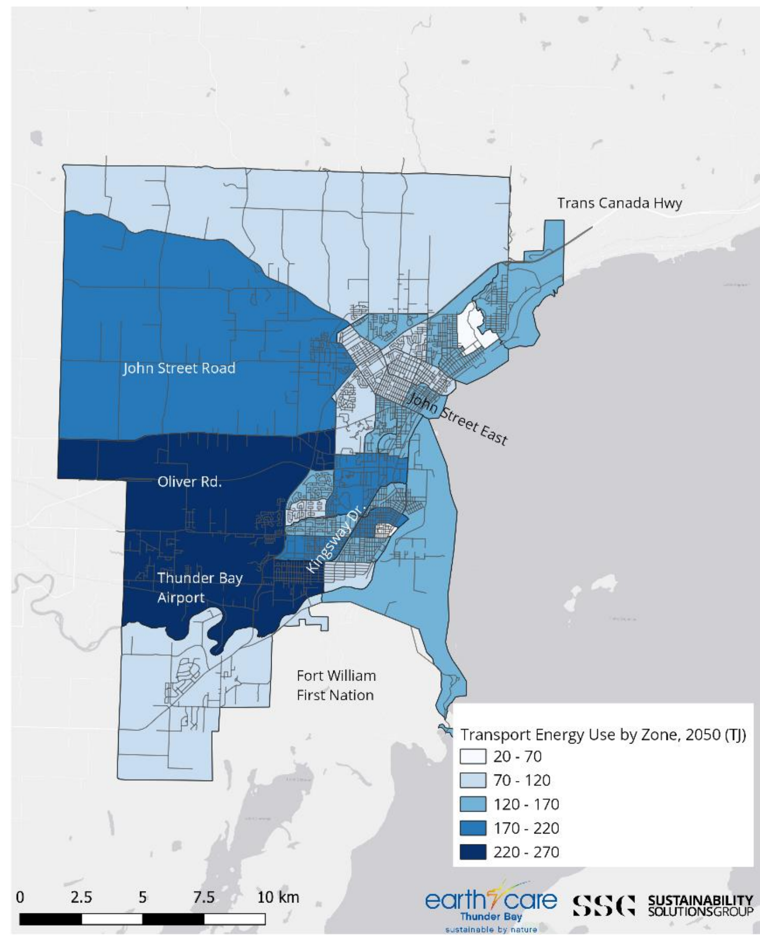


Figure 37: Transportation Energy Use, 2050

Appendix 3: Key BAP Assumptions

MODEL VARIABLE	ASSUMPTION	SOURCE	NOTES
ENERGY GENERATION			
Local energy generation			
Biomass	62.4 MW	Resolute Pulp & Paper	CHP. Owned by Resolute Pulp & Paper. Contracted from 2011-2021. Transmission Connected. Nameplate capacity of 62.4 MW, of which 40 MW is contracted to the OPA. CHP capacity is held constant to 2050.
Hydro	0 MW	IESO Contracted Renewable Generation list (as of September 2019)	Hydro capacity held constant to 2050.
Landfill gas	3.2 MW	IESO Contracted Renewable Generation list (as of September 2019)); City website	Landfill gas capacity held constant to 2050.
Anaerobic Digester methane	0.6 MW	Thunder Bay Wastewater Treatment (Annual Report) 2017-2018	Wastewater anaerobic digestion is used for process heat
Solar PV	1.57 MW	IESO Contracted Renewable Generation list (as of September 2019)	Solar capacity in 2016 is held constant to 2050.
Natural Gas	3 MW	Thunder Bay Regional Health Sciences Centre.	Cogeneration at hospital, held constant to 2050.
Energy Storage	n/a		No storage deployed.
TRANSPORTATION			
Transit			
Expansion of transit	Existing transit service unchanged 2016-2050; no expansion of transit assumed.	Thunder Bay Transit Master Plan (2019); EarthCare Sustainability Plan report (2014-2020)	No change in transit mode share assumed 2016-2050.
Electric vehicle transit	No electrification of the transit vehicle fleet assumed.	Corporate Energy Management Plan 2019-2024	No electrification of the transit vehicle fleet assumed 2016-2050.

Active			
Cycling & walking infrastructure	An increase of 1% from 2016 by 2020 (from 6-7%).	Census data; Thunder Bay Active Transport Plan (2019); EarthCare Sustainability Report (2017).	An increase of 1% from 2016 by 2020 (from 6-7%). Held constant to 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.	Vehicle kilometres travelled projections are driven by buildings projections. The number and location of dwellings and non-residential buildings over time in the BAP drive the total number of internal and external person trips. Person trips are converted to vehicle trips using the baseline vehicle occupancy. Vehicle kilometres travelled is calculated from vehicle trips using the baseline distances between zones and average external trip distances.
Vehicle fuel efficiencies	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.	Fuel efficiency standards are applied to all new vehicle stocks starting in 2016.
Vehicle share	Personal vehicle stock share changes between 2016-2050. Commercial vehicle stock unchanged 2016-2050.	CANSIM and Natural Resources Canada's Demand and Policy Analysis Division.	The total number of personal use and corporate vehicles is proportional to the projected number of households in the BAP.

Electric vehicles	14% new sales by 2030; share holds constant to 2050	Jonn Axsen, 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.
WASTE			
Waste generation	46,516 kg residential waste in 2017	Solid Waste Management Strategy (2014); EarthCare Sustainability Plan report (2017).	Waste generation per capita held constant from 2016-2050.
Waste diversion	27% waste diversion from landfill in 2018	Solid Waste Management Strategy (2014); EarthCare Sustainability Plan report (2017).	Waste diversion rates held constant from to 2050.
Waste treatment	Existing waste treatment processes unchanged.		No change in waste treatment processes assumed 2016-2050.
FINANCIAL			
Energy costs	Energy intensity costs by fuel increase incrementally between 2016-2050 per projections.	National Energy Board. (2019). Canada's Energy Future 2016.	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	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: Livestock	Varies per animal Type Kg CH4/ head Assume no change towards 2050 in livestock	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	Reflects development patterns by the City (2016-2050)	Census; 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)	Agricultural and land based emissions are calculated as change of activities, uses, and land over time. Land that is currently predominantly forested or agriculturally based and is projected to be developed will have population and floor space per person associated with it. Floorspace is assigned through building type (single detached, apartment, row, etc.), and the resulting net loss of open or undeveloped land results in a net increase in GHG emissions associated with that land.

Appendix 4: GPC Emissions Scope

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**	NR
I.5.2	2	Emissions from grid-supplied energy consumed within the city boundary	**No**	NR
I.5.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	**No**	NR
I.6		**Non-specified sources**		
I.6.1	1	Emissions from fuel combustion within the city boundary	**No**	NR
I.6.2	2	Emissions from grid-supplied energy consumed within the city boundary	**No**	NR
I.6.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	**No**	NR
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**	NR
I.8		**Fugitive emissions from oil and natural gas systems**		
I.8.1	1	Emissions from fugitive emissions within the city boundary	**Yes**	

II		**TRANSPORTATION**		
II.1		**On-road transportation**		
II.1.1	1	Emissions from fuel combustion for on-road transportation occurring within the city boundary	**Yes**	
II.1.2	2	Emissions from grid-supplied energy consumed within the city boundary for on-road transportation	**Yes**	

II.1.3	3	Emissions from portion of transboundary journeys occurring outside the city boundary, and transmission and distribution losses from grid-supplied energy consumption	**Yes**	
II.2		**Railways**		
II.2.1	1	Emissions from fuel combustion for railway transportation occurring within the city boundary	**No**	NR
II.2.2	2	Emissions from grid-supplied energy consumed within the city boundary for railways	**No**	NR
II.2.3	3	Emissions from portion of transboundary journeys occurring outside the city boundary, and transmission and distribution losses from grid-supplied energy consumption	**No**	NR
II.3		**Water-borne navigation**		
II.3.1	1	Emissions from fuel combustion for waterborne navigation occurring within the city boundary	**No**	N/A
II.3.2	2	Emissions from grid-supplied energy consumed within the city boundary for waterborne navigation	**No**	N/A
II.3.3	3	Emissions from portion of transboundary journeys occurring outside the city boundary, and transmission and distribution losses from grid-supplied energy consumption	**No**	N/A
II.4		**Aviation**		
II.4.1	1	Emissions from fuel combustion for aviation occurring within the city boundary	**No**	N/A
II.4.2	2	Emissions from grid-supplied energy consumed within the city boundary for aviation	**No**	N/A
II.4.3	3	Emissions from portion of transboundary journeys occurring outside the city boundary, and transmission and distribution losses from grid-supplied energy consumption	**No**	N/A
II.5		**Off-road**		
II.5.1	1	Emissions from fuel combustion for off-road transportation occurring within the city boundary	**No**	NR
II.5.2	2	Emissions from grid-supplied energy consumed within the city boundary for off-road transportation	**No**	NR

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**	N/A
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**	N/A
III.2.3	1	Emissions from waste generated outside the city boundary but treated biologically within the city boundary	**No**	N/A
III.3		**Incineration and open burning**		
III.3.1	1	Emissions from solid waste generated and treated within the city boundary	**No**	N/A
III.3.2	3	Emissions from solid waste generated within the city boundary but treated outside of the city boundary	**No**	N/A
III.3.3	1	Emissions from waste generated outside the city boundary but treated within the city boundary	**No**	N/A
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**	N/A

IV		**INDUSTRIAL PROCESSES AND PRODUCT USE (IPPU)**		
IV.1	1	Emissions from industrial processes occurring within the city boundary	**No**	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	**No**	NR
V.2	1	Emissions from land within the city boundary	**No**	NR
V.3	1	Emissions from aggregate sources and non-CO2 emission sources on land within the city boundary	**No**	NR

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

Reasons for	**N/A**	Not Applicable, or not included in
	ID	Insufficient Data
	NR	No Relevance, or limited activities
	Other	Reason provided in other comments

					in tonnes			
GPC ref No.	**Scope**	**GHG Emissions Source**	**Inclusion**	**Reason for exclusion (if applicable)**	**CO2**	**CH4**	**N2O**	**Total CO2e**
I		**STATIONARY ENERGY SOURCES**						
I.1		**Residential buildings**						
I.1.1	1	Emissions from fuel combustion within the city boundary	**Yes**		205,870	7,966	2,074	215,911
I.1.2	2	Emissions from grid-supplied energy consumed within the city boundary	**Yes**		10,117	98	86	10,302
I.1.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	**Yes**		953	9	8	970
I.2		**Commercial and institutional buildings/facilities**						
I.2.1	1	Emissions from fuel combustion within the city boundary	**Yes**		110,734	75	814	111,623
I.2.2	2	Emissions from grid-supplied energy consumed within the city boundary	**Yes**		8,314	81	71	8,466
I.2.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	**Yes**		783	8	7	797
I.3		**Manufacturing industry and construction**						
I.3.1	1	Emissions from fuel combustion within the city boundary	**Yes**		227,414	1,443	8,969	237,827
I.3.2	2	Emissions from grid-supplied energy consumed within the city boundary	**Yes**		11,521	112	98	11,731
I.3.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	**Yes**		1,085	11	9	1,105
I.4		**Energy industries**						
I.4.1	1	Emissions from energy used in power plant auxiliary operations within the city boundary	**No**	NR	6,070	4	32	6,106

I.4.2	2	Emissions from grid-supplied energy consumed in power plant auxiliary operations within the city boundary	**No**	NR	0	0	0	0
I.4.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption in power plant auxiliary operations	**No**	NR	0	0	0	0
I.4.4	1	Emissions from energy generation supplied to the grid	**No**	NR	0	0	0	0
I.5		**Agriculture, forestry and fishing activities**						
I.5.1	1	Emissions from fuel combustion within the city boundary	**No**	NR	0	0	0	0
I.5.2	2	Emissions from grid-supplied energy consumed within the city boundary	**No**	NR	0	0	0	0
I.5.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	**No**	NR	0	0	0	0
I.6		**Non-specified sources**						
I.6.1	1	Emissions from fuel combustion within the city boundary	**No**	NR	0	0	0	0
I.6.2	2	Emissions from grid-supplied energy consumed within the city boundary	**No**	NR	0	0	0	0
I.6.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	**No**	NR	0	0	0	0
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**	NR	0	0	0	0
I.8		**Fugitive emissions from oil and natural gas systems**						
I.8.1	1	Emissions from fugitive emissions within the city boundary	**Yes**		14	62,521	0	62,535
II		**TRANSPORTATION**						
II.1		**On-road transportation**						
II.1.1	1	Emissions from fuel combustion for on-road transportation occurring within the city boundary	**Yes**		283,792	529	1,926	286,247
II.1.2	2	Emissions from grid-supplied energy consumed within the city boundary for on-road transportation	**Yes**		1	0	0	1

II.1.3	3	Emissions from portion of transboundary journeys occurring outside the city boundary, and transmission and distribution losses from grid-supplied energy consumption	**Yes**		130,483	266	398	131,148
II.2		**Railways**						
II.2.1	1	Emissions from fuel combustion for railway transportation occurring within the city boundary	**No**	NR	10,069	19	1,227	11,315
II.2.2	2	Emissions from grid-supplied energy consumed within the city boundary for railways	**No**	NR	0	0	0	0
II.2.3	3	Emissions from portion of transboundary journeys occurring outside the city boundary, and transmission and distribution losses from grid-supplied energy consumption	**No**	NR	0	0	0	0
II.3		**Water-borne navigation**						
II.3.1	1	Emissions from fuel combustion for waterborne navigation occurring within the city boundary	**No**	N/A	161	0	20	181
II.3.2	2	Emissions from grid-supplied energy consumed within the city boundary for waterborne navigation	**No**	N/A	0	0	0	0
II.3.3	3	Emissions from portion of transboundary journeys occurring outside the city boundary, and transmission and distribution losses from grid-supplied energy consumption	**No**	N/A	0	0	0	0
II.4		**Aviation**						
II.4.1	1	Emissions from fuel combustion for aviation occurring within the city boundary	**No**	N/A	0	0	0	0
II.4.2	2	Emissions from grid-supplied energy consumed within the city boundary for aviation	**No**	N/A	0	0	0	0
II.4.3	3	Emissions from portion of transboundary journeys occurring outside the city boundary, and transmission and distribution losses from grid-supplied energy consumption	**No**	N/A	184	0	0	184
II.5		**Off-road**						
II.5.1	1	Emissions from fuel combustion for off-road transportation occurring within the city boundary	**No**	NR	68,882	912	6,003	75,797

II.5.2	2	Emissions from grid-supplied energy consumed within the city boundary for off-road transportation	**No**	NR	0	0	0	0
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**		0	44,971	0	44,971
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**		0	0	0	0
III.1.3	1	Emissions from waste generated outside the city boundary and disposed in landfills or open dumps within the city boundary	**No**	N/A	0	0	0	0
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**		0	534	351	885
III.2.2	3	Emissions from solid waste generated within the city boundary but treated biologically outside of the city boundary	**No**	N/A	0	0	0	0
III.2.3	1	Emissions from waste generated outside the city boundary but treated biologically within the city boundary	**No**	N/A	0	0	0	0
III.3		**Incineration and open burning**						
III.3.1	1	Emissions from solid waste generated and treated within the city boundary	**No**	N/A	0	0	0	0
III.3.2	3	Emissions from solid waste generated within the city boundary but treated outside of the city boundary	**No**	N/A	0	0	0	0
III.3.3	1	Emissions from waste generated outside the city boundary but treated within the city boundary	**No**	N/A	0	0	0	0
III.4		**Wastewater treatment and discharge**						
III.4.1	1	Emissions from wastewater generated and treated within the city boundary	**Yes**		0	1,361	333	1,695
III.4.2	3	Emissions from wastewater generated within the city boundary but treated outside of the city boundary	**No**	NR	0	0	0	0

III.4.3	1	Emissions from wastewater generated outside the city boundary	**No**	N/A	0	0	0	0
IV		**INDUSTRIAL PROCESSES AND PRODUCT USE (IPPU)**						
IV.1	1	Emissions from industrial processes occurring within the city boundary	**No**	ID	0	0	0	0
IV.2	1	Emissions from product use occurring within the city boundary	**No**	ID	0	0	0	0
V		**AGRICULTURE, FORESTRY AND LAND USE (AFOLU)**						
V.1	1	Emissions from livestock within the city boundary	**No**	NR	0	5,372	0	5,372
V.2	1	Emissions from land within the city boundary	**No**	NR	0	0	0	0
V.3	1	Emissions from aggregate sources and non-CO2 emission sources on land within the city boundary	**No**	NR	0	0	0	0
VI		**OTHER SCOPE 3**						
VI.1	3	Other Scope 3	**No**	N/A	0	0	0	0
							TOTAL	**1,225,169**