City of Spruce Grove

Climate Change Action Plan

GHG Emission Projections and Reduction Scenarios

Technical Report #2

31 December 2021

Prepared for:

City of Spruce Grove

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Important Abbreviations

The City	The City of Spruce Grove
CCAP	Climate Change Action Plan
GHG	Greenhouse gas
GWP	Global Warming Potential
ha	Hectare
t $C0_2e$	Tonnes of carbon dioxide equivalent
kt	Kilo-tonne (1,000 tonnes)
Mt	Mega-tonne (1,000,000 tonnes)
°C	Degrees Celsius

1 INTRODUCTION

Climate scientists agree that rapidly rising global temperatures have created a climate crisis. There is unequivocal evidence that the global climate system has warmed at an unprecedented rate since the pre-industrial era—from observations of rising air and sea surface temperatures globally and in Canada. Indeed, Canada has been warming at about double the global rate. The effects of this warming are already affecting many weather and climate extremes, such as heatwaves, heavy precipitation, droughts, etc. These trends will continue as some further warming is unavoidable until at least mid-century. The science is equally clear that most of the observed increase in temperatures is due to emissions of heat-trapping greenhouse gases (GHGs) from human activity and that continued emissions of GHGs will cause further warming and long-lasting changes in the climate system. Under a very high GHG emissions scenario (e.g., where few actions are taken to reduce global GHG emissions), global temperatures are very likely to rise by 3.3°C to 5.7°C above pre-industrial levels; even under an intermediate emission scenario, warming of 2.1°C to 3.5°C is very likely. At the same time, the climate science is unambiguous about the catastrophic and long-term, irreversible consequences for human and ecological systems of allowing global temperature to rise more than even 1.5°C above pre-industrial levels. Importantly, to limit future warming to 1.5°C and avoid the worst impacts of climate change, GHG emissions must be dramatically reduced in the coming decades—halved by 2030—with carbon neutrality achieved by mid-century.

Like many local governments in Canada and internationally, the City of Spruce Grove (the City) is taking steps to proactively address the climate change challenge by developing a comprehensive Climate Change Action Plan (CCAP). The CCAP is a 12-year guiding document that will outline feasible, effective and equitable actions to both reduce greenhouse gas (GHG) emissions which will contribute to the collective goal of limiting future global temperature increases, and to enhance community resilience and protect the local economy, environment and community from current and future climate-related impacts. The long-term goal is to ensure Spruce Grove remains a resilient, safe and attractive City to live, work and play, and that the City does its part to address global climate change.

This report is one of three technical reports that will inform the design of the CCAP. It presents the results of energy and GHG emission modelling for the City of Spruce Grove to:

- Construct a detailed “corporate” and “community” GHG emission inventory for 2020;
- Develop GHG emission projections (or the “Reference Case”) for the period 2020-2050;
- Create two GHG emission reduction scenarios for the period 2022-2050; and
- Define three, four-year carbon budgets commensurate with each emission reduction scenario, covering the 12-year life of the CAPP (2022-2033).

A separate technical report identifies and evaluates a range of actions to achieve the GHG emission reductions necessary to stay within the carbon budgets defined in this report.

2 GHG EMISSION PROJECTIONS

To effectively manage GHG emissions the City must first measure community-wide emissions. An accurate and reliable GHG inventory provides the foundations for developing a climate mitigation strategy. First, it enables the City to identify energy- and emission-intensive sources within the corporation and broader community. Second, it provides decision-makers at the City with a set of metrics upon which reduction targets and actions can be developed. Third, it provides the City and external stakeholders with baseline information against which the performance of actions and the emission reduction strategy can be tracked, evaluated and reviewed over time.

In this section, the methodology used: (a) to develop community-wide (i.e., inclusive of both corporate operations and services and the community as a whole) GHG emission projections for the period 2020-2050 and (b) to develop emission reduction scenarios, is first described. This is followed by a presentation of the results.

2.1 Methodology

Our approach to the energy and GHG emission modelling is described below with reference to panels (a) – (f) in Figure 1.

Step 1 (**panel a**) A GHG emission inventory, by source sector, activity (e.g., end-uses, such as space heating, driving light duty vehicles, etc.) and energy source (e.g., natural gas, electricity, gasoline, etc.) is generated for the 2020 base year. In total, nine emission source sectors are included in the modelling:

1. Residential buildings;
2. Commercial and institutional buildings;
3. Industry (construction and manufacturing);
4. Transportation;
5. Municipal solid waste;
6. Civic buildings and facilities;
7. Corporate fleet and equipment;
8. Water and wastewater; and
9. Streetlights and signs.

The “community” GHG inventory comprises the first five source sectors; the “corporate” GHG inventory comprises the last four source sectors.

At the most basic level, total GHG emissions from a source sector are given by the product, for a given activity indicator, of the energy intensity of that activity and the GHG intensity of the energy—summed over all fuels, end-uses and relevant activities. Where possible, Spruce Grove specific data is used; otherwise, default values for the City of Edmonton or Alberta are used. Appendix 1 contains the key modelling assumptions and data inputs.

Step 2 (**panel b**) Each determinant of 2020 GHG emissions is projected into the future, using a combination of the City of Spruce Growth's own growth forecasts (e.g., for population, homes and land absorption), projections obtained from the literature (e.g., energy price forecasts from the National Energy Board), and relationships derived from statistical (regression) analysis of relevant City of Edmonton and Alberta data (e.g., the relationship between demand for light-duty vehicles and the number of households). Projections of activity indicators are generated for the period 2020-2050, the last year of the projection period. All price projections are expressed in 2020 constant dollars.

Step 2 (**panel c**) The primary outcome of Step 2 is a **Reference Case** projection of GHG emissions for Spruce Grove covering the period 2020-2050, which is disaggregated by emission source sectors, relevant activities, corresponding end-uses, and energy sources.

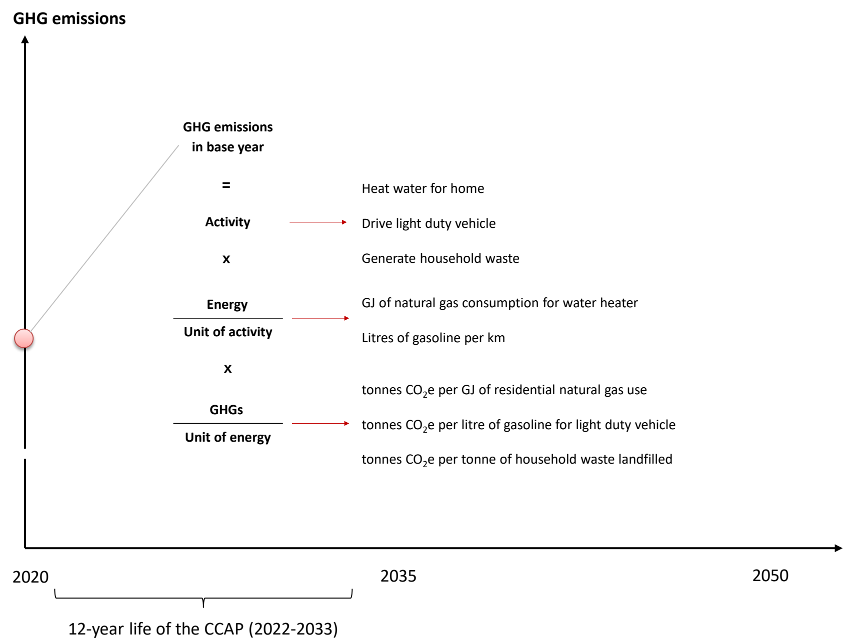
Step 3 (**panel d**) The third step involves defining an emission reduction scenario(s). Two GHG emission reduction scenarios are considered in this report—one more ambitious than the other. These emission reduction scenarios are described in more detail in Section 3. In short, a long-term per capita emissions target is set for the year 2050. A near-term per capita emissions target is then set for the year 2030, which falls within the lifetime of the current CCAP (2022-2033) and that sets Spruce Grove along a path to achieve the defined long-term target. A logistic curve is then fit between the 2020 base year and the near-term target for 2030 and then again linking the target for 2030 with the long-term target for 2050. These curves define the GHG emission reduction scenarios.

Step 4 (**panel e**) The required emission reductions needed to close the gap between the Reference Case and each emission reduction scenario are next calculated for each source sector, and relevant activities and energy sources. Annual and cumulative energy, GHG emissions, and energy costs savings are calculated.

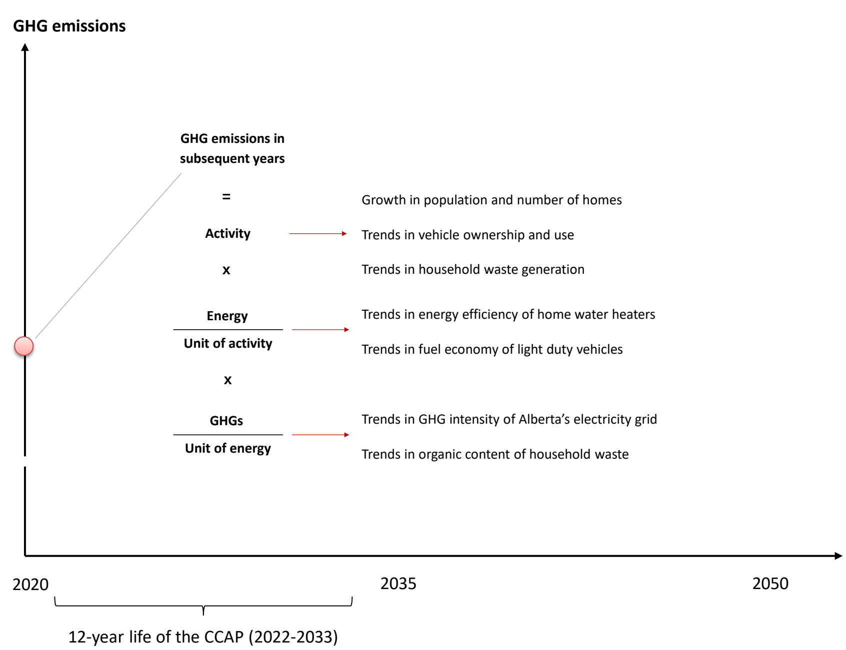
Step 5 (**panel f**) The final analytical step involves identifying projects, programs and policies—i.e., the 'actions'—to achieve the required GHG emission reductions from each source sector, starting in 2022 (the first year of the CCAP). A broad range of different actions are considered: actions to (1) reduce activities that generate GHG emissions, (2) improve the energy intensity of the activities, (3) switch to less GHG-intensive energy sources; and finally, (4) remove GHGs from the atmosphere. The identification, assessment and prioritization, and packaging of actions is not included in this report but is rather the focus of a third technical report.

Figure 1: Framework for modelling projected GHG emissions and reduction scenarios

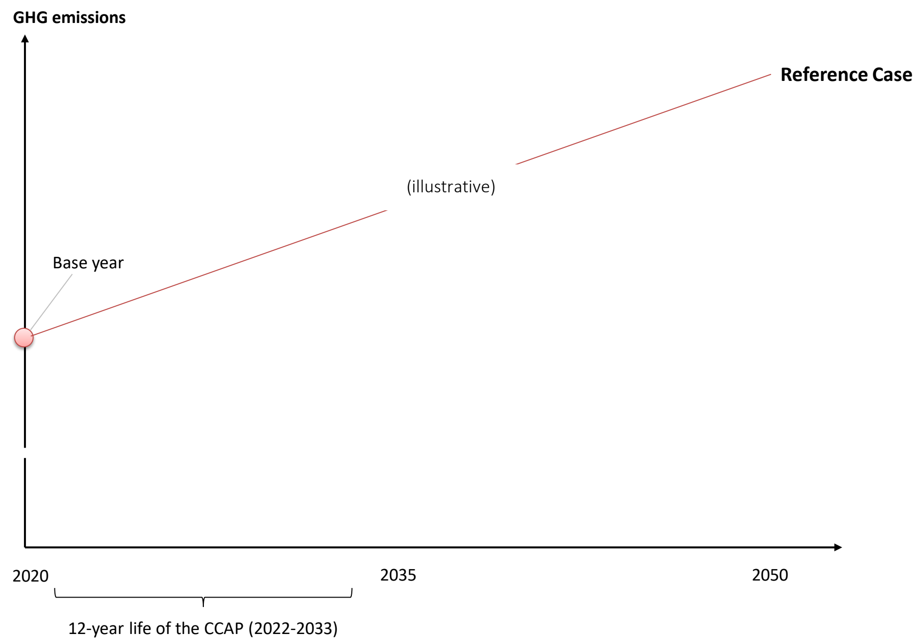
(a)



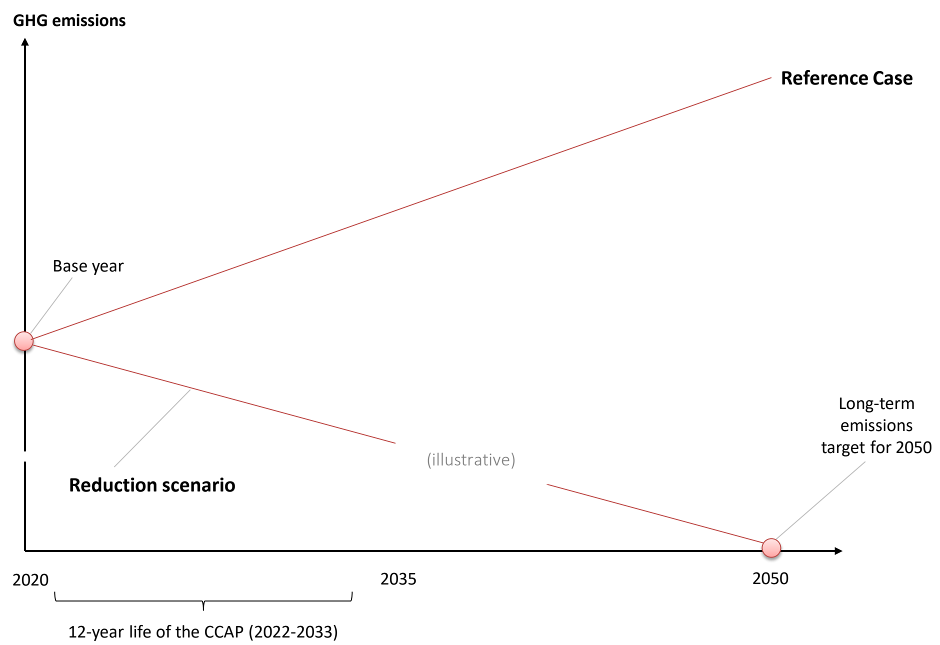
(b)



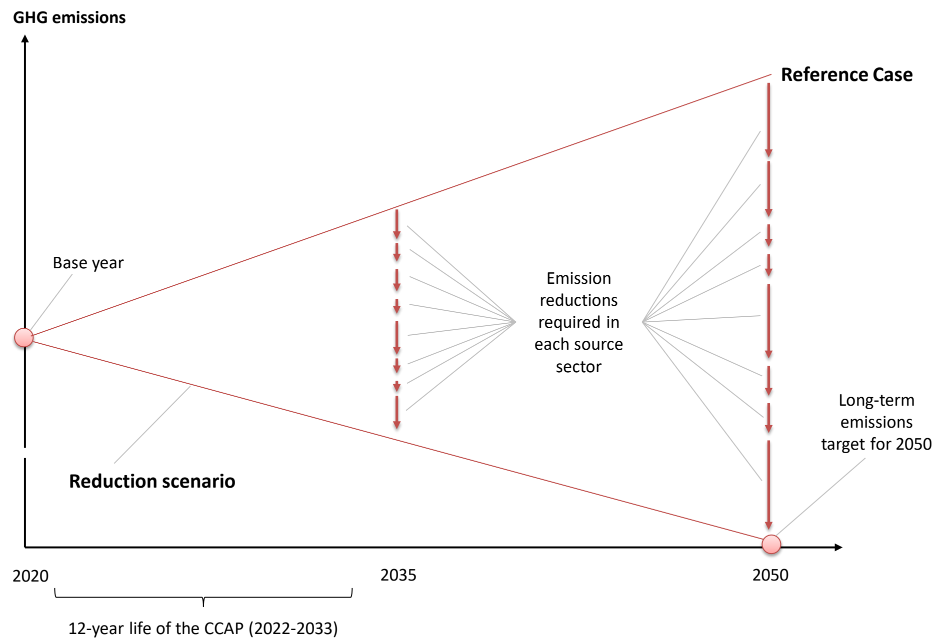
(c)


GHG emissions
Reference Case
(illustrative)
Base year
2020
2035
2050
12-year life of the CCAP (2022-2033)

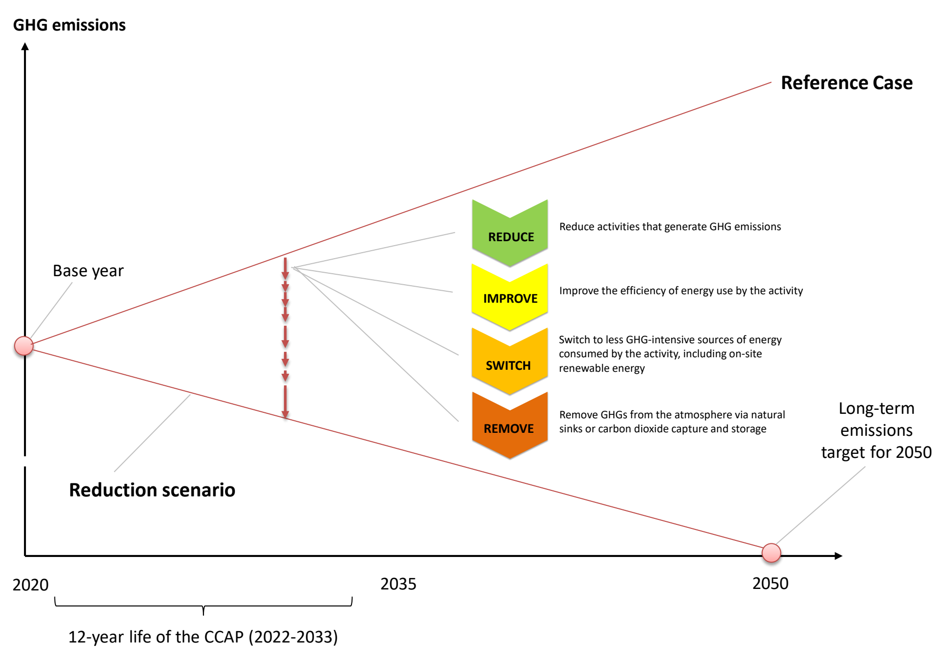
(d)


GHG emissions
Reference Case
Base year
Long-term emissions target for 2050
(illustrative)
Reduction scenario
2020
2035
2050
12-year life of the CCAP (2022-2033)

(e)


GHG emissions
Reference Case
Base year
Emission reductions required in each source sector
Long-term emissions target for 2050
Reduction scenario
2020
2035
2050
12-year life of the CCAP (2022-2033)

(f)


GHG emissions
Reference Case
REDUCE
Reduce activities that generate GHG emissions
IMPROVE
Improve the efficiency of energy use by the activity
SWITCH
Switch to less GHG-intensive sources of energy consumed by the activity, including on-site renewable energy
REMOVE
Remove GHGs from the atmosphere via natural sinks or carbon dioxide capture and storage
Base year
Long-term emissions target for 2050
Reduction scenario
2020
2035
2050
12-year life of the CCAP (2022-2033)

2.2 Projected GHG emissions under the Reference Case

For context: the City completed its first GHG emissions inventory in 1996. At that time, total emissions amounted to 271.5 kt CO_2e or 19.2 t CO_2e per person. By 2019, total emissions had risen to 449.6 kt CO_2e, though emission per person had reduced to 12.1 t CO_2e. Only 1.8% of total emissions in 2019 were sourced from corporate operations and services; 98.2% originated from community sources. Projected GHG emissions for the period 2020-2050 by source sector, activity and fuel are presented below. The last GHG inventory for Spruce Grove was prepared for 2019; hence, the first year of the projection period is 2020.

2.2.1 City-level projections

Projected city-wide GHG emissions under the Reference Case for 2020 and 2050 are shown in Figure 2; first by source sector, and second, by energy source. Detailed tables are provided in Appendix 2. Estimated total emissions for 2020 amount to 458.3 kt CO_2e, which is equivalent to 12.0 t CO_2e per person. By 2050, total emissions are projected to rise by about 39%, to 635.2 kt CO_2e. This equates to about 8.6 t CO_2e per person. In both years the largest source of GHG emissions is road transportation, followed by residential buildings. Institutional and commercial (C&I) buildings' share of total emissions increases significantly over the projection period; this is largely due to relatively large projected increases in C&I floorspace, which are sufficient to offset any expected energy efficiency improvements in buildings.

Given road transportation's share of overall emissions it is unsurprising to see road fuels (and in particular, gasoline) account for the largest proportion of total emissions in both 2020 and 2050. Of the main energy sources for buildings, electricity's share of total emissions falls by about five percentage points between 2020 and 2050, in turn, increasing natural gas' share. This is primarily due to improvements in the GHG intensity of the provincial grid.

In 2020, total energy costs across all emission source sectors are estimated at $117.5 million (2020 dollars) (see Figure 3). By 2050, total energy costs are projected to rise to $217.3 million. This increase is due to both increased energy consumption over the projection period and real terms increases in energy prices. Road fuels account for just over 70% of total energy costs in 2020. Of the energy sources included in the modelling, road fuels have the highest price on an energy basis. When combined with road transportation's relatively large share of total emission, this explains its high share of total energy costs. By the end of the projection period, road transportation's share of total energy costs has fallen to 55%. In contrast, electricity's contribution to total costs moved significantly in the opposite direction; rising from 14% in 2020 to 27% in 2050.

Over the entire projection period 2020-2050, cumulative energy costs across all source sectors included in the inventory amount to $5.8 billion (2020 dollars, undiscounted). On average over the projection period, that equates to about $3,365 per person per year (2020 dollars). The current value of estimated cumulative energy costs is $3.7 billion (2020 dollars, discounted at a real annual rate of 3.5%). A conservative estimate of economic damages, in dollar terms, resulting from projected emissions of GHGs under the Reference Case was made using published values for the Social Cost of Carbon (see Box 1).

Cumulative economic damages associated with projected GHG emissions amount to $1.0 billion (2020 dollars, undiscounted); the same damages stated in present value terms are about $0.6 billion (2020 dollars, discounted at a real annual rate of 3.5%).

Figure 2: Projected city-wide GHG emissions under the Reference Case for 2020 and 2050, by source sector and by energy source

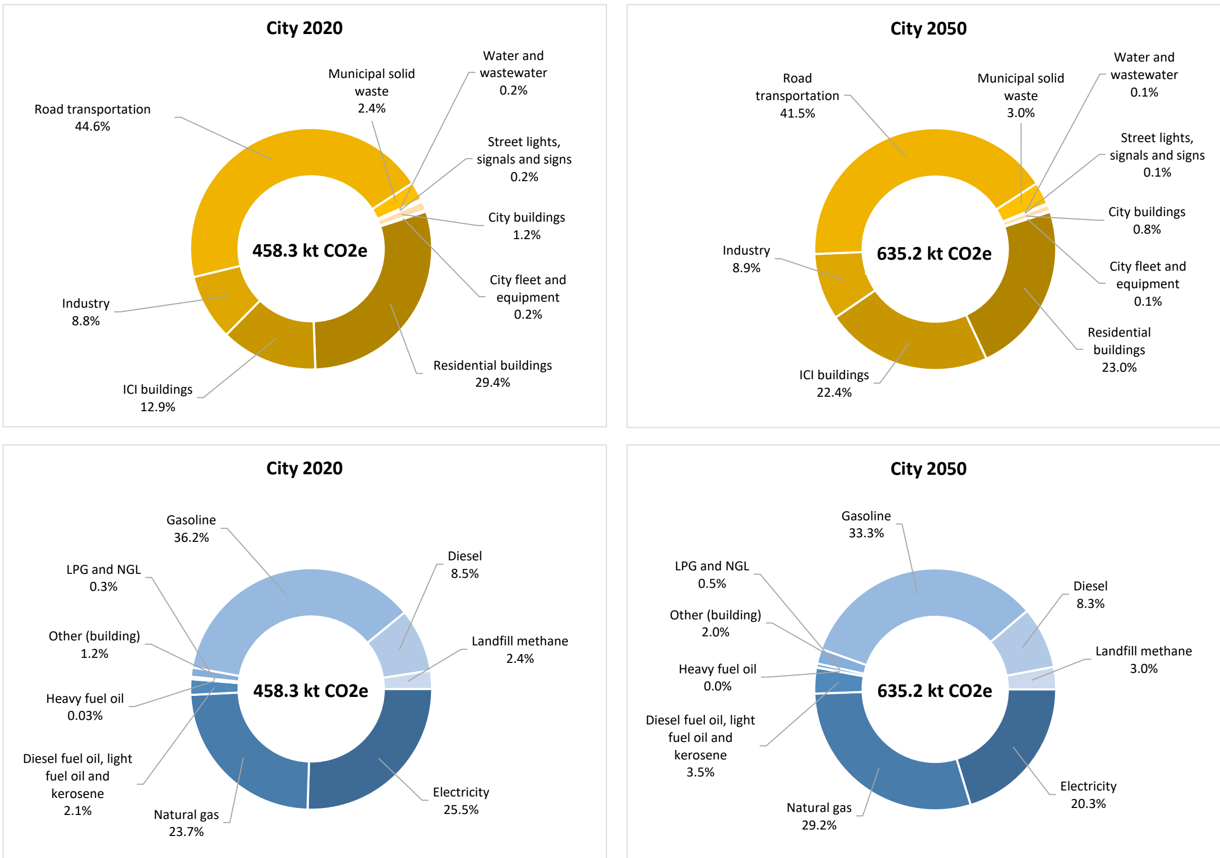
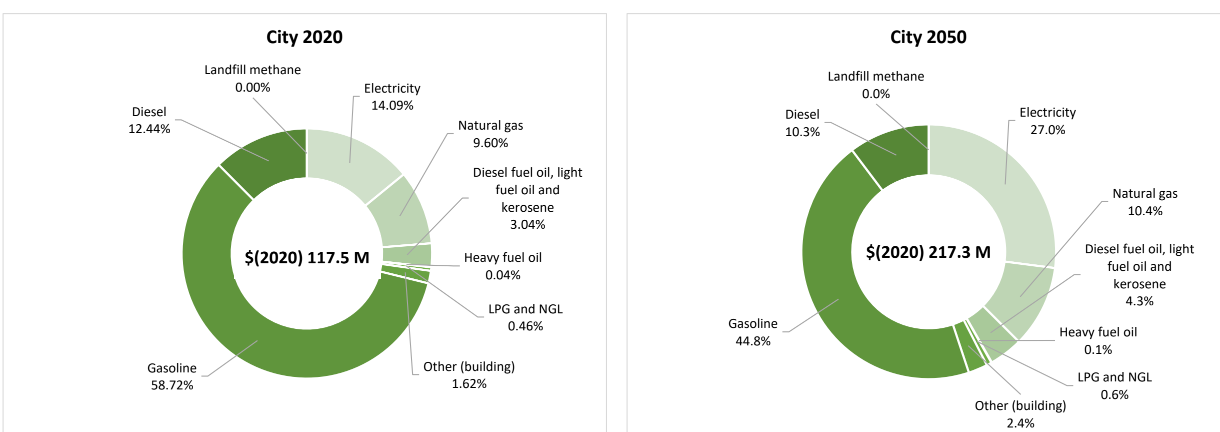


Figure 3: Projected annual city-wide energy costs under the Reference Case for 2020 and 2050, by energy source

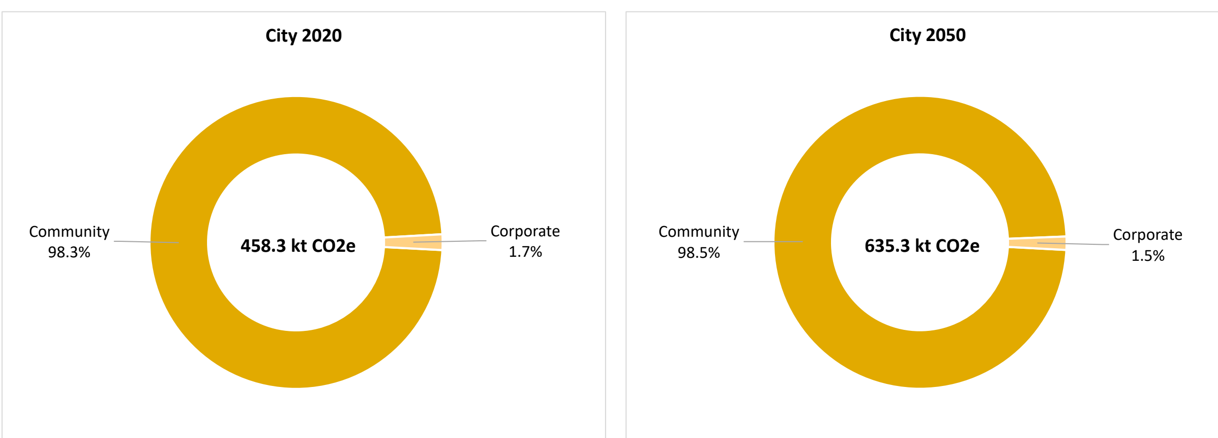


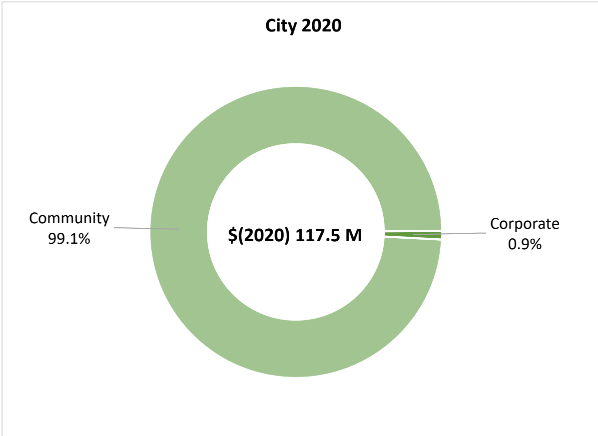
Box 1: Valuing the economic damage costs of GHG emissions

The social cost of carbon (SCC) is used in economic analyses of climate mitigation policy to estimate, in dollar terms, the tangible (market) and intangible (non-market) benefits of GHG emission reductions. Conversely, it can be used to used to estimate the economic damages that would result from activities that increase emissions of GHGs to the atmosphere. It is a measure of the expected net damages associated with global climate change that results from the release of an additional tonne of carbon dioxide (CO_2) to the atmosphere. It is intended to capture the monetized value of net impacts—negative and positive—from, among other things, changes to agricultural productivity, human health, property damage from flooding, and the loss of ecosystem services because of climate change. The SCC is usually calculated as the net present value of the difference between economic costs under a baseline climate and socioeconomic scenario and the economic costs of the same scenario with an additional incremental pulse of CO_2 emissions. It is typically calculated using global Integrated Assessment Models (IAMs), which combine climate processes and economic growth into a single model. A recent estimate of the SCC from the US Government is USD $51 per t CO_2 (2020 dollars) emitted in 2020. Further information can be found in Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide, Interim Estimates under Executive Order 13990, Interagency Working Group on Social Cost of Greenhouse Gases, United States Government, February 2021.

Figure 4 shows the breakdown of total city-level GHG emissions and energy costs under the Reference Case between the “corporation” and the “community”. In both 2020 and 2050—and over the entire projection period—the community accounts for more than 98% of total GHG emissions. Furthermore, the community’s share is increasing ever so slightly over time—primarily due to growth in emissions from C&I buildings. Similarly, the community accounts for just over 99% of total energy costs over the entire projection period, with no change in share between 2020 and 2050.

Figure 4: Projected city-wide GHG emissions and energy costs under the Reference Case for 2020 and 2050, allocated to corporate operations and services and the community





2.2.2 Corporate projections

Projected corporate GHG emissions under the Reference Case for 2020 and 2050 are shown in Figure 5, by source sector. Estimated total emissions for 2020 amount to 7.9 kt CO_2e. By 2050, total emissions are projected to fall slightly by about 7%, to 7.4 kt CO_2e. The decrease in emissions is primarily a result of improvements in the GHG intensity of the provincial electricity grid, combined with assumptions that the City's buildings, facilities, fleet and equipment remain static at 2020 levels, with the exception of the planned Civic Centre, which is assumed to be operational by 1 January 2025. In both 2020 and 2050 the largest source of GHG emissions is civic buildings and facilities (about 69%-72% of total corporate emissions), followed by the corporate fleet and equipment (about 11%-12%). The Agrena accounts for 36% of total emissions from civic buildings and facilities in 2020 and 23% of total corporate emissions; Figure 6 shows the contribution of each asset to total GHG emissions from buildings and facilities in both 2020 and 2050. The new Civic Centre is assumed to have a larger carbon footprint than the Agrena, when it becomes operational in 2025. The largest source of GHG emissions from the corporate fleet is "tractors and agricultural equipment", followed by "off-road and construction" vehicles (see Figure 7).

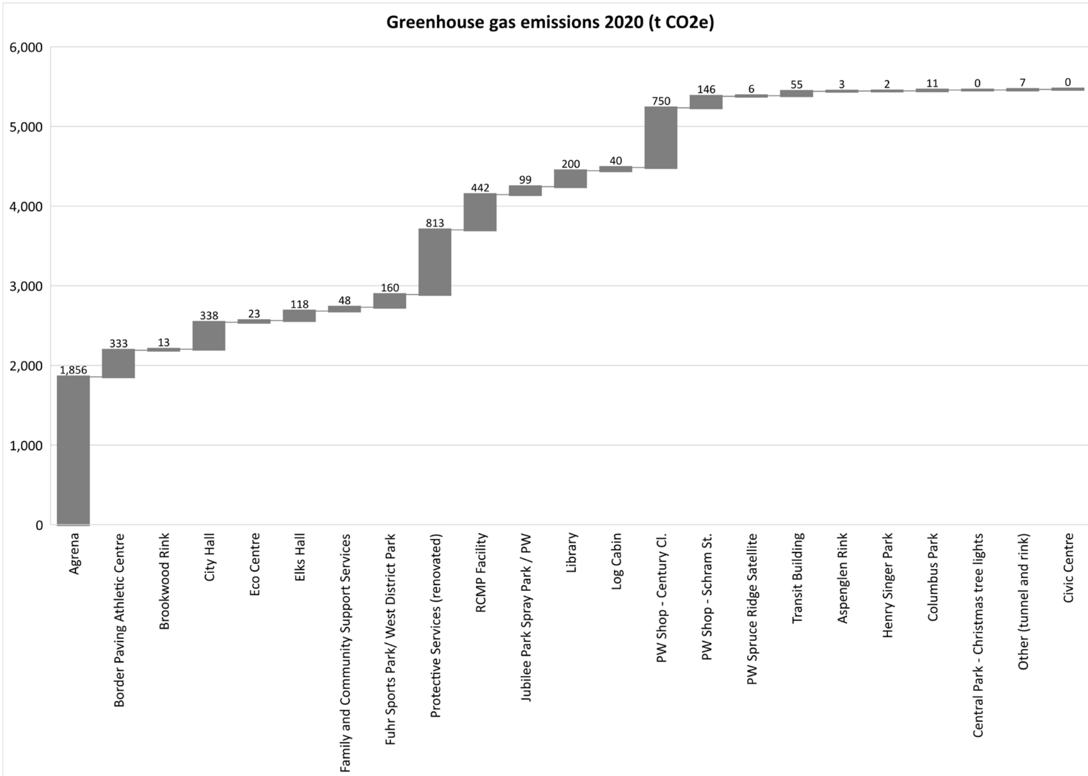
By 2050, civic buildings and facilities' share of total corporate emissions increases slightly relative to 2020 due to the commissioning of the new Civic Centre in 2025. The contribution of water and wastewater and streetlights, signals and signs to total corporate emissions declines over time—since electricity is the predominant fuel for these energy source and given the anticipated improvements in the GHG intensity of the provincial grid.

In 2020, total energy costs across all corporate emission sources are estimated at $1.1 million (2020 dollars). By 2050, total energy costs are projected to rise to $2.0 million. This increase is mainly due to real term increases in energy prices, since energy consumption is fairly flat over time. Reflecting their significant share of total energy consumption and GHG emissions, civic buildings and facilities account for the largest proportion of total energy costs; about 51% in 2020, rising to 59% in 2050. Corporate fleet's contribution to total energy costs is considerable higher than its contribution to total GHG emissions due to the relatively high price of road fuels (on an energy basis) compared with other energy sources consumed by corporate activities.

Over the entire projection period 2020-2050, cumulative energy costs across all corporate source sectors included in the inventory amount to $53.9 million (2020 dollars, undiscounted). The same costs stated in present value terms are $34.8 million (2020 dollars, discounted at a real annual rate of 3.5%).

Figure 5: Projected corporate GHG emissions and energy costs under the Reference Case for 2020 and 2050, by source sector

Figure 6: Projected corporate GHG emissions under the Reference Case for 2020 and 2050, by building and facility



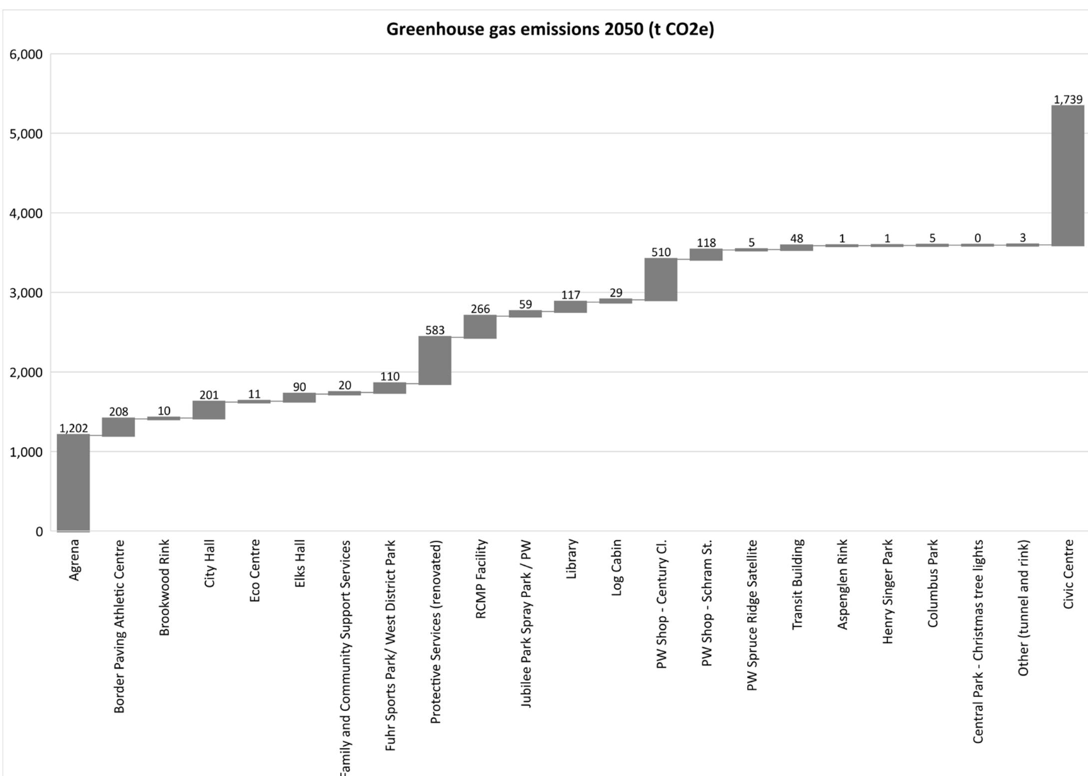
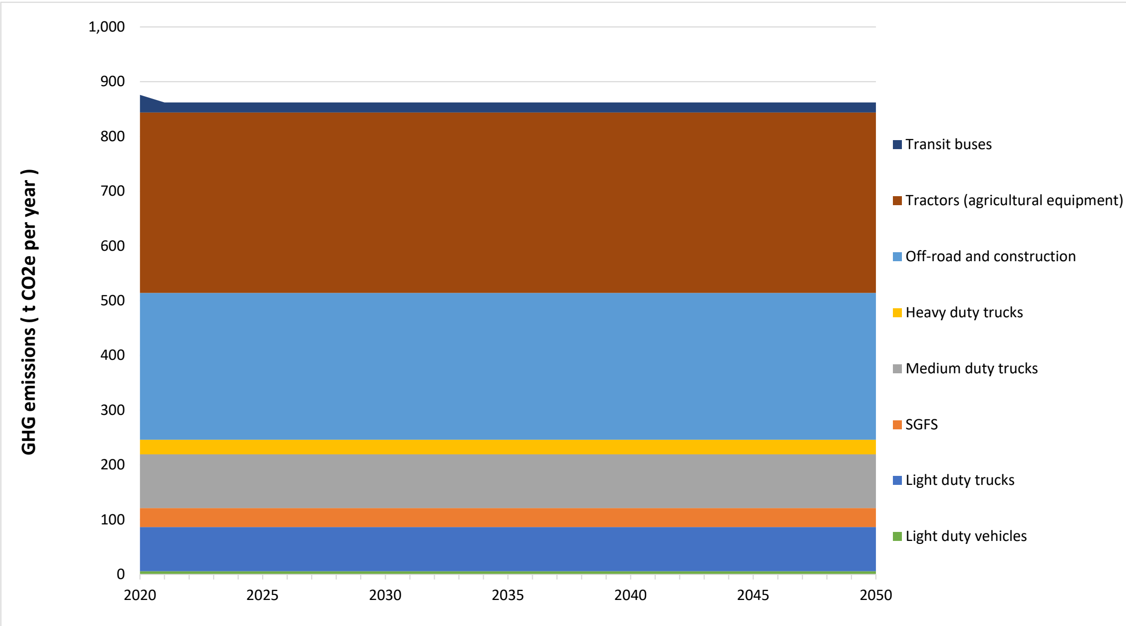


Figure 7: Projected corporate fleet and equipment GHG emissions under the Reference Case for the period 2020-2050, by vehicle type



2.2.3 Community projections

Projected community GHG emissions under the Reference Case for 2020 and 2050 are shown in Figure 8, by source sector. Estimated total emissions for 2020 amount to 450.4 kt CO_2e. By 2050, total emissions are projected to increase by just over 39%, to 627.9 kt CO_2e. This increase is largely due to growth in emission sources—the number of homes, commercial buildings, motor vehicles, etc.—which are not offset by energy efficiency and fuel economy improvements over time. In both 2020 and 2050 the largest source of GHG emissions is road transportation (about 42%-45% of total community emissions), followed by residential buildings (about 23%-30%). By 2050, commercial and institutional (C&I) buildings also account for 23% of total community emissions. As noted above, this is due to large projected increases in C&I floorspace (+177% between 2020 and 2050) relative to residential buildings (+109%). Individual community emission sources are explored in further detail below.

In 2020, total energy costs across all community emission sources are estimated at $116.4 million (2020 dollars). By 2050, total energy costs are projected to rise to $215.4 million. As explained above, this increase is due to a combination of growth in emission sources and energy consumption over the projection period, as well as real terms increases in energy prices. Road fuels account for nearly 72% of total energy costs in 2020. By the end of the projection period, however, road transportation's share of total energy costs has fallen to just over 55%. In contrast, the contribution of C&I buildings to total community energy costs is projected to increase threefold between 2020 and 2050.

Over the entire projection period 2020-2050, cumulative energy costs across all community source sectors included in the inventory amount to $5.7 billion (2020 dollars, undiscounted). The same costs, stated in present value terms, just under \$3.7 billion (2020 dollars, discounted at a real annual rate of 3.5%).

Figure 8: Projected community GHG emissions and energy costs under the Reference Case for 2020 and 2050, by source sector

Notes: Emissions from municipal solid waste disposal are based on a GWP of 25 for CH_4, as per the PCP Protocol used by the City of Spruce Grove and hence for this project (see Table 11 in Appendix 2). However, the GWP for CH_4 was updated in the IPCC's Fifth Assessment report to a value of 28. This has implications for estimated emissions from waste disposal at landfill; emissions in 2020 increase from 10,880 t CO_2e to 12,184 t CO_2e and in 2050 emissions increase from 19,000 t CO_2e to 21,280 t CO_2e. As a result, the disposal of municipal solid waste would now account for 2.8% and 3.4% of total community GHG emissions in 2020 and 2050, respectively.

2.2.3.1 Road transportation

Projected road transportation GHG emissions under the Reference Case for 2020 and 2050 are summarised in Appendix 3. Estimated total emissions for 2020 amount to 204.4 kt CO2e. By 2050, total emissions are projected to increase by about 29%, to 263.6 kt CO2e. No single vehicle type has a dominant share of total emissions in either 2020 or 2050. However, the contribution of "medium trucks" to total road transportation emissions is anticipated to increase from 25% in 2020 to nearly 36% by 2050. Extrapolating historical trends, the registration of medium trucks in Spruce Grove is projected to increase at an average annual rate of 4.8%, which is significantly higher than the other vehicle types.

By far, the vast majority of projected GHG emissions result from the consumption of gasoline; accounting for 80%-81% of total road transportation emissions in 2020 and 2050. Electricity accounts for less than one percent of total GHG emissions in 2050 under the Reference Case. This is because plug-in hybrid and battery electric vehicles account for only 0.7% of total registered light duty vehicles (passenger cars, SUVs and station wagons) in Spruce Grove in 2019. So, even with an assumed increase of 2.3% per year, on average, over the projection period, these vehicles still only account for a relatively small share of total vehicles by 2050.

Over the entire projection period 2020-2050, cumulative energy costs for road transportation amount to $3.7 billion (2020 dollars, undiscounted). The current value of estimated cumulative energy costs is just under $2.5 billion (2020 dollars, discounted at a real annual rate of 3.5%). Over 80% of these costs are attributable to the consumption of gasoline.

It should be noted that GHG emissions from road transportation are estimated using a bottom-up approach with detailed activity data, as opposed to a top-down approach that uses fuel sales within the City boundary as a proxy for driving behaviour. Specifically, a variation of the "resident activity method" is used, in which only emissions from transportation activities undertaken by vehicles registered in the City are included, as well as grid-supplied electricity for plug-in hybrids and electric vehicles. There are two limitations with this approach:

1. First, transport activity by "non-residents", that originates outside the City but ends at destinations within the City, is excluded. This omission will lead to an underestimation of road transportation emissions induced by Spruce Grove.
2. Second, not all trips that originate in the City are fully contained within the City's boundaries; a portion of total vehicle kilometres travelled by vehicles registered in Spruce Grove will be for transboundary trips to outside the City. This omission will lead to an overestimation of road transportation emissions induced by Spruce Grove.

The net effect of these two limitations on projected GHG emissions from road transportation is indeterminant, in the absence of origin-destination survey data for Spruce Grove.[1]

2.2.3.2 Residential buildings

Projected GHG emissions from residential buildings under the Reference Case for 2020 and 2050 are summarised in Appendix 4. Estimated total emissions for 2020 amount to 134.9 kt CO2e. By 2050, total emissions are projected to increase by about 8.5%, to 146.3 kt CO2e. Single-family detached dwellings account for about 70% of total residential sector emissions in both 2020 and 2050. Single-family attached dwellings account for a further 17% and 15% in 2020 and 2050, respectively. In terms of end-use activities, the majority of GHG emissions from residential buildings result from space heating, which contributes 52% and 60% of total emissions in, respectively, 2020 and 2050. In 2020, the second largest

[1] The Global Protocol for Community-Scale Greenhouse Gas Emission Inventories recommends that all road transportation emissions induced by a city are included where feasible and calculated as follows: total GHG emissions = 100% of in-boundary trips + 100% of grid-supplied electricity used for electric-powered vehicles + 50% of transboundary trips that originate or terminate within the city boundaries (the other 50% is allocated to the origin / destination city). As an example of what an origin-destination survey reveals, the 2019 Vancouver Panel Survey finds that 8.8% of all trips recorded within the City of Vancouver are transboundary inbound, whereas 9.1% of all trips are transboundary outbound, with 78.4% of trips beginning and ending in Vancouver and the remaining 3.7% neither originating nor terminating within the city.

source of GHG emissions is appliances (with a 24% share). However, by 2050 appliances account for only 15% of total emissions from homes, with water heating now accounting for 19%; up from 16% in 2020. In general, emissions from end-use activities that primarily consume electricity—like appliances—decline over time, other things being equal, because of anticipated improvements in the GHG intensity of the provincial grid. The contribution of end-use activities that largely consume natural gas or other fuels (e.g., propane), in contrast, increases over time. Indeed, natural gas and electricity account for 55% and 43% of total residential GHG emissions in 2020, respectively; but by 2050, the contributions have changed to 65% (natural gas) and 33% (electricity).

In 2020, energy costs for the residential sector are estimated at $20.3 million (2020 dollars). By 2050, energy costs are anticipated to rise to $42.8 million. Over the entire projection period 2020-2050, cumulative energy costs for residential buildings amount to $1.0 billion (2020 dollars, undiscounted). The same costs, stated in present value terms, are just under $650 million (2020 dollars, discounted at a real annual rate of 3.5%).

2.2.3.3 Commercial and institutional buildings

Projected GHG emissions from commercial and institutional (C&I) buildings under the Reference Case for 2020 and 2050 are summarised in Appendix 5. Estimated total emissions for 2020 amount to 59.3 kt CO2e. By 2050, total emissions are projected to increase by about 140%, to 142.2 kt CO2e. As noted above, this large increase in emissions is due to substantial growth in floorspace (based on historical trends) that is not compensated for through improvements in the energy efficiency of the building stock. Retail trade accounts for the largest share of total emissions from C&I buildings in 2020; accounting for 50% of total emissions. While retail trade remains the dominant source of emissions by 2050, its share of total emissions from C&I buildings falls to 28%, with offices now accounting for 24% of emissions, up from 5% in 2020. By 2050, buildings in the healthcare and social assistance sector are anticipated to account for nearly 15% of total GHG emissions from C&I buildings, up from 7% in 2020. In terms of end-use activities, the majority of GHG emissions from C&I buildings result from space heating, which contributes 37% and 43% of total emissions in, respectively, 2020 and 2050. In 2020, the second largest source of GHG emissions is auxiliary equipment (with a 24% share). By 2050, auxiliary equipment is projected to account for 39% of total emissions from C&I buildings. This is due to assumed increases in the energy intensity of this end-use; based on extrapolation of historical trends, energy consumption for auxiliary equipment is anticipated to grow at an annual average rate of 7.6%, which is double the rate for any other end-use activity.

Given the mix of electricity-intensive end-use activities in C&I buildings, it is not surprising that electricity consumption is the largest source of GHG emissions in both 2020 (61% of total emissions) and 2050 (50%). Despite the fact that electricity's share of total energy use increases from 32% in 2020 to 42% in 2050, its contribution to total GHG emissions falls due to the improvements in the GHG intensity of the provincial grid.

In 2020, energy costs for the C&I sector are estimated at $6.5 million (2020 dollars). By 2050, energy costs are anticipated to rise to $38.2 million. The shares of these costs by economic sector, closely reflects their share of total GHG emissions, with retail trade accounting for the largest proportion of total energy costs; 50% in 2020 and 27% in 2050. Over the entire projection period 2020-2050, cumulative energy costs for C&I buildings amount to $623 million (2020 dollars, undiscounted). The same costs, stated in present value terms, are just under $362 million (2020 dollars, discounted at a real annual rate of 3.5%).

2.2.3.4 Industry

Projected GHG emissions from industry—specifically, the construction and manufacturing sectors—under the Reference Case for 2020 and 2050 are summarised in Appendix 6. Estimated total emissions for 2020 amount to 40.5 kt CO2e. By 2050, total emissions are projected to increase by about 40%, to 56.7 kt CO2e. This increase is a result of projected (employment) growth in both sectors, which is not offset by anticipated improvements in the energy intensity of employment based on an extrapolation of historical trends. In 2020, nearly half of total industry GHG emissions result from the consumption of electricity (about 46%). But, by 2050, most emissions result from the consumption of natural gas (with a 43% share of total emissions) and light fuel oils, diesel and kerosene (with a 39% share of the total).

In 2020, energy costs for the industrial sector are estimated at $6.3 million (2020 dollars). By 2050, energy costs are anticipated to rise to $14.8 million. In both periods, the consumption of light fuel oils, diesel and kerosene is by far the largest source of energy costs; accounting for 57% and 63% of total costs in, respectively, 2020 and 2050. Over the entire projection period 2020-2050, cumulative energy costs for industry amount to $357 million (2020 dollars, undiscounted). The same costs, stated in present value terms, are just under $225 million (2020 dollars, discounted at a real annual rate of 3.5%).

3 GHG REDUCTION SCENARIOS

After generating a community-wide GHG inventory for the 2020 base year and developing a scenario for future emissions based on projected growth and the extrapolation of past trends, the City now has a "Reference Case" to serve as a basis for setting science-based targets and identifying actions to achieve these targets and for monitoring progress. The Reference Case, or projected baseline, is a "zero-action" scenario that aims to characterize future emissions from Spruce Grove assuming no additional climate mitigation actions are taken. The scenario includes an assumption that energy efficiency in homes, businesses and transportation will improve at the same rate as they have improved historically. The Reference Case not only provides insight into the scale of the emissions reduction challenge at hand, but also helps decision-makers understand the contribution of different activities (emission sources) and determine where best to focus the City's mitigation efforts.

In this section, existing emission reduction commitments made by the City are first introduced, before developing two alternative science-based emission reduction scenarios or pathways, with interim and long-term targets. For each scenario, the volume of emission savings is presented. For both emission reduction scenarios, the corresponding carbon budgets are then calculated of the life of the CCAP (2022-2034).

3.1 Past and current commitments

The City completed its first GHG emissions inventory in 1996, prior to joining the Partners for Climate Protection Program (PCP). When it joined the program in 2003, it set targets to reduce corporate GHG emissions to 20% below 1996 levels by 2013 and community GHG emissions to 6% below 1996 levels by 2013. However, since 2003, the city's population more than doubled. This created challenges to reducing GHG emissions. As a result, despite declines in energy use and GHG emissions per person, the City failed to achieve the 2013 targets, which were defined in absolute terms.

In 2016, as part of a long-term plan to reduce GHG emissions, the City's "Energy Management Plan and GHG Reduction Strategy" set updated targets for energy consumption and GHG emissions:

Energy use:

- Reduce *corporate* energy use per capita to 40% below 2015 levels by 2035.
- Reduce *community* energy use per capita to 25% below 2015 levels by 2035.

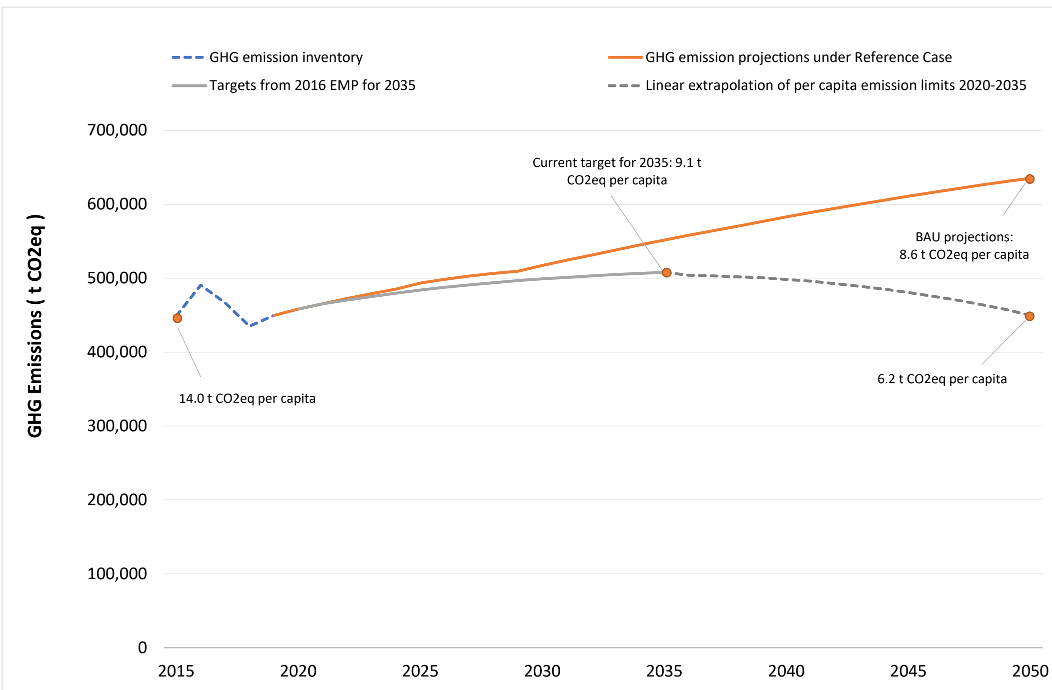
GHG Emissions:

- Reduce *corporate* GHG emissions per capita to 50% below 2015 levels by 2035.
- Reduce *community* GHG emissions per capita by 35% below 2015 levels by 2035.

Figure 9 plots the projected Reference Case for Spruce Grove (solid orange line) and a scenario that achieves the combined corporate and community GHG emission reduction targets for 2035 contained in the 2016 EMP (solid grey line). In 2015, total community-wide emissions amounted to 14.0 t CO_2e per person. The combined target for 2035 equates to an emission limit for 2035 of about 9.1 t CO_2e per person. This corresponds to a reduction of about 43.7 kt CO_2e (or 8%) relative to the Reference Case projection for 2035. Linear extrapolation of the required decline in per person emissions over the period 2020-2035 through to 2050 results in an emission limit of 6.2 t CO_2e per person in that year (shown as the dashed grey line). Relative to the Reference Case projection for 2050, this represents a reduction of about 185.8 kt CO_2e (or 29%). However, relative to base year emission in 2020, it only results in reductions of 8.8 kt CO_2e (or 2%).

Overall, the emissions reduction scenario based on achievement and extrapolation of current commitments for 2035 (shown by the solid and dashed grey lines in Figure 9), results in cumulative savings of about 1,985 kt CO_2e relative to the Reference Case over the period 2020-2050. Cumulative residual emissions (i.e., the area under the grey lines in Figure 9) over the projection period amount to about 15,090 kt CO_2e.

Figure 9: Reference Case and combined 2035 GHG emission reduction target from the 2016 EMP



3.2 Public views on stringency of GHG emission reduction targets

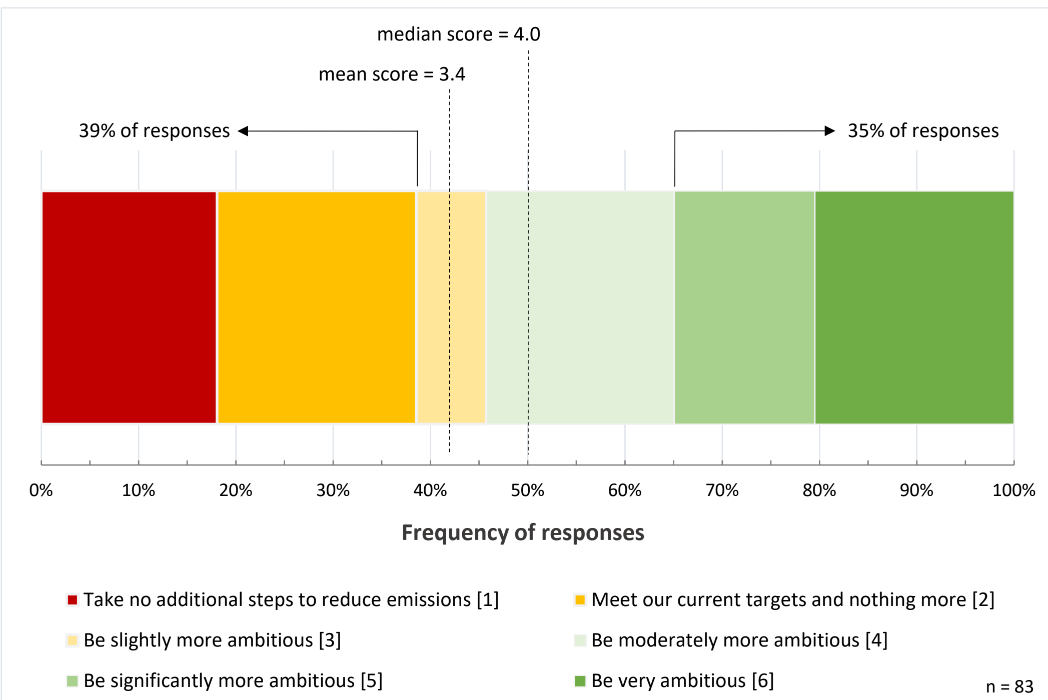
As part of the engagement plan to inform the CCAP, an online survey was designed and made open to the public from May 10 to June 8, 2021. The survey was advertised on the Spruce Grove Connect website, on Spruce Grove social media, and in the local newspaper. A total of 22 questions were asked in this initial survey; some relating to climate adaptation, some relating to climate mitigation, as well as some demographic questions to help characterize the respondents. One question sought to elicit views on the level of ambition the City should strive for when setting GHG emissions reduction targets. Specifically, the public was asked:

As part of the CCAP, the City is updating its GHG emission reduction targets. Looking at the options in the table [listed below], *how ambitious should the City's GHG reduction targets be?*

- *Take no additional steps to reduce emissions* [score = 1];
- *Meet our current targets* [for 2035] *and nothing more* [score = 2];
- *Be slightly more ambitious* [score = 3];
- *Be moderately more ambitious* [score = 4];
- *Be significantly more ambitious* [score = 5]; or
- *Be very ambitious—would imply that per person GHG emissions would fall to 3.0 tonnes by 2030and to 0 (zero) tonnes per person by 2050* [score = 6].

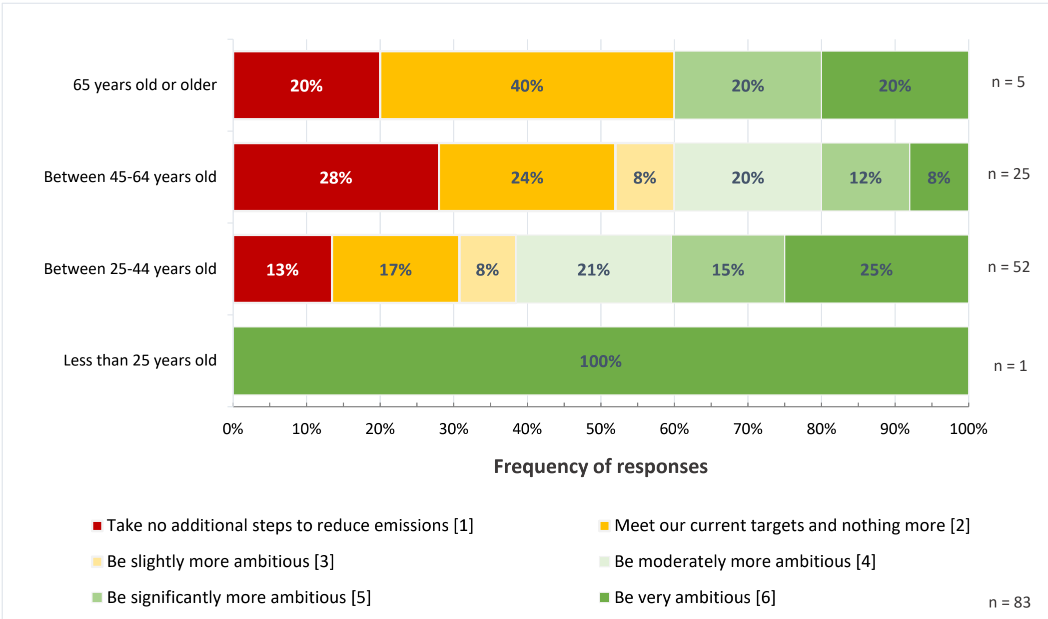
Eighty-three respondents answered this question; the results are summarized in Figure 10. Public opinion ranges widely on this question. About 39% of respondents believe the City should—at most—do nothing more than achieve the 2016 EMP targets for 2035, whilst 35% of respondents believe the City should—at least—be significantly more ambitious. Roughly one-fifth of respondents supported taking no further action to reduce emissions and about the same proportion supported reductions compatible with keeping global temperature increases to +1.5°C above pre-industrial levels (see below). Looking at the median score across the options, half of the respondents support being moderately more ambitious than the 2016 EMP targets.

Figure 10: Public views on levels of ambition for GHG emission reductions in the CCAP



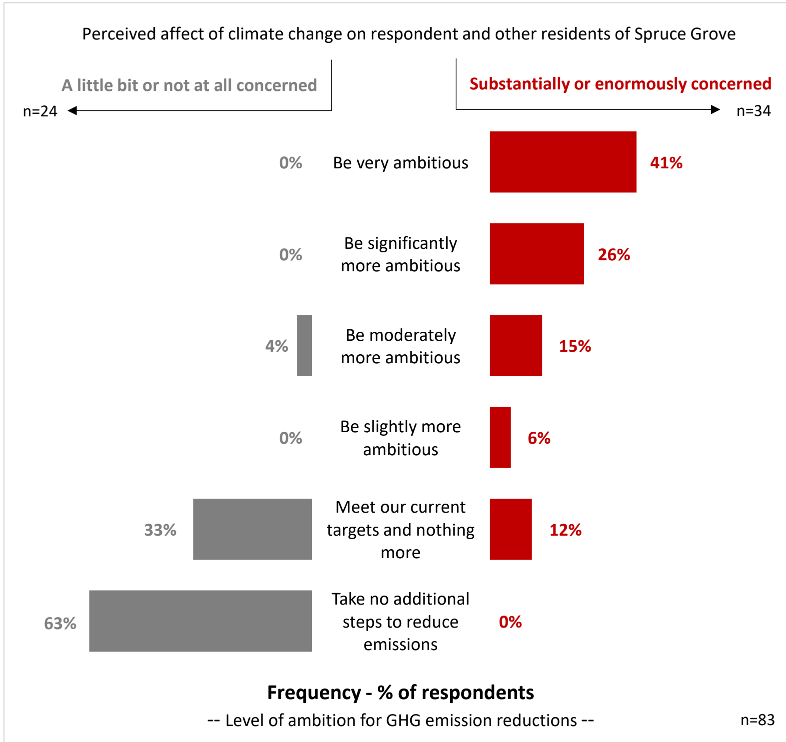
Public opinion on how ambitious the City should be when it comes to setting targets for reducing GHG emissions is strongly influenced by age (see Figure 11). Sixty percent of respondents 65 years and older believe the City should—at most—do nothing more than achieve the 2016 EMP targets for 2035; only 30% of respondents between 25-44 years old expressed this view. Indeed, 61% of respondents between 25-44 years olds stated the City should—at least—be moderately more ambitious.

Figure 11: Influence of age on supported levels of ambition for GHG emission reductions in the CCAP



Public opinion on levels of ambition for GHG emission reduction targets is also strongly influenced by perceptions of how climate change will impact themselves and other residents of Spruce Grove (see Figure 12). As evident from Figure 12, of the 24 respondents who where “a little bit or not at all concerned” about the impacts of climate change on themselves or others in the City, 96% believe the City should—at most—do nothing more than achieve the 2016 EMP targets for 2035. In contrast, the 34 respondents who where “substantially or enormously concerned” about the impacts of climate change, 82% believe the City should—at least—be moderately more ambitious, with 41% stating the City should be very ambitious.

Figure 12: Influence of perceived impacts of climate change in Spruce Grove on supported levels of ambition for GHG emission reductions in the CCAP



This question, regarding the level of ambition that the City should take towards greenhouse gas mitigation, was also asked at three other CCAP engagement events: at a booth at an in-person farmer's market on September 25, 2021; at a classroom of Grade 10 science students St. Peter the Apostle Catholic High School on September 28, 2021; and in a second online survey that was open between September 24 – October 26, 2021. Overall, the results from these engagement events support the conclusions made above. More specifically:

- At the farmer's market; of the people who recorded their preferences (n=9):
  - 11% of respondents thought the City should take no additional actions;
  - 44% of respondents thought the City should take actions that are slightly to moderately more ambitious than the current target; and
  - The remaining 44% of respondents thought that the City should be very ambitious.
- In the classroom of Grade 10 students; of students who reported an opinion (n=24):
  - 17% of students thought the City should take no additional actions;
  - 25% of students thought the City should take actions that are slightly to moderately more ambitious than the current target; and
  - 58% of students thought that the City should be very or significantly more ambitious than the current target.

- In the second online survey, responses to the question about how ambitious the city's greenhouse gas reduction target should be (n=34) were substantially similar to responses obtained in the first survey:
  - 39% of respondents thought the city should either meet current targets or take no additional steps;
  - 30% of respondents thought that the city should be slightly or moderately more ambitious than current targets; and
  - 33% of respondents thought that the city should be very or significantly more ambitious than current targets.

3.3 Alternative emission reduction targets and scenarios

Based on discussions with the City—taking account of responses to the public engagements, targets being adopted by peers and higher levels of government, and recommendations in the climate science literature, two additional GHG emission reductions scenarios were formulated for more in-depth consideration, as alternatives to the scenario based on the 2016 EMP targets for 2035 shown in Figure 9. Both alternative scenarios are considered "science-based" as they are in line with the aims and ambitions of the Paris Agreement and the IPCC Special Report on Global Warming of 1.5°C. [2] [3] This means limiting increases in global mean temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels (i.e., the average of the period 1850-1900). Indeed, both additional scenarios represent different route maps for limiting global warming to 1.5°C above pre-industrial levels.

[2] UNFCCC, 2015, Paris Agreement (https://unfccc.int/sites/default/files/english_paris_agreement.pdf).

[3] IPCC, 2018, Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global GHG emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, et al.(eds.)]. World Meteorological Organization, Geneva, Switzerland.

3.3.1 Setting science-based climate targets

Science-based climate targets have three features—they must be (1) science-driven, (2) equitable, and (3) complete.[4]

3.3.1.1 Science-driven

A science-driven target is one that is based on the latest climate science. This involves limiting global warming to 1.5°C above pre-industrial levels. It also means defining the direction of travel—or pathway—to this end, by setting a clear end goal and a mid-term, interim target, where emissions peak soon and decline at different rates thereafter toward the end goal. This provides a robust approach for defining ambition and formulating plans and actions. In terms of the end goal or long-term target, there is an emerging consensus that cities should set a net-zero emissions target for 2050 and a mid-term, interim target for 2030.[5] Net-zero emissions—also referred to as carbon neutrality—describes a state where annual residual GHG emissions are completely cancelled out through offsetting[6] or removed through negative emission technologies, including Carbon Dioxide Removal (CDR) measures[7]. Setting the interim target for 2030 is less straightforward, as there are multiple pathways through 2030 for reaching net-zero by 2050.

3.3.1.2 Equitable

The three main equity considerations most often discussed in the context of setting the level of emissions reductions expected of individual cities, include:[8]

- **Responsibility** for reducing GHG emissions should consider the contribution of cities to climate change, historically and in the future. Responsibility is associated with the "polluter pays" principle.
- The **capacity** of cities to take action to reduce GHG emissions or to offset or remove GHGs from the atmosphere; different cities will have different capacities depending on their respective levels of socioeconomic development. Capacity is linked with the "ability to pay" principle.
- All residents should have **equal** rights to emit GHGs irrespective of their level of socioeconomic development.

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[4] Science-Based Climate Targets: A Guide for Cities, Science-Based Targets Network, Global Commons Alliance, November 2020.

[5] See, for example, C40 Cities, 2016, Deadline 2020 – How cities will get the job done. C40 Cities, London, UK., WWF, 2021, One Planet City Challenge, Updated Assessment Framework: Technical Document 2021, World Wildlife Fund, Sweden, or visit the Science-Based Targets Network (SBTN), the Cities Race to Zero Initiative, or the UN Race to Zero Campaign.

[6] A mechanism for cancelling out residual GHG emissions by developing, funding, or financing carbon credit projects (and retiring associated credits) that avoid or sequester GHG emissions outside of the City's GHG accounting boundary. (Defining Carbon Neutrality for Cities and Managing Residual Emissions, Cities' Perspectives and Guidance, C40 Cities, April 2019.)

[7] Carbon Dioxide Removal (CDR) measures refer to processes that remove CO_2 from the atmosphere by either increasing biological sinks of CO_2 or using chemical processes to directly bind CO_2. (*Ibid*.)

[8] Averchenkova, A., Stern, N. and Zenghelis, D., 2014, Taming the beasts of 'burden-sharing': an analysis of equitable mitigation actions and approaches to 2030 mitigation pledges. Centre for Climate Change Economics and Policy and the Grantham Research Institute on Climate Change and the Environment, London School of Economics, London, UK.

These equity principles will have a strong influence on the trajectory cities take towards net-zero emissions by 2050. They suggest that cities in developed, high-income countries like Canada with relatively high baseline emissions per person, should immediately and rapidly reduce emissions towards the 2050 goal. In contrast, cities in developing, low-income countries with relatively low baseline emissions per person, should be allowed to benefit further from unrestricted development, with emissions peaking in the not too distant future before steadily falling to net-zero by 2050. Spruce Grove would fall into the former category, characterized by a “steep decline” emissions reduction pathway.

3.3.1.3 Complete

Complete simply means the targets should be comprehensive and cover all community-wide emission sources and GHGs (CO_2, CH_4, and N_2O). The emissions reduction scenarios developed below must therefore apply to all sources included in the full Reference Case.

3.3.2 C40 Cities “Deadline 2020” and WWF’s “One Planet City Challenge”

There are numerous approaches for cities to set science-based GHG emissions reduction targets. These methodologies were thoroughly critiqued by the Science-Based Targets Network for their 2020 “Guide for Cities”. Two approaches recommended by the Network are presented below as a means for defining an alternative emissions reduction scenario for Spruce Grove—with a particular focus on the mid-term, interim target for 2030. Both approaches were assessed as being based on the latest climate science, strongly grounded in equity principles, and comprehensive in scope.

3.3.2.1 C40 Cities “Deadline 2020”

The “Deadline 2020” approach was developed by the C40 Cities Leadership Group for cities in the C40 network. The goal was to provide cities with a route map to follow so they can play their part in achieving the Paris Agreement commitments. Given the accepted net-zero target for 2050, the methodology focused on helping cities set a target for 2030 to guide emissions reduction strategies and actions over the next 10 years that will keep them on a path to this long-term goal. Based on modelling performed by ARUP (an international consulting company) for the report, an emissions target of 3.2 t CO_2e per person was set for C40 cities for 2030.[9] At the time, this value was consistent with an emissions reduction scenario designed to keep atmospheric concentrations of CO_2e in 2100 between 430 parts per million (ppm) and 480 ppm, which was “likely” to limit global warming to +2.0°C, but “more unlikely than likely” to keep limit warming to +1.5°C.[10] Hence, the only means to keep global warming below the +1.5°C target by 2100 would require significant negative emissions measures after 2050. In the absence of negative emissions, the modelling suggested that C40 cities would need to achieve net-zero emissions by about 2030 to limit global warming to +1.5°C this century.

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[9] For further details of the methodology see C40 Cities and ARUP, 2016, Deadline 2020 –Method Report. C40 Cities, London, UK.

[10] See Table SPM.1 in IPCC, 2014, Climate Change 2014 Synthesis Report: Summary for Policy Makers (https://www.ipcc.ch/site/assets/uploads/2018/02/AR5_SYR_FINAL_SPM.pdf).

The City of Edmonton's emissions reduction goal for 2030 is based on the C40 Cities "Deadline 2020" approach.

3.3.2.2 WWF's "One Planet City Challenge"

The World Wildlife Fund's (WWF) "One Planet City Challenge (OPCC)" developed a methodology to extend the "Deadline 2020" approach to a broader set of cities. The OPCC method is based on the latest scientific evidence published in the Intergovernmental Panel on Climate Change's (IPCC) Special Report on Global Warming of 1.5°C, which provides significantly revised scenarios for cumulative global GHG emissions that cannot be exceeded if global warming is to be limited to +1.5°C this century.[11] Based on analyses of the emissions reductions required between 2018 and 2030 under the "1.5°C-low-overshoot"[12] scenarios in the Special Report, it was concluded that per capita emissions globally need to fall by about 40%-60% by 2030. The OPCC methodology defined a 2030 target for cities as the mid-point—a 50% reduction in per person emissions relative to 2018 values.

As well as using the latest climate science, the OPCC approach goes one step further and builds in an additional layer of equity and fairness—on top of what is already captured in the IPCC scenarios—using the Human Development Index (HDI). The HDI is used to make a country-specific adjustment to the 2030 target for cities—essentially requiring faster rates of emission reductions from cities in more developed nations. The adjustment is performed as follows:

$$\text{Adjusted reduction \% for 2030} = 1 - (0.5 \times \text{HDI adjustment factor})$$

Where:

$$\text{HDI adjustment factor} = 1 - ((\text{HDI}_{\text{Canada}} - \text{HDI}_{\text{global average}}) / \text{HDI}_{\text{global average}})$$

Performing this calculation for Spruce Grove yields the following per person emissions target for 2030:

$$\text{Adjusted reduction \% for 2030} = 1 - (0.5 \times (1 - ((0.929 - 0.737) / 0.737))) = 0.63 \text{ or } 63\%$$ [13]

$$(1 - 0.63) \times 12.2 \text{ t } CO_2e \text{ per person}^{[14]} = 4.5 \text{ t } CO_2e \text{ per person}$$

The "1.5°C-low-overshoot" scenario upon which this target is based accepts there is a 50–67% probability of temporarily overshooting the +1.5°C target before 2100, by as much as 0.1°C, requiring large-scale deployment of negative emissions measures after 2050 to keep warming below 1.5°C by 2100.[15]

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[11] IPCC, 2018, *ibid*.

[12] An "overshoot" is a temporary exceedance of a specified level of global warming, such as +1.5°C, during the century, followed by a reduction in global warming achieved through removal of GHGs from the atmosphere.

[13] The HDI values are from Table 2 in Human Development Report 2020, The Next Frontier: Human Development and the Anthropocene, the UN Development Program, New York, USA.

[14] This is the estimated total (City-level) GHG emissions per person for Spruce Grove in 2018.

[15] See Table 2.1 in IPCC, 2018, *ibid*.

Since the OPCC approach is (a) grounded in climate science that updates the science underpinning the "Deadline 2020" method and (b) builds in an additional element of equity and fairness, it is used as the basis for one of the alternative emissions reduction scenarios modelled in this report. As this scenario requires immediate and steep declines in emissions per person in Spruce Grove it is aptly named the "steep decline +1.5°C scenario". Specifically, the assumed targets for 2030 and 2050 are, respectively, 4.5 t CO_2e per person and zero t CO_2e per person. Divergence from the Reference Case is not assumed to start until 2022, the first year of the CCAP. Annual emissions per capita between 2022-2030 and between 2030-2050 are estimated by, first, fitting a logistic growth function between the values for 2022 and 2030 and next, between the values for 2030 and 2050. Absolute annual emissions over the projection period are calculated by multiplying annual emissions per person by projected population in the corresponding year. The modelled results are shown as the solid yellow line in Figure 13 and Figure 14. Cumulative GHG emissions are calculated as the total area under the solid blue trajectory curve. The estimated GHG emissions savings are summarized in Table 1.

Under this scenario, GHG emissions per person would need to fall by about 77% relative to 2020 levels of 12.0 t CO_2e by the end of the CCAP on 31 Dec 2033. This represents a 72% reduction in projected Reference Case levels in 2033. Over the course of the CCAP, cumulative emissions savings of 3.0 Mt CO_2e are required to stay on target for 2050.

Figure 13: Reference Case, the combined 2035 GHG emission reduction target from the 2016 EMP, and the "steep decline +1.5°C scenario"

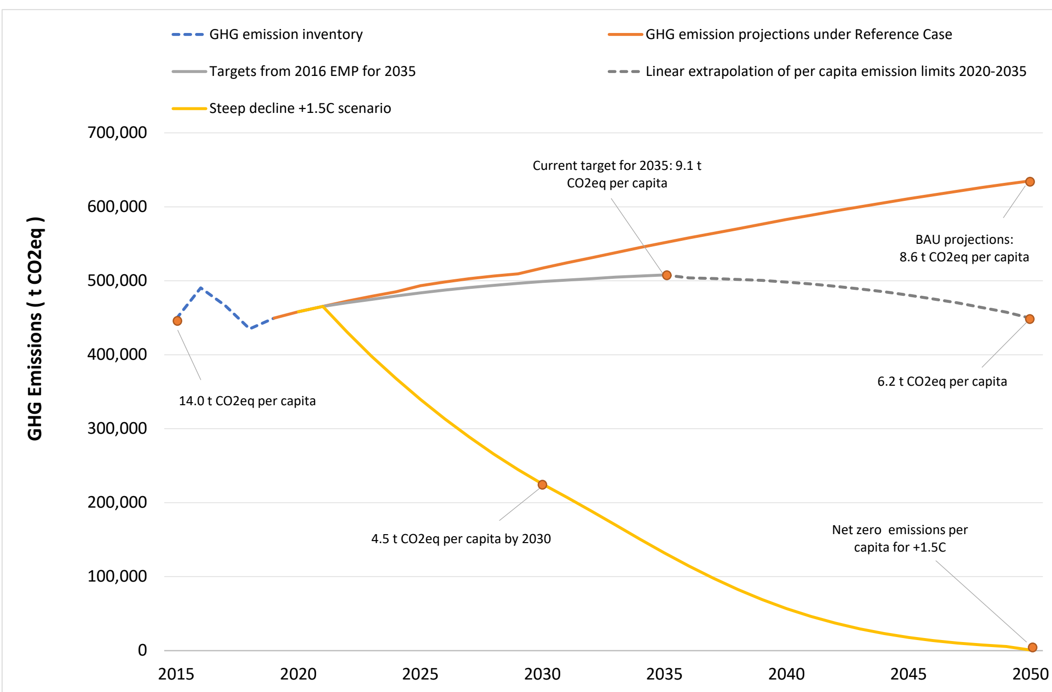


Figure 14: Projected emissions per person under the "steep decline +1.5C scenario" relative to the Reference Case and past GHG emission inventories for Spruce Grove (2015-2019)

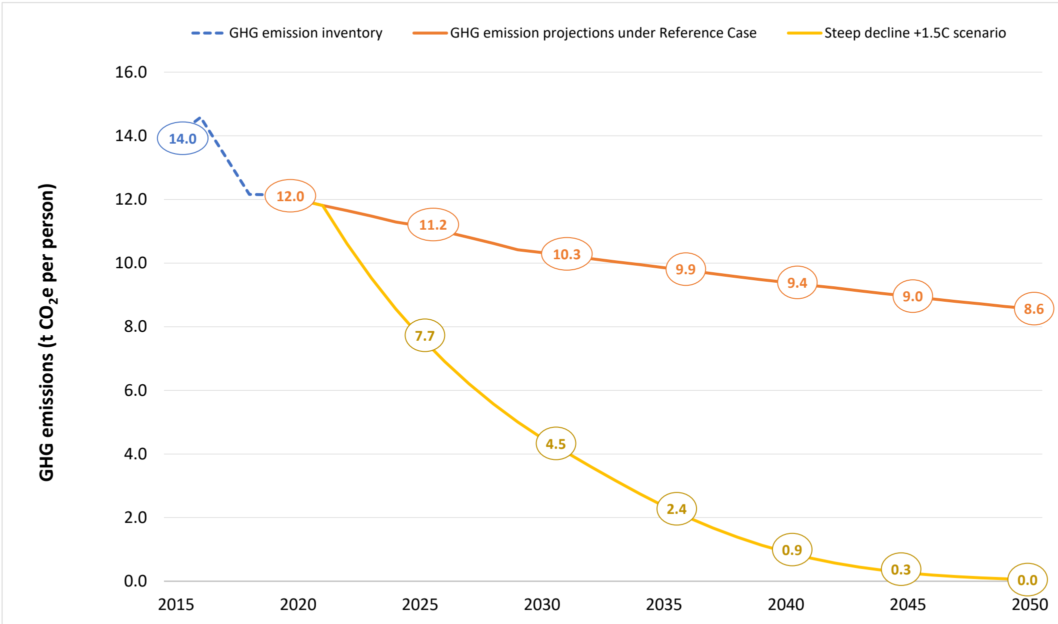


Table 1: Projected emissions per person, emission savings and residual emissions under the "steep decline +1.5°C scenario"

Year	GHG emissions	Reduction relative to 2020	Reduction relative to Reference Case	Cumulative emission savings	Cumulative residual emissions
	(t CO2e per person)	(%)	(%)	(kt CO2e)	(t CO2e)
2020	12.0	-	-	-	458.3
2022 [a]	10.6	12	9	42.0	1,354.1
2025	7.7	36	31	394.3	2,459.4
2030	4.5	63	57	1,590.9	3,797.0
2033 [b]	3.2	74	69	2,619.2	4,362.4
2035	2.4	80	76	3,433.2	4,645.0
2040	0.9	92	90	5,864.8	5,065.5
2045	0.3	98	97	8,711.3	5,218.7
2050	0.0	100	100	11,803.1	5,256.1

Note: a. 2022 (1 Jan) is the first year of the CCAP, when cumulative emission savings start accruing. b. 2033 (Dec 31) is the end of the CCAP.

3.3.3 Government of Canada's targets

On June 29th, 2021, The Canadian Net-Zero Emissions Accountability Act was enshrined in legislation, which commits Canada to avert the worst impacts of climate change by achieving net-zero emissions by 2050. Furthermore, under the Paris Agreement, signatories like Canada are required to submit national GHG emission reduction targets—called Nationally Determined Contributions (NDCs)—every five years, with each successive NDC being more ambitious than its predecessor. In July 2021, the Government of

Canada submitted its latest NDC to the United Nations, in which it committed Canada to cut its GHG emissions by 40-45% below 2005 levels by 2030; previously, the target for 2030 was 30% below 2005 levels.

In 2005, total GHG emissions in Canada were 739 Mt CO_2e from all sources, of which 556 Mt CO_2e were from GHG emission sources included in Spruce Grove's inventory and Reference Case—i.e., 341 Mt CO_2e from *stationary combustion sources*, 190 Mt CO_2e from *transportation*, and 25 Mt CO_2e from *solid waste disposal at landfills*.[16] A 42.5% reduction (mid-point between 40% and 45%) of 556 Mt CO_2e would cap emissions at 320 Mt CO_2e in 2030—i.e., 556 Mt CO_2e x (1 – 0.425). Under a medium growth scenario, Canada's population in 2030 is projected to range from 41,884,500 to 41,889,500 (average = 41,887,600).[17] A per capita emissions reduction target for 2030 for Spruce Grove, that is consistent with both Spruce Grove's inventory and Reference Case, and the Government of Canada's updated 2030 target, is thus: 7.6 t CO_2e per person (556 Mt CO_2e divided by 41,887,600).

Hence, another plausible emissions reduction scenario for Spruce Grove involves converging to Canada's mid-term, interim goal for 2030 of 7.6t CO_2e per person, before contracting to the Canada's long-term net-zero goal by 2050. Annual emissions per capita between 2020-2030 and between 2030-2050 are estimated by fitting a logistic growth function between the values for 2020 and 2030 and then between the values for 2030 and 2050. Similar to the "steep decline +1.5°C scenario", absolute annual emissions over the projection period for this so-called "Canadian path to +1.5°C scenario" are calculated by multiplying annual emissions per person by projected population in the corresponding year. The results are shown as the solid dark blue line in Figure 15 and Figure 16. Cumulative GHG emissions are, as above, calculated as the total area under the solid blue trajectory curve. The estimated GHG emissions savings are summarized in Table 2.

Under this scenario, GHG emissions per person will need to fall by about 61% relative to 2020 levels of 12.0 t CO_2e by the end of the CCAP in 2034. This represents a 53% reduction in projected Reference Case levels in 2034. Over the course of the CCAP, cumulative emissions savings of 1.6 Mt CO_2e are required to stay on target for 2050.

Cumulative residual emissions through 2050 under "Canadian path to +1.5°C scenario" amount to 7.2 Mt CO_2e. This is considerably more than under the "steep decline +1.5°C scenario"; about 37% more. This has important implications for the deployment of negative emission measures after 2050 under this scenario since changes in global temperatures increase fairly linearly with cumulative GHG emissions. As noted above, large-scale deployment of negative emissions measures is already needed to limit global warming to +1.5°C by 2100. Consequently, under the "Canadian path to +1.5°C scenario" significantly higher levels of deployment of these measures will be needed than is already required under the "steep decline +1.5°C scenario" to return levels of global warming to +1.5°C by 2100.

[16] These amounts for 2005 are based on the 2021 National Inventory Report for 1990-2019.

[17] Statistics Canada, Table 17-10-0057-01, released 17-09-2019.

Figure 15: Reference Case, the combined 2035 GHG emission reduction target from the 2016 EMP, the "steep decline +1.5°C scenario", and the "Canadian path to +1.5°C scenario"

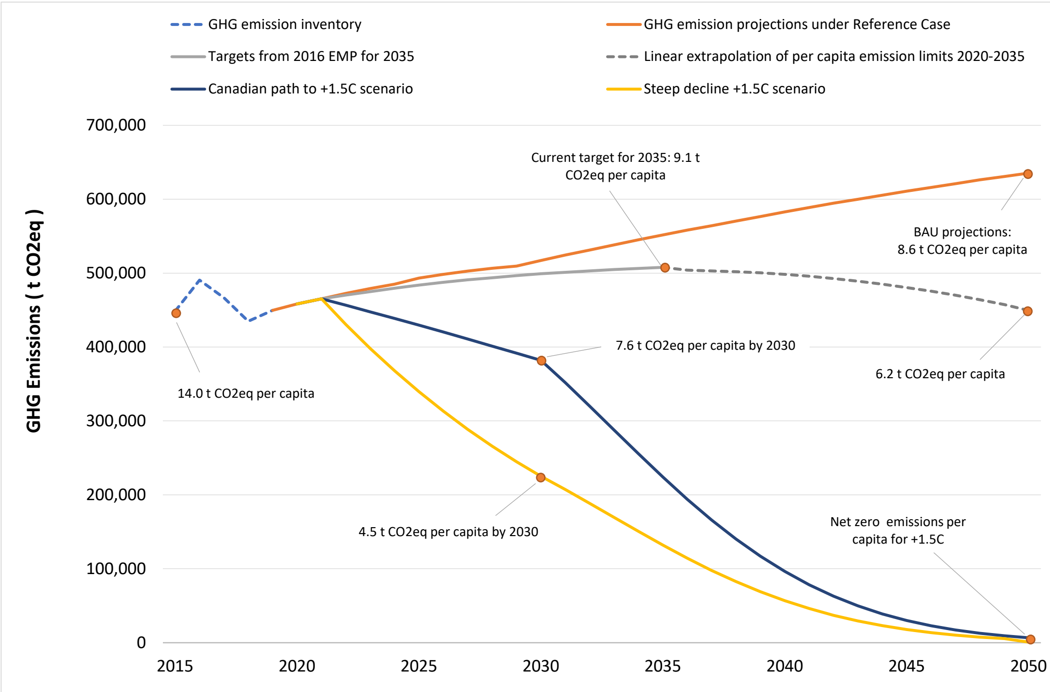


Figure 16: Projected emissions per person under the "Canadian path to +1.5C scenario" relative to the Reference Case and past GHG emission inventories for Spruce Grove (2015-2019)

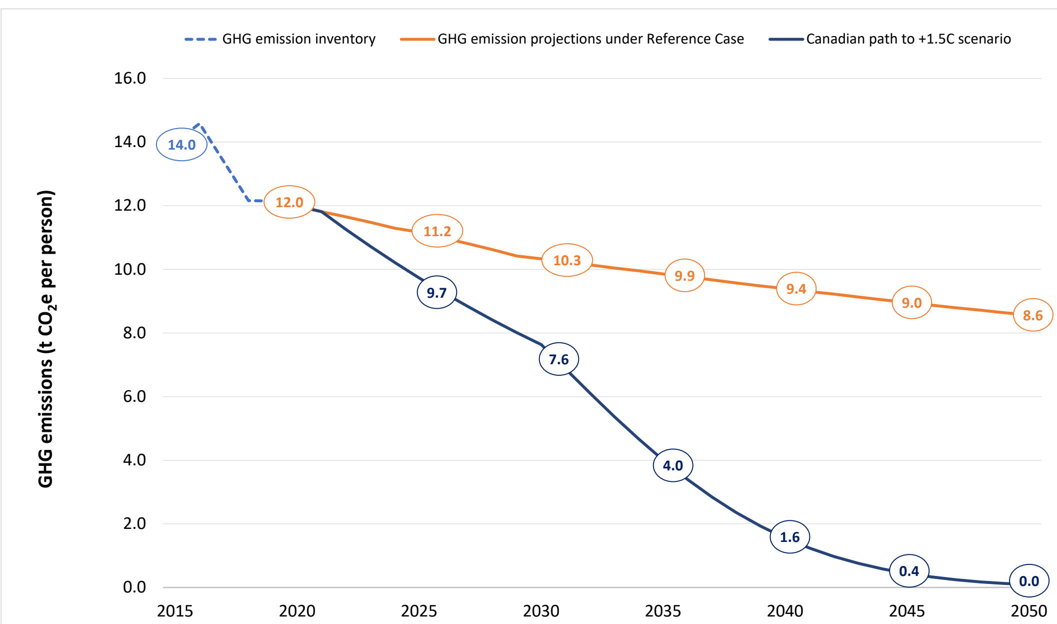


Table 2: Projected emissions per person, emission savings and residual emissions under the "Canadian path to +1.5°C scenario"

Year	GHG emissions	Reduction relative to 2020	Reduction relative to Reference Case	Cumulative emission savings	Cumulative residual emissions
	(t CO2e per person)	(%)	(%)	(kt CO2e)	(t CO2e)
2020	12.0	-	-	-	458.3
2022 [a]	11.3	6	3	16.0	1,380.2
2025	9.7	19	13	157.6	2,696.1
2030	7.6	36	26	685.9	4,702.1
2033 [b]	5.4	55	47	1,319.8	5,661.8
2035	4.0	67	59	1,936.8	6,141.4
2040	1.6	87	84	4,075.2	6,855.0
2045	0.4	96	95	6,814.8	7,115.2
2050	0.0	100	100	9,875.0	7,184.1

Note: a. 2022 (1 Jan) is the first year of the CCAP, when cumulative emission savings start accruing. b. 2033 (31 Dec) is the end of the CCAP.

3.4 Carbon budgets

A carbon budgeting and accounting framework is proposed as a means for implementing the necessary GHG emissions reduction strategies and actions to achieve the City's mid-term, interim and long-term goals. The idea of "carbon budgets" first emerged as a scientific concept from the IPCC's 2014 Synthesis Report on Climate Change and relate to the total level of GHG emissions that is still permissible under an agreed climate goal, such as limiting global warming to 1.5°C above pre-industrial levels this century. In fact, both the C40 Cities Deadline 2020 and WWF's One Planet City Challenge approaches described above—that underpin the "steep decline +1.5C scenario" for Spruce Grove—essentially allocate to cities a portion of the overall global carbon budget commensurate with a +1.5C target.

At a city level, a carbon budget functions similarly to a financial budget, setting out how much GHG emissions can be spent over a fixed period. Once the allowable GHG emissions or carbon budget is spent, it cannot be replenished, unless budget deficits are offset, or negative emission technologies are rolled out at an appropriate scale to extract GHGs from the atmosphere to rebalance the budget. If rebalancing the budget is not feasible, then a carbon deficit may be carried forward to the next budget cycle; likewise, carbon surpluses may also be carried forward. This process is illustrated in Figure 17.

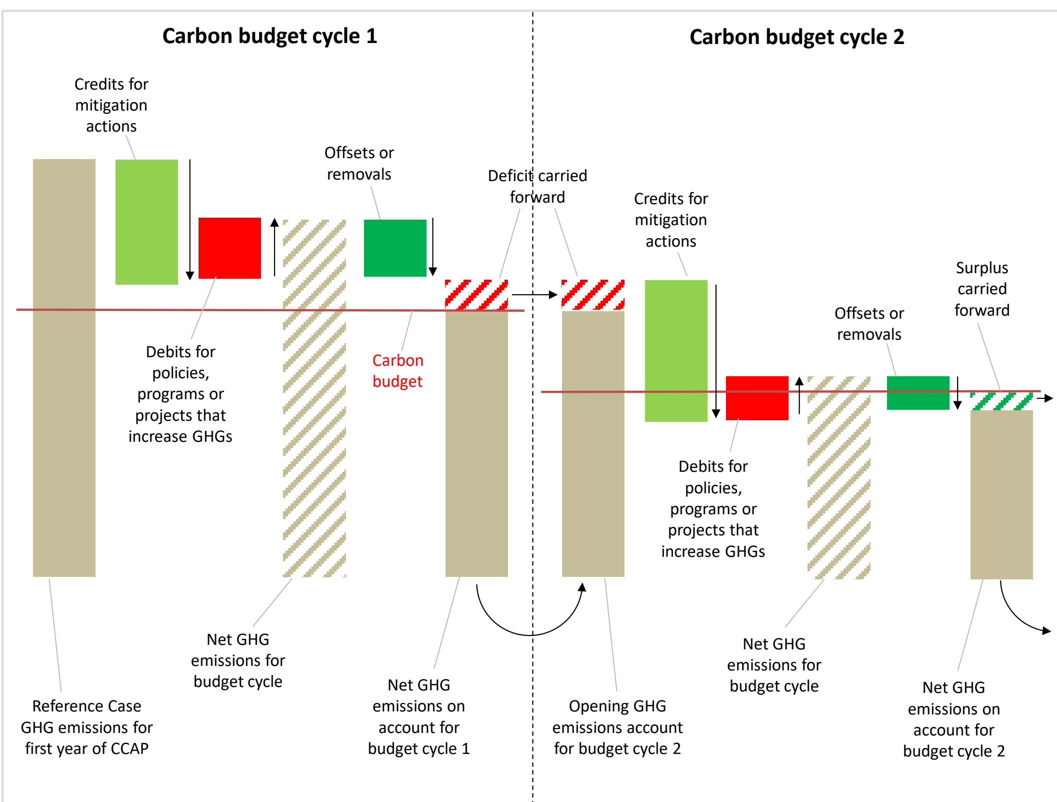
With a carbon budgeting approach, a city's total allowable emissions to achieve a long-term target is typically broken down into a series of multi-year budgets or emissions caps. Each multi-year budget sets progressively lower emissions limits and acts as a roadmap towards achieving mid-term, interim and long-term targets for 2030 and 2050, respectively. The length of a multi-year budget can be set to align with existing financial planning for capital and operating budgets, or to align with political cycles. We suggest the City considers using 4-year carbon budgets, to roughly coincide with the municipal election cycle. This will enable the City to plan out major policies, plans and projects for several years at a time which may represent a more practical solution than to do so annually. The first 4-year carbon budget could start 1

Jan 2022 and end 31 Dec 2025—accepting it is unlikely to be actionable until the later in 2022. The second 4-year carbon budget would cover the period 1 Jan 2026 to 31 Dec 2029, the third 4-year carbon budget would cover the period 1 Jan 2030 to 31 Dec 2033, and so on. The CCAP would then include actions designed to be implemented over the first three 4-year carbon budgets, ending 31 Dec 2033.

To support the implementation of a carbon budgeting approach, a "carbon accounting tool" is needed to quantitatively analyse the GHG impacts of current and proposed policies, practices and spending decisions, as well as generate annual emission inventories necessary to track progress towards achieving the level of emissions specified in the carbon budget for the period. A key advantage of using carbon budgets with the support of a carbon accounting framework is that it puts climate mitigation plans and actions at the center of City policy and budgetary discussions and decisions. City initiatives can then be prioritized taking account of their implications for future climate change, along with other considerations important to the decision-makers.

The carbon budgets for each of the alternative GHG emissions reduction scenarios for Spruce Gove developed in Section 3.3.2 are presented below—assuming 4-year carbon budgets, starting 1 Jan 2022. Design details for a carbon budgeting process and accounting framework are not developed further in this report, but rather left to the forthcoming "implementation plan", in case this is not the approach the City wishes to pursue.

Figure 17: Illustrating the process for determining the net GHG account for Spruce Grove using a carbon budgeting and accounting framework



3.4.1 Steep decline +1.5°C scenario

The total carbon budget for the "steep decline +1.5°C scenario" for the period 2022-2050 is estimated at 4.3 Mt CO_2e (see Figure 18). Since 2015, Spruce Grove's community-wide GHG emissions have fluctuated between 435 kt CO_2e and 490.5 kt CO_2e but are anticipated to trend upward under the Reference Case through 2050. If the emissions projections under the Reference Case are realized, Spruce Grove will exhaust its total carbon budget by 2030 (see Figure 19). To stay within the 4.3 Mt CO_2e carbon budget, total emissions savings of 11.8 Mt CO_2e are required over the period 2022-2050 relative to the projected Reference Case; indicated by the sum of the orange bordered transparent bars in Figure 20. The height of each of these bars indicates the annual emissions reductions needed to stay on course to achieve the 2030 and 2050 targets of 4.5 t CO_2e per person and zero t CO_2e per person, respectively. The corresponding first three 4-year carbon budgets are shown in Figure 21 (given by the sum of the solid orange bars falling within each budget period):

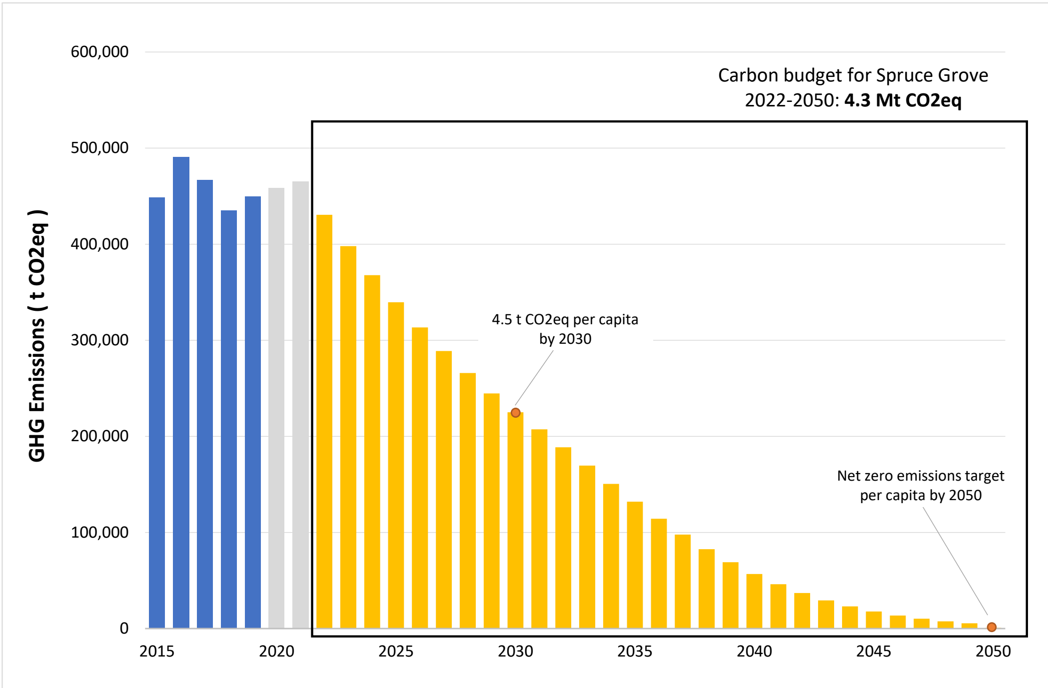
- Carbon budget 1 = 1.54 Mt CO_2e for the period 1 Jan 2022 to 31 Dec 2025;
- Carbon budget 2 = 1.11 Mt CO_2e for the period 1 Jan 2026 to 31 Dec 2029; and
- Carbon budget 3 = 0.79 Mt CO_2e for the period 1 Jan 2030 to 31 Dec 2033.

As the City progresses towards increasingly stringent GHG emissions reduction targets, each successive carbon budget is smaller than its predecessor.

Figure 22 shows the GHG emissions reductions required from each source sector included in the Reference Case. For the purpose of this report, the emissions reductions are shared equally across all sources; all sources are expected to deliver the same percentage reductions in each year. Put another way, the carbon budgets are allocated ("grandfathered") to each emissions source based on their respective contribution to overall city-wide emissions under the Reference Case. It is thus not surprising that the largest emissions reductions are required from road transport, followed by buildings.

A more detailed breakdown of the required emissions savings from each source in the City is provided in Table 3 for each of the first three carbon budget cycles. Over the course of the first carbon budget, emissions reductions of 394.3 kt CO_2e are required. The corresponding energy cost savings are estimated at $129.8 million (2020 dollars), of which $1.2 million relate to corporate operations and services. Climate change damage costs avoided—measured using the Social Cost of Carbon—are estimated at $18.8 million. By the third carbon budget, emissions reductions of 1,320.3 kt CO_2e are required. The corresponding energy cost savings in the third carbon budget are estimated at $463.2 million, of which $4.5 million relate to corporate operations and services. Climate change damage costs avoided are estimated at $72.5 million.

Figure 18: Steep decline +1.5°C scenario: total carbon budget for 2022-2050



Note: the blue bars relate to years for which a GHG emission inventory was generated for Spruce Grove prior to the start of this project. The grey and orange bars are projected GHG emissions generated in this project; the orange bars signify years covered by the carbon budget corresponding to "steep decline +1.5°C scenario". The CCAP starts in 2022.

Figure 19: Steep decline +1.5°C scenario: year carbon budget is exceeded under the Reference Case

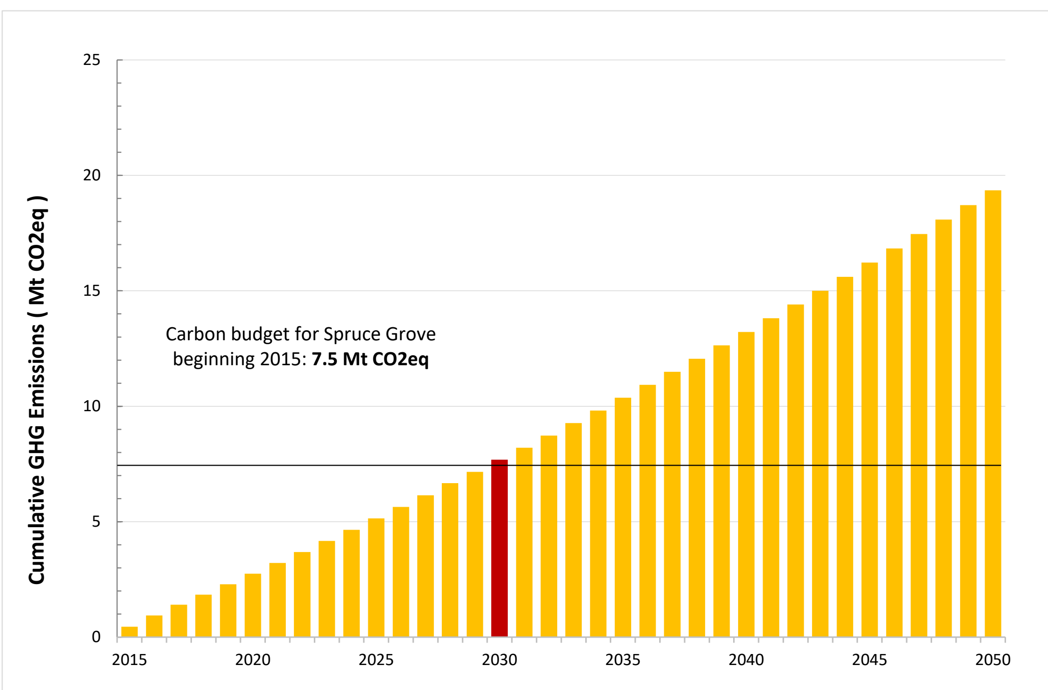


Figure 20: Steep decline +1.5°C scenario: GHG emission reductions required to comply with carbon budget

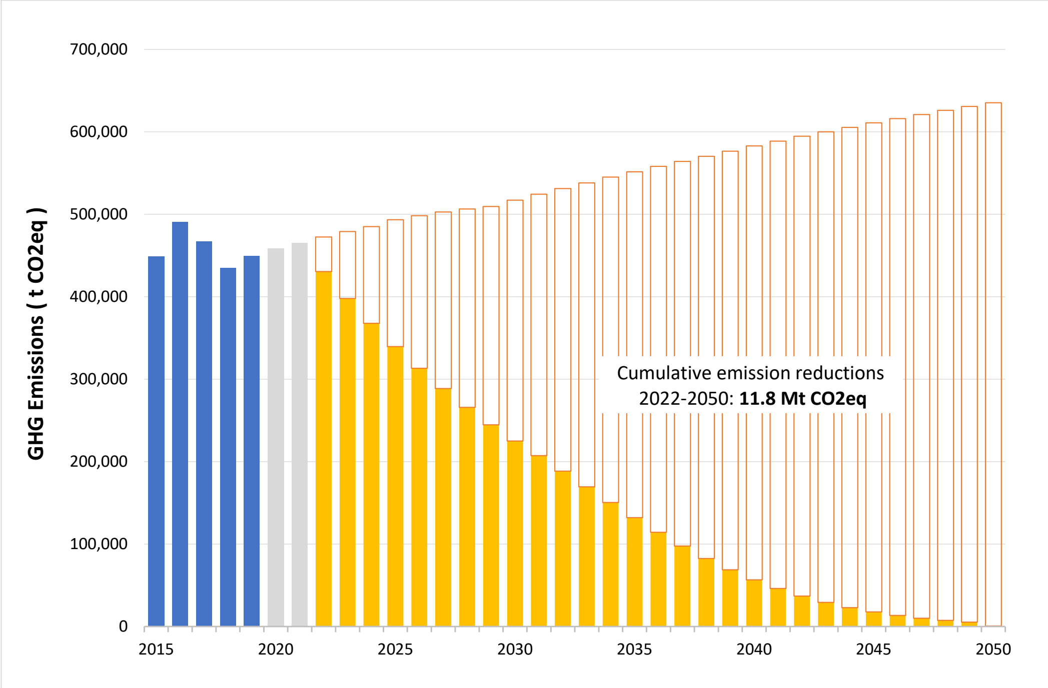


Figure 21: Steep decline +1.5°C scenario: first three carbon budgets included in the CCAP

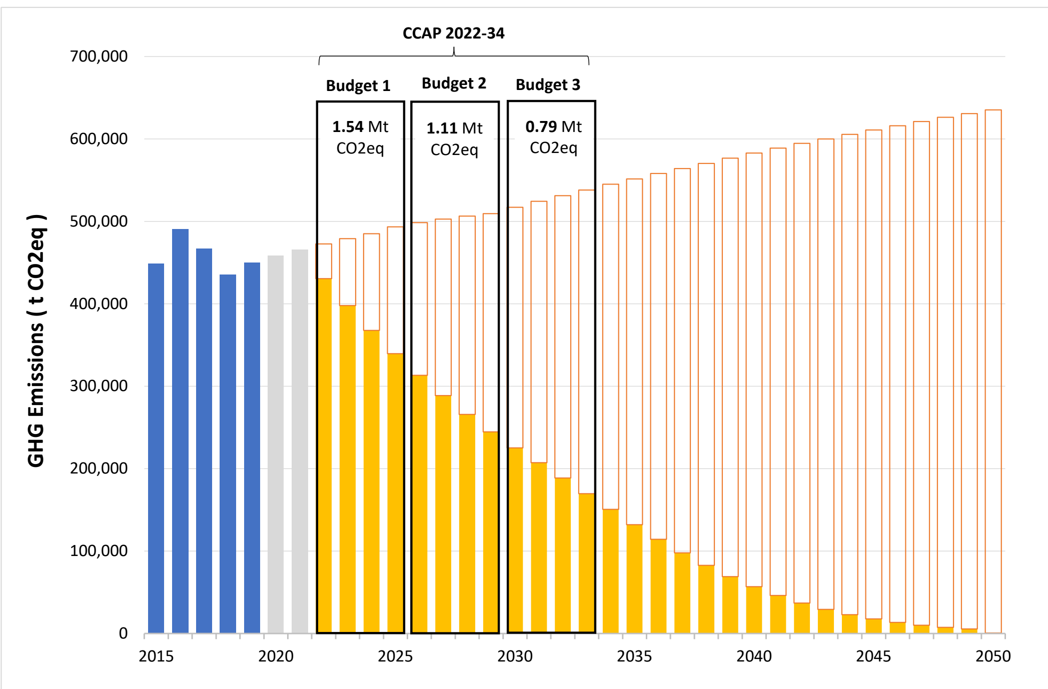
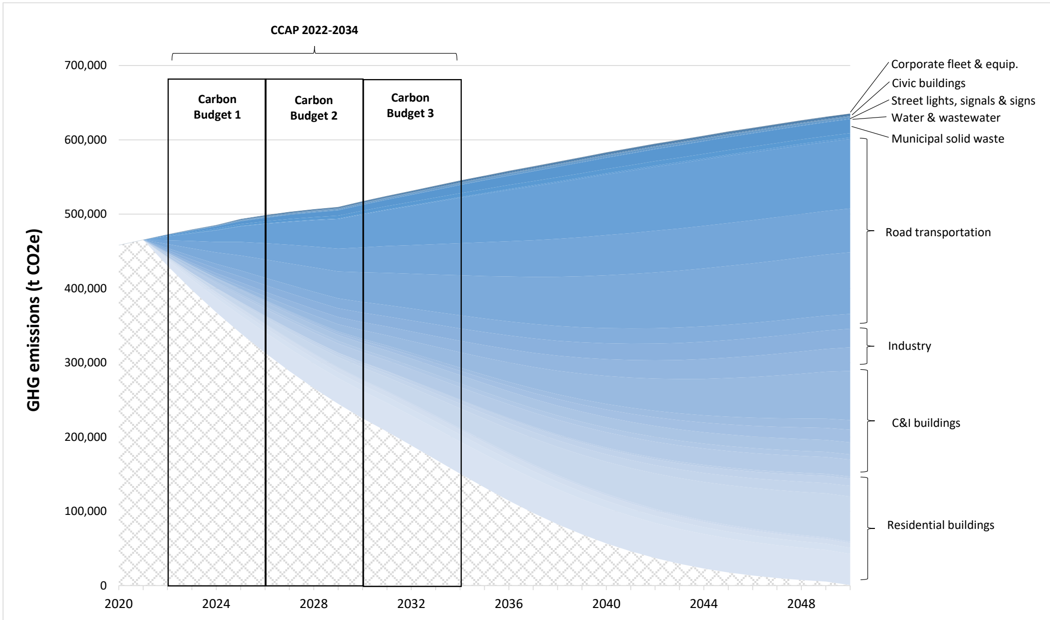


Figure 22: Steep decline +1.5°C scenario: required emissions savings by broad source sector



3.4.2 Canadian path +1.5°C scenario

The total carbon budget for the "Canadian path to +1.5°C scenario" for the period 2022-2050 is estimated at 6.3 Mt CO_2e (see Figure 23). If the emissions projections under the Reference Case are realized, Spruce Grove will exhaust this carbon budget by 2034 (see Figure 24). To stay within the 6.3 Mt CO_2e carbon budget, total emissions savings of 9.9 Mt CO_2e are required over the period 2022-2050 relative to the projected Reference Case (see Figure 25). The corresponding first three 4-year carbon budgets are shown in Figure 26 (given by the sum of the solid orange bars falling within each budget period):

- Carbon budget 1 = 1.77 Mt CO_2e for the period 1 Jan 2022 to 31 Dec 2025;
- Carbon budget 2 = 1.62 Mt CO_2e for the period 1 Jan 2026 to 31 Dec 2029; and
- Carbon budget 3 = 1.34 Mt CO_2e for the period 1 Jan 2030 to 31 Dec 2033.

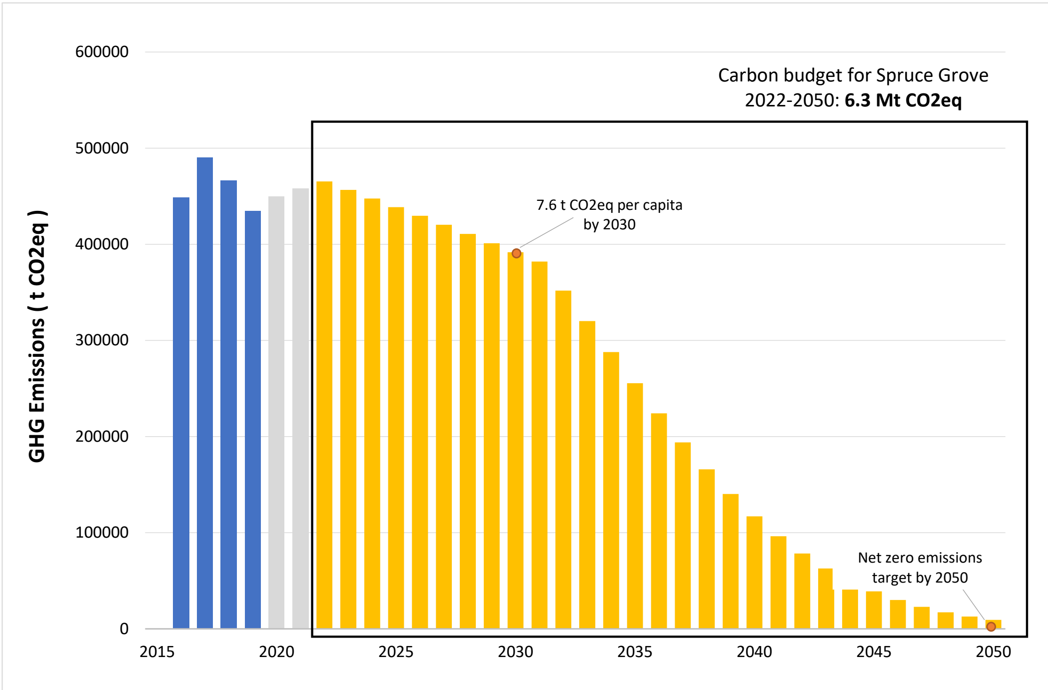
Figure 27 shows the GHG emissions reductions required from each source sector included in the Reference Case. For the reasons given above, the largest emissions reductions are required from road transport, followed by buildings.

A more detailed breakdown of the required emissions savings from each source in the City is provided in Table 4 for each of the first three carbon budget cycles. Over the course of the first carbon budget, emissions reductions of 157.6 kt CO_2e are required. The corresponding energy cost savings are estimated at $52 million (2020 dollars), of which $0.5 million relate to corporate operations and services. Climate change damage costs avoided are estimated at $7.5 million. By the third carbon budget, emissions reductions of 769 kt CO_2e are required. The corresponding energy cost savings are estimated at $269.6 million (2020 dollars), of which $2.6 million relate to corporate operations and services. Climate change damage costs avoided are estimated at $42.4 million.

Table 3: Steep decline+1.5°C scenario: required GHG emissions savings and corresponding energy cost savings and climate change damages avoided for each of the first three carbon budgets

Emissions source	Budget 1	Budget 2	Budget 3
Emissions savings by source (t CO_2e):			
Residential – Existing homes – Single family detached	64,322	125,035	157,299
Residential – Existing homes – Single family attached	14,874	28,026	34,293
Residential – Existing homes - Apartments	10,018	19,241	23,969
Residential – Existing homes - Mobile	2,778	5,483	6,987
Residential – New homes – Single family detached	12,278	42,690	80,300
Residential – New homes – Single family attached	2,934	10,121	18,972
Residential – New homes - Apartments	1,950	6,791	12,832
Residential – New homes - Mobile	530	1,869	3,555
C&I – Existing buildings - Retail trade	21,602	43,641	58,446
C&I – Existing buildings - Educational services	6,212	12,646	17,054
C&I - Existing buildings – Other sectors	13,796	28,153	38,195
C&I – New buildings - Retail trade	2,427	8,596	16,868
C&I – New buildings - Educational services	1,742	6,219	12,286
C&I - New buildings – Other sectors	8,377	29,964	59,585
Industry - Construction	12,849	31,908	49,959
Industry - Manufacturing	20,205	41,495	56,808
Road transport - Passenger cars	21,957	46,779	62,554
Road transport - SUVs & station wagons	51,539	122,182	180,576
Road transport - Light trucks & vans	47,512	106,087	148,945
Road transport - Medium trucks	52,337	131,960	202,158
Road transport - Motor cycles	966	2,359	3,618
Road transport - Buses	6,459	13,612	18,067
Solid waste disposal	10,044	24,071	36,262
Water & wastewater	523	1,030	1,380
Streetlights, signals & signs	628	1,227	1,629
Civic buildings – Existing - Agrena	1,353	2,683	3,514
Civic buildings – Existing - Border Paving Athletic Centre	241	474	617
Civic buildings – Existing - City Hall	242	471	609
Civic buildings – Existing -Protective Services (renovated)	606	1,230	1,635
Civic buildings – Existing - RCMP Facility	317	618	801
Civic buildings – Existing - PW Shop - Century Cl.	552	1,107	1,461
Civic buildings – Existing - Other	685	1,371	1,806
Civic buildings – New - Civic Centre	734	3,900	5,101
Fleet & equipment - Light duty vehicles	5	10	14
Fleet & equipment - Light duty trucks	65	145	202
Fleet & equipment - SGFS	28	63	87
Fleet & equipment - Medium duty trucks	80	176	245
Fleet & equipment - Heavy duty trucks	22	48	67
Fleet & equipment - Off-road & construction	218	480	670
Fleet & equipment - Tractors & agricultural equipment	268	591	824
Fleet & equipment - Transit buses	15	33	46
Total all sources	394,290	904,584	1,320,295
Reference Case emissions	1,930,087	2,014,112	2,110,806
Less total savings	394,290	904,584	1,320,295
Equals residual emissions	1,535,797	1,112,528	790,511
Carbon budget *equals* residual emissions	**1,535,797**	**1,112,528**	**790,511**
Energy cost savings ($ 2020 M):			
Community	128.7	315.7	458.7
Corporate	1.2	3.1	4.5
Total	129.8	318.8	463.2
Climate change damages avoided ($ 2020 M):	18.8	46.0	72.5

Figure 23: Canadian path to +1.5°C scenario: total carbon budget for 2022-2050



Note: the blue bars relate to years for which a GHG emission inventory was generated for Spruce Grove prior to the start of this project. The grey and orange bars are projected GHG emissions generated in this project; the orange bars signify years covered by the carbon budget corresponding to "steep decline +1.5°C scenario". The CCAP starts in 2022.

Figure 24: Canadian path to +1.5°C scenario: year carbon budget is exceeded under the Reference Case

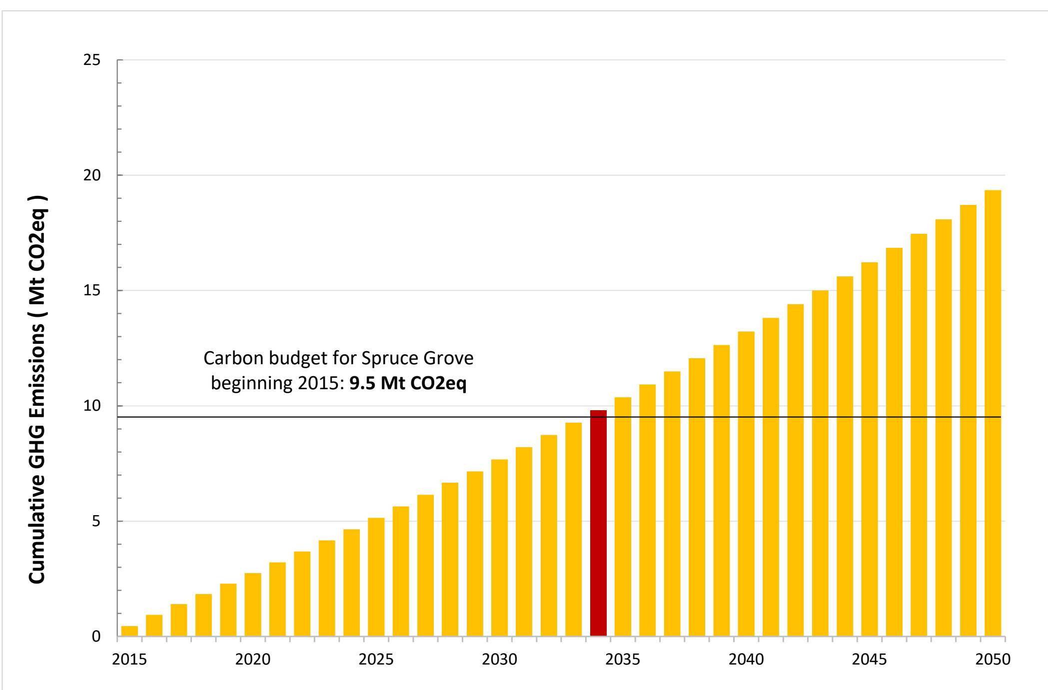


Figure 25: Canadian path to +1.5°C scenario: GHG emission reductions required to comply with carbon budget

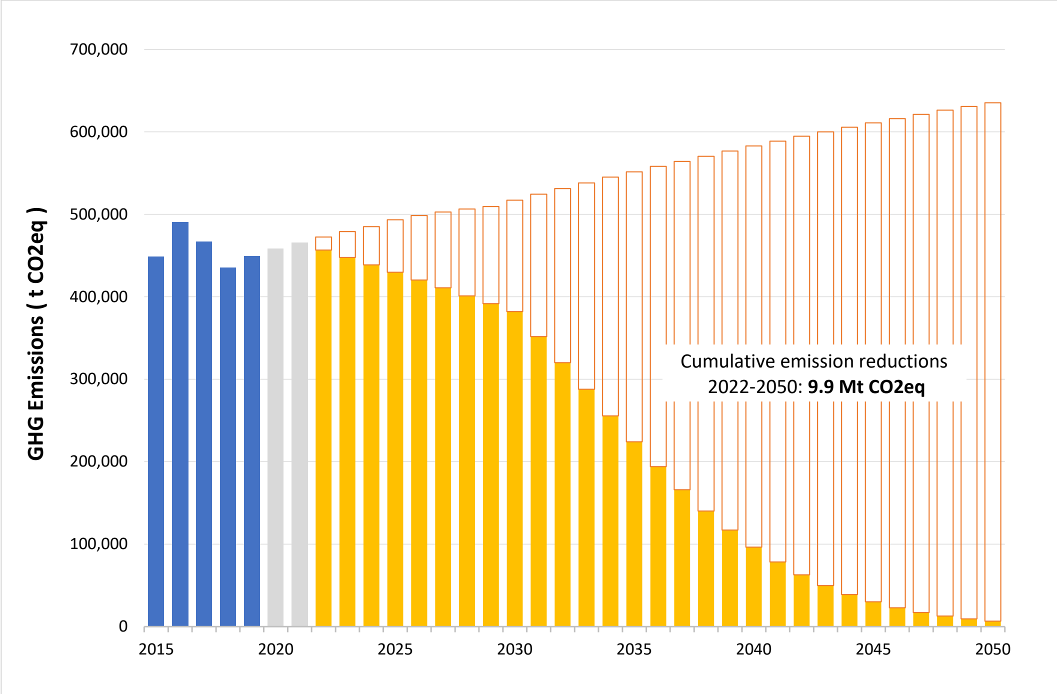


Figure 26: Canadian path to +1.5°C scenario: first three carbon budgets included in the CCAP

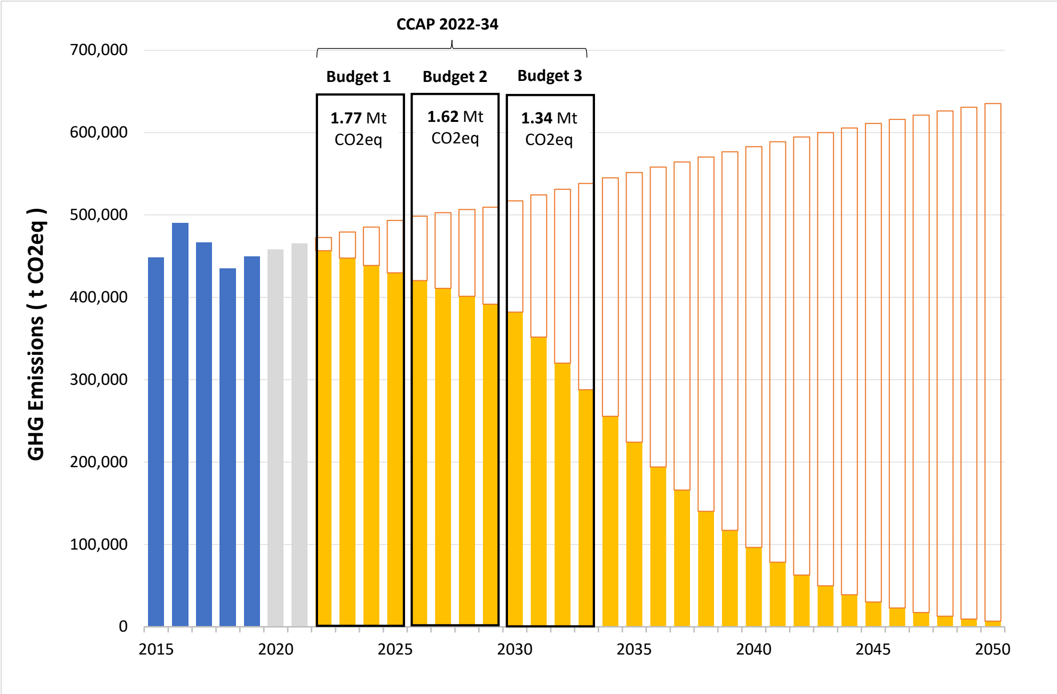


Figure 27: Canadian path to +1.5°C scenario: required emissions savings by broad source sector

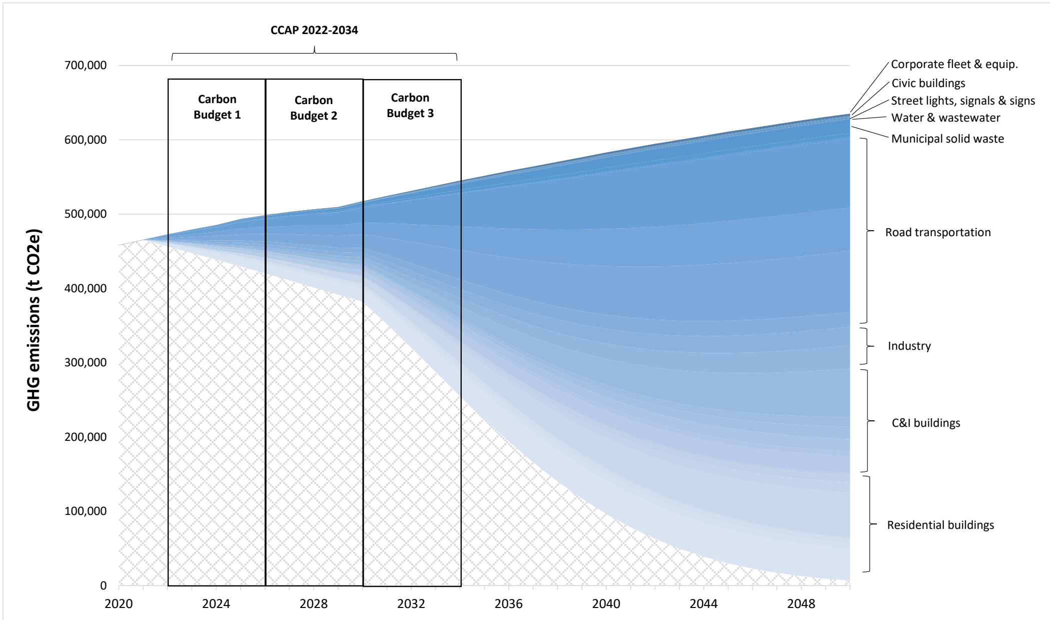


Table 4: Canadian path to +1.5°C scenario: required GHG emissions savings and corresponding energy cost savings and climate change damages avoided for each of the first three carbon budgets

Emissions source	Budget 1	Budget 2	Budget 3
Emissions savings by source (t CO_2e):			
Residential – Existing homes – Single family detached	25,676	54,296	91,143
Residential – Existing homes – Single family attached	5,936	12,168	19,851
Residential – Existing homes - Apartments	3,999	8,355	13,884
Residential – Existing homes - Mobile	1,109	2,381	4,050
Residential – New homes – Single family detached	4,933	18,587	47,142
Residential – New homes – Single family attached	1,179	4,406	11,137
Residential – New homes - Apartments	783	2,957	7,535
Residential – New homes - Mobile	213	814	2,088
C&I – Existing buildings - Retail trade	8,626	18,955	33,965
C&I – Existing buildings - Educational services	2,481	5,493	9,913
C&I - Existing buildings – Other sectors	5,509	12,229	22,209
C&I – New buildings - Retail trade	975	3,743	9,923
C&I – New buildings - Educational services	700	2,708	7,229
C&I - New buildings – Other sectors	3,367	13,048	35,073
Industry - Construction	5,140	13,876	29,167
Industry - Manufacturing	8,069	18,025	33,042
Road transport - Passenger cars	8,771	20,325	36,300
Road transport - SUVs & station wagons	20,608	53,117	105,173
Road transport - Light trucks & vans	18,988	46,106	86,594
Road transport - Medium trucks	20,942	57,384	117,857
Road transport - Motor cycles	386	1,026	2,111
Road transport - Buses	2,580	5,914	10,482
Solid waste disposal	4,016	10,466	21,139
Water & wastewater	209	447	803
Streetlights, signals & signs	251	533	947
Civic buildings – Existing - Agrena	540	1,165	2,040
Civic buildings – Existing - Border Paving Athletic Centre	96	206	358
Civic buildings – Existing - City Hall	97	204	353
Civic buildings – Existing -Protective Services (renovated)	242	534	950
Civic buildings – Existing - RCMP Facility	127	268	465
Civic buildings – Existing - PW Shop - Century Cl.	220	481	848
Civic buildings – Existing - Other	274	595	1,049
Civic buildings – New - Civic Centre	304	1,694	2,962
Fleet & equipment - Light duty vehicles	2	5	8
Fleet & equipment - Light duty trucks	26	63	117
Fleet & equipment - SGFS	11	27	51
Fleet & equipment - Medium duty trucks	32	76	143
Fleet & equipment - Heavy duty trucks	9	21	39
Fleet & equipment - Off-road & construction	87	209	389
Fleet & equipment - Tractors & agricultural equipment	107	257	479
Fleet & equipment - Transit buses	6	14	27
Total all sources	157,626	393,176	769,034
Reference Case emissions	1,930,087	2,014,112	2,110,806
Less total savings	157,626	393,176	769,034
Equals residual emissions	1,772,461	1,623,936	1,341,772
Carbon budget *equals* residual emissions	**1,772,461**	**1,623,936**	**1,341,772**
Energy cost savings ($ 2020 M):			
Community	51.5	137.2	267.0
Corporate	0.5	1.4	2.6
Total	52.0	138.6	269.6
Climate change damages avoided ($ 2020 M):	7.5	20.0	42.4

4 NEXT STEPS

After generating a projected GHG emissions inventory for Spruce Grove (Section 2.2), formulating science-based GHG emissions reduction targets for 2030 and 2050 (Section 3.3), and simulating scenarios and carbon budgets to achieve these targets (Section 3.4), the next step is to identify the specific things that need to change in Spruce Grove over the life of the CCAP to achieve the 2030 targets and keep the city on course to meet the long-term target for 2050. The emissions reduction scenarios simulated above identified the cuts required of each source in Spruce Grove to keep within the specified carbon budgets. We are now in a position to define and prioritize the actions (any policy, program, project, strategy, partnership, investment or infrastructure that leads to emissions reductions) needed to deliver the required emissions reductions over the period 2022-2030, and subsequently assemble them into a coherent implementation plan. These activities are covered in a separate technical report.

5 APPENDIX 1: MODELLING ASSUMPTIONS

Table 5: Reference Case: energy costs

Commodity	Units	Average value 2020-2050
Gasoline	($ 2020 per GJ)	33.0
Diesel	($ 2020 per GJ)	33.5
Electricity:		
Residential	($ 2020 per GJ)	37.1
Commercial & institutional	($ 2020 per GJ)	26.4
Industrial	($ 2020 per GJ)	19.6
Natural gas:		
Residential	($ 2020 per GJ)	7.9
Commercial & institutional	($ 2020 per GJ)	5.0
Industrial	($ 2020 per GJ)	4.3
Fuel oils:		
Residential	($ 2020 per GJ)	31.9
Commercial & institutional	($ 2020 per GJ)	30.4
Industrial	($ 2020 per GJ)	33.4

Source: National Energy Board, Canada's Energy Outlook 2020, Data Appendices [end-use prices under "Reference" scenario]

Table 6: Valuation of damages from GHG emissions

Valuation basis	Units	Average value 2020-2050
Social Cost of Carbon	($ 2020 per t CO_2)	60.0

Source: Authors calculations from Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide, Interim Estimates under Executive Order 13990, Interagency Working Group on Social Cost of Greenhouse Gases, United States Government [mean value at 3.5% real annual discount rate].

Table 7: Energy density of fuels

Commodity	Units	2020-2050
Gasoline	(GJ per m^3)	34.660
Diesel	(GJ per m^3)	38.680
Light fuel oil	(GJ per m^3)	37.027
Heavy fuel oil	(GJ per m^3)	41.730
Propane	(GJ per m^3)	25.530
Natural gas	(GJ per m^3)	0.0373

Source: Canada Energy Regulator (https://www.cer-rec.gc.ca/en/data-analysis/energy-conversion-tools/index.html)

Table 8: Reference Case: emission factors: stationary sources (excluding electricity)

Fuel	Units	CO_2	CH_4	N_2O	CO_2e
Natural gas	(grams per m^3)	1,928	0.037	0.035	1,939
Light fuel oil [a]	(grams per litre)	2,753	0.026	0.031	2,763
Heavy fuel oil [a]	(grams per litre)	3,156	0.057	0.064	3,176
Propane [b]	(grams per litre)	1,515	0.027	0.108	1,548
Propane [c]	(grams per litre)	1,515	0.024	0.108	1,548

Source: Based on Environment Canada's National Inventory Report 1990-2019: Greenhouse Gas Sources and Sinks in Canada, Part 2, Annex 6 Emission Factors [https://publications.gc.ca/collections/collection_2021/eccc/En81-4-2019-2-eng.pdf]

Notes: a. industry use; b. residential use; c. all other uses.

Table 9: Reference Case: emission factors: stationary sources (excluding electricity)

Fuel	Units	2020-2050
Gasoline – light duty vehicles	(t CO_2e per GJ)	0.0663
Gasoline – light duty trucks	(t CO_2e per GJ)	0.0663
Gasoline – heavy duty vehicles	(t CO_2e per GJ)	0.0678
Gasoline – off-road vehicles and equipment	(t CO_2e per GJ)	0.0743
Gasoline – motorcycles	(t CO_2e per GJ)	0.0675
Diesel – light duty vehicles	(t CO_2e per GJ)	0.0744
Diesel – light duty trucks	(t CO_2e per GJ)	0.0744
Diesel – heavy duty vehicles	(t CO_2e per GJ)	0.0739
Diesel – off-road vehicles and equipment	(t CO_2e per GJ)	0.0733

Source: Motorcycles is based on Environment Canada's National Inventory Report 1990-2019: Greenhouse Gas Sources and Sinks in Canada, Part 2, Annex 6 Emission Factors. All other fuels based on Partners for Climate Partners Protocol, Canadian Supplement to the International Emissions Analysis Protocol.

Table 10: Reference Case: emission factors: electricity from provincial grid

	Units	2020	2035	2050
Consumption intensity	(t CO_2e per GJ)	0.170	0.097	0.073

Source: Based on Environment Canada's National Inventory Report 1990-2019: Greenhouse Gas Sources and Sinks in Canada, Part 3, Annex 13 Electricity in Canada – Summary and Intensity Tables [https://publications.gc.ca/collections/collection_2021/eccc/En81-4-2019-3-eng.pdf] and AESO 2021 Long-term Outlook, June 2021. These consumption intensity emission factors include transmission line losses, metering differences and other losses.

Table 11: Global Warming Potential (GWP)

Commodity	100-year GWP
Methane, CH_4	25
Nitrous oxide, N_2O	298

Source: PCP Protocol, Canadian Supplement to the International Emissions Analysis Protocol, https://www.pcp-ppc.ca/resources/partners-for-climate-protection-protocol.

Notes: A global warming potential (GWP) is the time-integrated change in radiative forcing due to the instantaneous release of 1 kg of GHG expressed relative to the radiative forcing from the release of 1 kg of CO_2. The GWP of a GHG takes into account both the instantaneous radiative forcing due to an incremental concentration increase and the lifetime of the gas. It is a relative measure that allows for the characterization of GHG emissions in terms of how much CO_2 would be required to produce a similar warming effect over a given time period. For example, an emission of 10 kilo-tonnes (kt) of CH_4 is equivalent to 25 x 10 kt = 250 kt CO_2 eq.

Note that the GWPs in the PCP Protocol, which are based on the IPCC's Fourth Assessment Report, have been updated in the IPCC's Fifth Assessment Report (the GWPs for CH_4 and N_2O are, respectively 28 and 265.

Table 12: Discount rates

Component	Units	Rate
General price inflation	(% per year)	2.21
Real social discount rate	(% per year)	3.50
Nominal social discount rate	(% per year)	5.79

Source: Real social discount rate from Boyd et al., 2012, Economic Guidance for the Appraisal and Prioritization of Adaptation Actions, Ch. 7 Discounting Future Costs and Benefits, NRCAN. Average annual rate of general price inflation in Edmonton over period 12.1990 – 12.2020 [CPI: all-items], Table: 18-10-0004-11 [Stats Canada].

Table 13: Reference Case: absorbed land

	Units	2020	2035	2050
Residential	(ha per year)	35.6	34.0	30.0
Commercial	(ha per year)	5.3	5.1	4.5
Industrial	(ha per year)	13.6	13.1	11.5

Source: Adapted from Spruce Grove Growth Study, Final Report, ISL Engineering and Land Services, December 2016.

Table 14: Reference Case: population and households

	Units	2020	2035	2050
Population	(number)	37,504	55,978	74,104
Households:				
Single-family detached				
Pre-2020 stock	(number)	8,477	8,227	7,983
New construction	(number)	17	5,294	10,727
Single-family attached				
Pre-2020 stock	(number)	2,224	2,158	2,094
New construction	(number)	4	1,424	2,910
Apartments				
Pre-2020 stock	(number)	1,849	1,794	1,741
New construction	(number)	4	986	1,900
Movable homes				
Pre-2020 stock	(number)	844	819	795
New construction	(number)	2	510	943

Source: Adapted from Spruce Grove Growth Study, Final Report, ISL Engineering and Land Services, December 2016.

Table 15: Reference Case: dwelling size and total energy use intensity

	Units	2020	2035	2050
Single-family detached:				
Size, pre-2020 stock	(m^2)	151	151	151
Size, new construction	(m^2)	152	160	168
Energy use intensity (total)	(GJ per m^2)	0.94	0.76	0.60
Single-family attached:				
Size, pre-2020 stock	(m^2)	202	202	202
Size, new construction	(m^2)	204	236	268
Energy use intensity (total)	(GJ per m^2)	0.62	0.45	0.34
Apartment:				
Size, pre-2020 stock	(m^2)	148	148	148
Size, new construction	(m^2)	150	166	183
Energy use intensity (total)	(GJ per m^2)	0.68	0.53	0.41
Movable home:				
Size, pre-2020 stock	(m^2)	42	42	42
Size, new construction	(m^2)	42	44	47
Energy use intensity (total)	(GJ per m^2)	1.53	1.25	1.03

Source: Author's calculations based on Natural Resources Canada's Comprehensive Energy End-use Database, Residential Sector, Alberta.

Table 16: Reference Case: industrial employment and total energy use intensity

	Units	2020	2035	2050
Construction sector:				
Employment	(employees)	3,175	6,210	10,975
Energy use intensity (total)	(GJ per employee)	65.29	53.20	43.36
Manufacturing sector:				
Employment	(employees)	1,100	1,450	1,730
Energy use intensity (total)	(GJ per employee)	374.48	271.94	197.48

Source: Author's calculations based on Natural Resources Canada's Comprehensive Energy End-use Database, Residential Sector, Alberta; Labour force characteristics by industry, annual, Statistics Canada, Table 14-10-0023-01; Natural Resources Canada's Comprehensive Energy End-use Database, Industrial Sector, Alberta; and Census Profile 2016, Spruce Grove CY, Statistics Canada.

Table 17: Reference Case: commercial floorspace and total energy use intensity

	Units	2020	2035	2050
Retail trade:				
Pre-2020 stock	(000 m^2)	201.4	195.0	189.6
New construction	(000 m^2)	4.7	72.1	141.2
Energy use intensity (total)	(GJ per m^2)	1.58	1.73	1.97
Offices:				
Pre-2020 stock	(000 m^2)	19.0	18.5	17.9
New construction	(000 m^2)	11.6	175.5	344.4
Energy use intensity (total)	(GJ per m^2)	1.14	1.27	1.51
Educational services:				
Pre-2020 stock	(000 m^2)	73.5	71.3	69.2
New construction	(000 m^2)	4.3	65.7	128.8
Energy use intensity (total)	(GJ per m^2)	1.29	1.42	1.66
Healthcare & social assistance:				
Pre-2020 stock	(000 m^2)	17.2	16.7	16.2
New construction	(000 m^2)	2.0	30.0	58.8
Energy use intensity (total)	(GJ per m^2)	2.17	2.84	4.36
Accommodation & food services:				
Pre-2020 stock	(000 m^2)	20.4	19.8	19.2
New construction	(000 m^2)	1.9	28.8	56.4
Energy use intensity (total)	(GJ per m^2)	2.23	2.43	2.79
Other services:				
Pre-2020 stock	(000 m^2)	25.5	24.8	24.0
New construction	(000 m^2)	0.4	6.6	13.0
Energy use intensity (total)	(GJ per m^2)	1.21	1.34	1.57
Wholesale, transport & warehousing:				
Pre-2020 stock	(000 m^2)	10.6	10.3	9.9
New construction	(000 m^2)	1.1	16.3	32.0
Energy use intensity (total)	(GJ per m^2)	1.22	1.30	1.43
Arts, entertainment, recreation, cultural:				
Size, pre-2020 stock	(000 m^2)	36.6	35.5	34.4
Size, new construction	(000 m^2)	1.4	20.9	40.9
Energy use intensity (total)	(GJ per m^2)	1.49	1.62	1.84

Source: Author’s calculations based on Natural Resources Canada’s Comprehensive Energy End-use Database, Residential Sector, Alberta.

Table 18: Reference Case: commercial floorspace and total energy use intensity

	Units	2020	2035	2050
Light duty vehicles:				
Registrations	(number)	12,670	16,530	20,735
Average distance travelled	(km)	12,970	11,500	10,195
Fuel economy - gasoline	(litres per 100 km)	7.5	6.4	5.5
Fuel economy - diesel	(litres per 100 km)	6.0	5.2	4.6
Light duty trucks:				
Registrations	(number)	29,590	45,605	63,040
Average distance travelled	(km)	13,800	13,620	13,440
Fuel economy - gasoline	(litres per 100 km)	12.1	10.8	9.5
Fuel economy - diesel	(litres per 100 km)	11.1	10.4	9.8
Medium trucks:				
Registrations	(number)	2,980	7,405	12,230
Average distance travelled	(km)	34,310	30,535	27,180
Fuel economy - gasoline	(litres per 100 km)	20.6	17.8	15.3
Fuel economy - diesel	(litres per 100 km)	20.5	17.4	14.8
Motorcycles:				
Registrations	(number)	2,080	2,345	4,515
Average distance travelled	(km)	4,110	4,330	4,560
Fuel economy - gasoline	(litres per 100 km)	5.3	5.5	5.7
Fuel economy - diesel	(litres per 100 km)	-	-	-
Buses:				
Registrations	(number)	120	125	130
Average distance travelled	(km)	49,050	52,650	56,510
Fuel economy - gasoline	(litres per 100 km)	34.3	29.8	25.9
Fuel economy - diesel	(litres per 100 km)	38.3	33.3	28.9

Source: Author's calculations based on Natural Resources Canada's Comprehensive Energy End-use Database, Residential Sector, Alberta; and vehicle registration data from the MOVES Vehicle Registry File of the Alberta Government.

Table 19: Reference Case: residential solid waste generation and diversion

	Units	2020	2035	2050
Waste generation	(tonnes)	13,660	20,054	26,600
Waste diversion from landfill	(%)	0.40	0.43	0.47

Source: City of Spruce Grove.

Table 20: Reference Case: residential water consumption

	Units	2020	2035	2050
Residential water use	(m3 per person per year)	73.2	62.8	60.7

Source: Based on historic water consumption data provided by the City of Spruce Grove

Table 21: Reference Case: streetlights and signs

	Units	2020	2035	2050
Crosswalks	(number)	9	12	15
Signs	(number)	6	8	10
Streetlights	(number)	3,645	4,890	6,040
Traffic lights	(number)	35	45	60

Source: Based on Spruce Grove Growth Study, Final Report, ISL Engineering and Land Services, December 2016; and City of Spruce Grove

Table 22: Reference Case: corporate fleet 2020-2050 [a]

Vehicle or equipment type	Vehicle count (number)	Average distance travelled (km per vehicle per year)
Light duty vehicles	4	6,740
Light duty trucks	39	7,125
Medium duty trucks	16	10,685
Heavy duty trucks	8	6,935
SGFS	6	10,950
Off-road and construction	20	16,095
Transit buses	6	4,220
Tractors and agricultural equipment	48	-

Source: City of Spruce Grove.

Notes: a. the number and average distance travelled of all corporate vehicles is assumed to remain unchanged across time under the Reference Case, with the exception of transit buses which increased from 3 in 2020 to 6 in 2021.

Table 23: Reference Case: civic buildings and facilities 2020-2050 [a]

Building or facility	Area (m^2)	Natural gas intensity (GJ per m^2)	Electricity intensity (GJ per m^2)
Agrena	7,462	1.85	0.90
Border Paving Athletic Centre	2,728	0.81	0.47
Brookwood Rink	107	1.58	0.21
City Hall	3,514	0.54	0.40
Eco Centre	108	0.37	1.14
Elks Hall	800	1.64	0.37
Family and Community Support Services	627	-	0.45
Fuhr Sports Park/ West District Park	733	1.92	0.69
Protective Services (renovated)	5,811	1.36	0.41
RCMP Facility	5,045	0.51	0.36
Jubilee Park Spray Park / PW	620	0.88	0.67
Library	1,705	0.63	0.50
Log Cabin	379	1.02	0.31
PW Shop - Century Cl.	7,176	0.89	0.34
PW Shop - Schram St.	1,825	1.02	0.16
PW Spruce Ridge Satellite	127	0.60	0.10
Transit Building	1,654	0.50	0.04
Aspenglen Rink	9	-	2.19
Henry Singer Park	89	-	0.16
Columbus Park	1,810	-	0.04
Central Park - Christmas tree lights	11,830	-	<0.01
Other (tunnel and rink)	1,200	-	0.03
Civic Centre [b]	12,077	1.62	0.82

Source: City of Spruce Grove and the City of Spruce Grove Energy Benchmarking Report, Municipal Climate Change Action Centre, August 30, 2021.

Notes: a. the size and energy intensity of all civic buildings and facilities is assumed to remain unchanged across time under the Reference Case; b. the new Civic Centre is assumed to be operational on 1 January 2025.

6 APPENDIX 2: CITY-LEVEL SUMMARY TABLES AND FIGURE

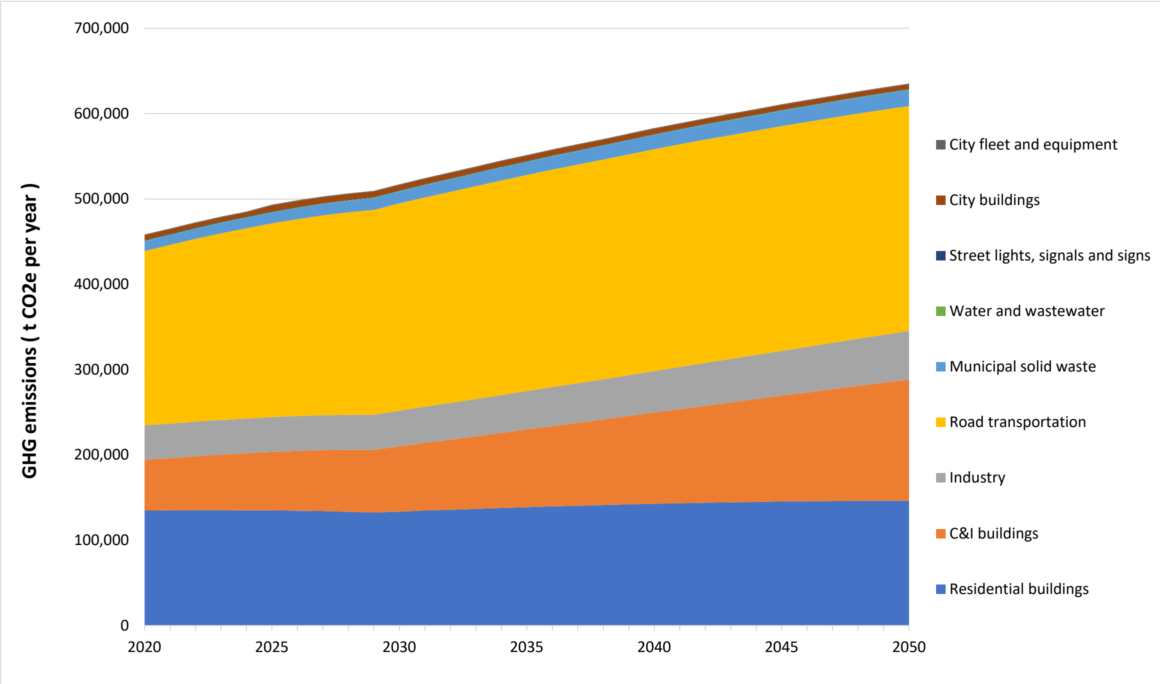
Table 24: Projected city-wide GHG emissions under the Reference Case for the period 2020-2050

		2020	2025	2030	2035	2040	2045	2050
Residential buildings								
Electricity	(t CO2e)	57,333	51,846	45,900	47,358	48,332	48,674	48,243
Natural gas	(t CO2e)	73,816	79,459	84,204	88,002	91,220	93,690	95,269
Other	(t CO2e)	3,766	3,667	3,529	3,362	3,191	3,013	2,830
Sub-total	(t CO2e)	134,915	134,972	133,633	138,722	142,743	145,377	146,342
ICI buildings								
Electricity	(t CO2e)	36,037	38,414	39,240	46,298	53,974	62,182	70,717
Natural gas	(t CO2e)	21,405	27,513	33,778	40,192	47,012	54,207	61,751
Other	(t CO2e)	1,847	2,584	3,480	4,572	5,937	7,638	9,753
Sub-total	(t CO2e)	59,289	68,511	76,499	91,062	106,923	124,026	142,221
Industry								
Electricity	(t CO2e)	18,724	14,874	11,471	10,265	9,040	7,823	6,629
Natural gas	(t CO2e)	10,714	12,738	14,854	17,085	19,479	22,014	24,615
Diesel fuel oil, light fuel oil and kerosene	(t CO2e)	9,566	11,374	13,263	15,255	17,393	19,656	21,978
Heavy fuel oil	(t CO2e)	138	164	191	219	250	283	316
LPG and NGL	(t CO2e)	1,383	1,645	1,918	2,206	2,515	2,842	3,178
Sub-total	(t CO2e)	40,525	40,795	41,695	45,030	48,676	52,617	56,716
Road transportation								
Gasoline	(t CO2e)	165,745	183,051	195,323	203,279	208,567	211,261	211,474
Diesel	(t CO2e)	38,228	43,515	47,207	49,568	51,080	51,808	51,820
Natural gas	(t CO2e)	0	0	0	0	0	0	0
Hybrid	(t CO2e)	455	399	327	323	314	301	283
Electric	(t CO2e)	19	15	12	11	10	9	8
Sub-total	(t CO2e)	204,446	226,979	242,869	253,181	259,971	263,379	263,585
Municipal solid waste								
Landfill methane	(t CO2e)	11,185	12,682	14,087	15,419	16,709	17,925	19,000
Water and wastewater								
Electricity	(t CO2e)	78	83	90	98	107	116	125
Natural gas	(t CO2e)	641	542	460	461	459	453	440
Sub-total	(t CO2e)	719	625	550	558	566	569	565
Street lights, signals and signs								
Electricity	(t CO2e)	851	752	650	654	649	630	602
City buildings								
Electricity	(t CO2e)	3,258	3,919	3,071	2,831	2,592	2,352	2,112
Natural gas	(t CO2e)	2,207	3,224	3,224	3,224	3,224	3,224	3,224
Sub-total	(t CO2e)	5,465	7,143	6,295	6,055	5,815	5,575	5,335
City fleet and equipment								
Gasoline	(t CO2e)	175	161	161	161	161	161	161
Diesel	(t CO2e)	701	701	701	701	701	701	701
Natural gas	(t CO2e)	0	0	0	0	0	0	0
Hybrid	(t CO2e)	0	0	0	0	0	0	0
Electric	(t CO2e)	0	0	0	0	0	0	0
Sub-total	(t CO2e)	876	862	862	862	862	862	862
All sources of GHG emissions								
Electricity	(t CO2e)	116,754	110,303	100,762	107,837	115,017	122,086	128,718
Natural gas	(t CO2e)	108,783	123,476	136,519	148,963	161,395	173,587	185,298
Diesel fuel oil, light fuel oil and kerosene	(t CO2e)	9,566	11,374	13,263	15,255	17,393	19,656	21,978
Heavy fuel oil	(t CO2e)	138	164	191	219	250	283	316
LPG and NGL	(t CO2e)	1,383	1,645	1,918	2,206	2,515	2,842	3,178
Other (buildings)	(t CO2e)	5,613	6,251	7,009	7,934	9,127	10,651	12,583
Gasoline	(t CO2e)	165,920	183,212	195,484	203,441	208,728	211,422	211,635
Diesel	(t CO2e)	38,929	44,216	47,908	50,269	51,781	52,509	52,521
Landfill methane	(t CO2e)	11,185	12,682	14,087	15,419	16,709	17,925	19,000
Total	(t CO2e)	**458,271**	**493,321**	**517,140**	**551,544**	**582,916**	**610,961**	**635,228**

Table 25: Projected city-wide energy costs under the Reference Case for the period 2020-2050

		2020	2025	2030	2035	2040	2045	2050
Residential buildings								
Electricity	($ 2020 M)	9.86	13.72	15.73	18.16	20.95	23.93	27.20
Natural gas	($ 2020 M)	9.11	11.74	13.15	13.57	14.16	14.33	14.33
Other	($ 2020 M)	1.29	1.70	1.65	1.54	1.44	1.34	1.23
Sub-total	($ 2020 M)	20.27	27.16	30.53	33.27	36.55	39.59	42.77
C&I buildings								
Electricity	($ 2020 M)	4.40	7.22	9.56	12.62	16.62	21.73	28.34
Natural gas	($ 2020 M)	1.48	2.56	3.40	3.97	4.67	5.27	5.83
Other	($ 2020 M)	0.61	1.15	1.56	1.99	2.55	3.24	4.06
Sub-total	($ 2020 M)	6.49	10.93	14.52	18.58	23.84	30.23	38.23
Industry								
Electricity	($ 2020 M)	1.70	2.08	2.08	2.08	2.07	2.03	1.97
Natural gas	($ 2020 M)	0.46	1.05	1.33	1.49	1.71	1.88	2.04
Diesel fuel oil, light fuel oil and kerosene	($ 2020 M)	3.57	5.45	6.30	6.98	7.76	8.55	9.29
Heavy fuel oil	($ 2020 M)	0.05	0.08	0.09	0.10	0.11	0.12	0.13
LPG and NGL	($ 2020 M)	0.54	0.82	0.95	1.05	1.17	1.29	1.40
Sub-total	($ 2020 M)	6.32	9.47	10.74	11.70	12.82	13.87	14.83
Road transportation								
Gasoline	($ 2020 M)	68.93	97.28	102.52	102.32	102.03	100.33	97.32
Diesel	($ 2020 M)	14.36	21.00	22.59	22.84	22.96	22.68	22.05
Natural gas	($ 2020 M)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hybrid	($ 2020 M)	0.07	0.10	0.11	0.12	0.13	0.14	0.16
Electric	($ 2020 M)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sub-total	($ 2020 M)	83.37	118.38	125.23	125.29	125.12	123.16	119.53
Municipal solid waste								
Landfill methane	($ 2020 M)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water and wastewater								
Electricity	($ 2020 M)	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Natural gas	($ 2020 M)	0.08	0.10	0.11	0.13	0.14	0.16	0.18
Sub-total	($ 2020 M)	0.08	0.11	0.12	0.14	0.15	0.17	0.19
Street lights, signals and signs								
Electricity	($ 2020 M)	0.10	0.14	0.16	0.18	0.20	0.22	0.24
City buildings								
Electricity	($ 2020 M)	0.40	0.74	0.75	0.77	0.80	0.82	0.85
Natural gas	($ 2020 M)	0.15	0.30	0.32	0.32	0.32	0.31	0.30
Sub-total	($ 2020 M)	0.55	1.04	1.07	1.09	1.12	1.13	1.15
City fleet and equipment								
Gasoline	($ 2020 M)	0.07	0.08	0.08	0.08	0.08	0.08	0.07
Diesel	($ 2020 M)	0.27	0.34	0.34	0.33	0.32	0.31	0.30
Natural gas	($ 2020 M)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hybrid	($ 2020 M)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Electric	($ 2020 M)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sub-total	($ 2020 M)	0.34	0.43	0.42	0.41	0.40	0.39	0.37
All sources of GHG emissions								
Electricity	($ 2020 M)	16.55	24.01	28.39	33.95	40.79	48.89	58.77
Natural gas	($ 2020 M)	11.29	15.75	18.32	19.48	21.00	21.95	22.68
Diesel fuel oil, light fuel oil and kerosene	($ 2020 M)	3.57	5.45	6.30	6.98	7.76	8.55	9.29
Heavy fuel oil	($ 2020 M)	0.05	0.08	0.09	0.10	0.11	0.12	0.13
LPG and NGL	($ 2020 M)	0.54	0.82	0.95	1.05	1.17	1.29	1.40
Other (buildings)	($ 2020 M)	1.90	2.85	3.21	3.53	3.99	4.58	5.29
Gasoline	($ 2020 M)	69.00	97.36	102.61	102.40	102.10	100.40	97.40
Diesel	($ 2020 M)	14.62	21.34	22.93	23.17	23.27	22.99	22.35
Landfill methane	($ 2020 M)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	($ 2020 M)	**117.52**	**167.66**	**182.80**	**190.65**	**200.19**	**208.76**	**217.32**

Figure 28: Projected city-wide GHG emissions under the Reference Case for the period 2020-2050



7 APPENDIX 3: ROAD TRANSPORTATION SUMMARY FIGURES

Figure 29: Projected road transportation GHG emissions under the Reference Case for 2020 and 2050, by vehicle type

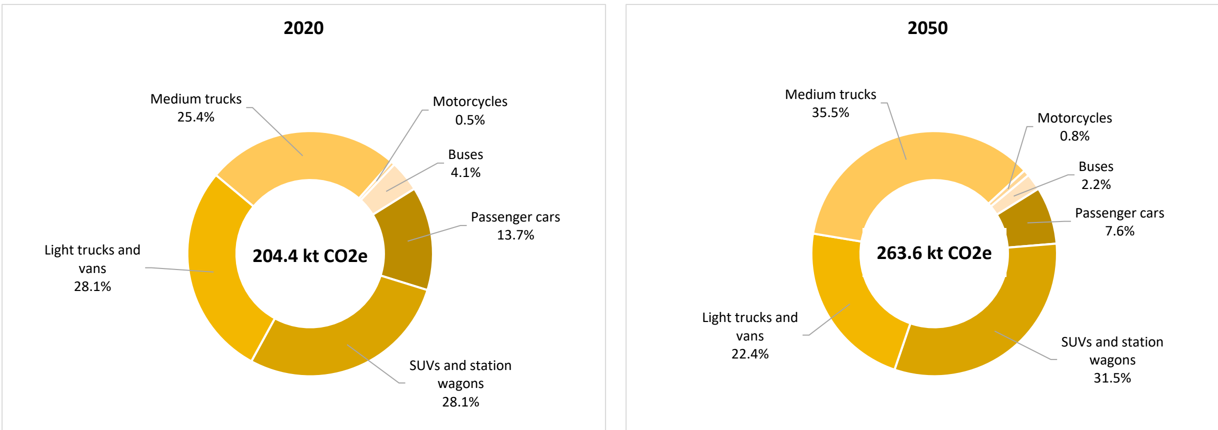


Figure 30: Projected road transportation GHG emissions and energy costs under the Reference Case for 2020 and 2050, by energy source

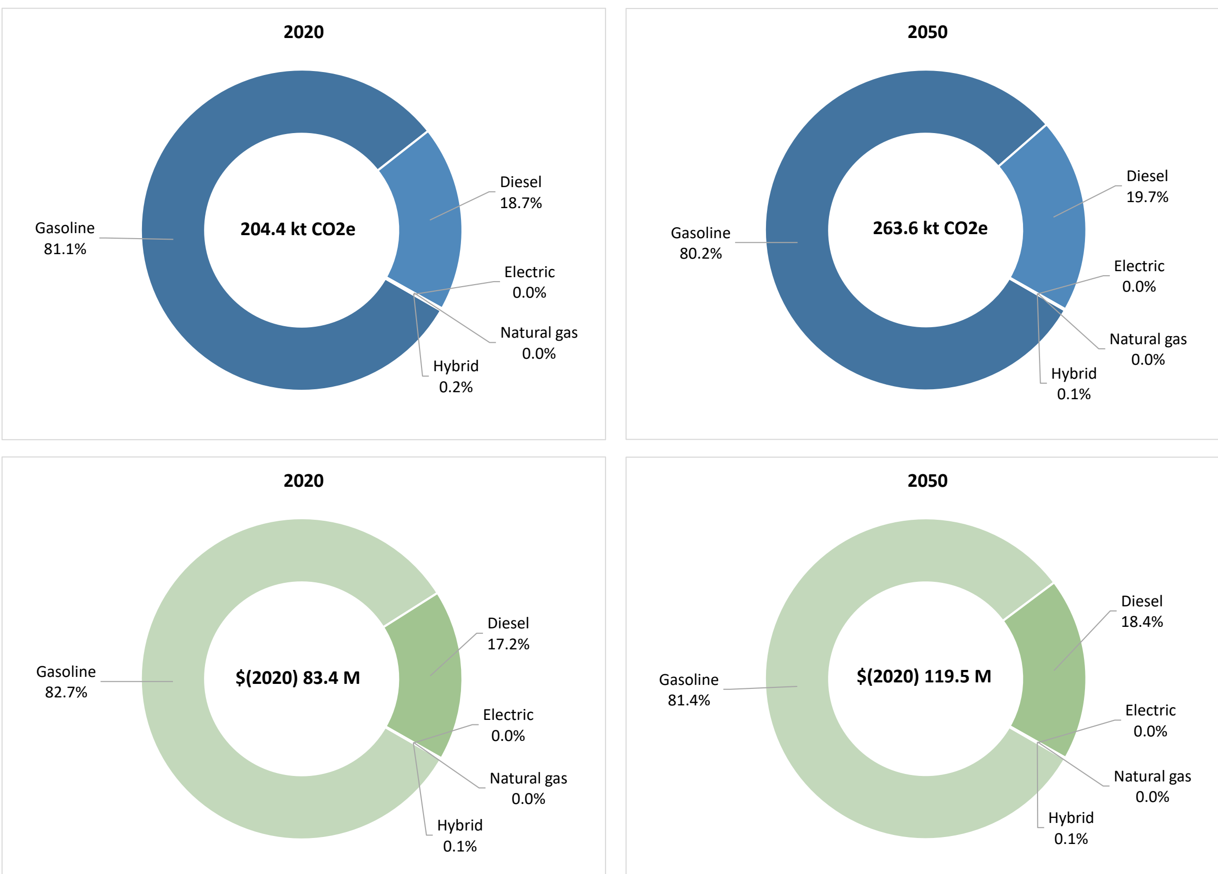
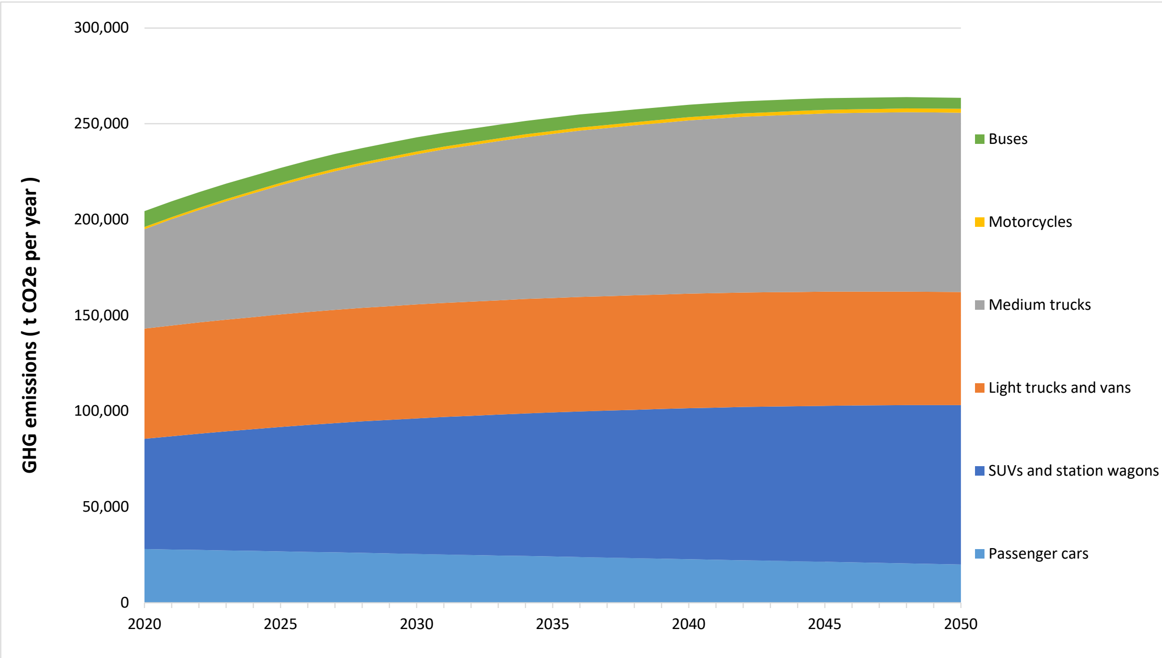


Figure 31: Projected road transportation GHG emissions under the Reference Case for the period 2020-2050, by vehicle type



8 APPENDIX 4: RESIDENTIAL SUMMARY FIGURES

Figure 32: Projected residential buildings GHG emissions under the Reference Case for 2020 and 2050, by building type, end-use activity, and energy source

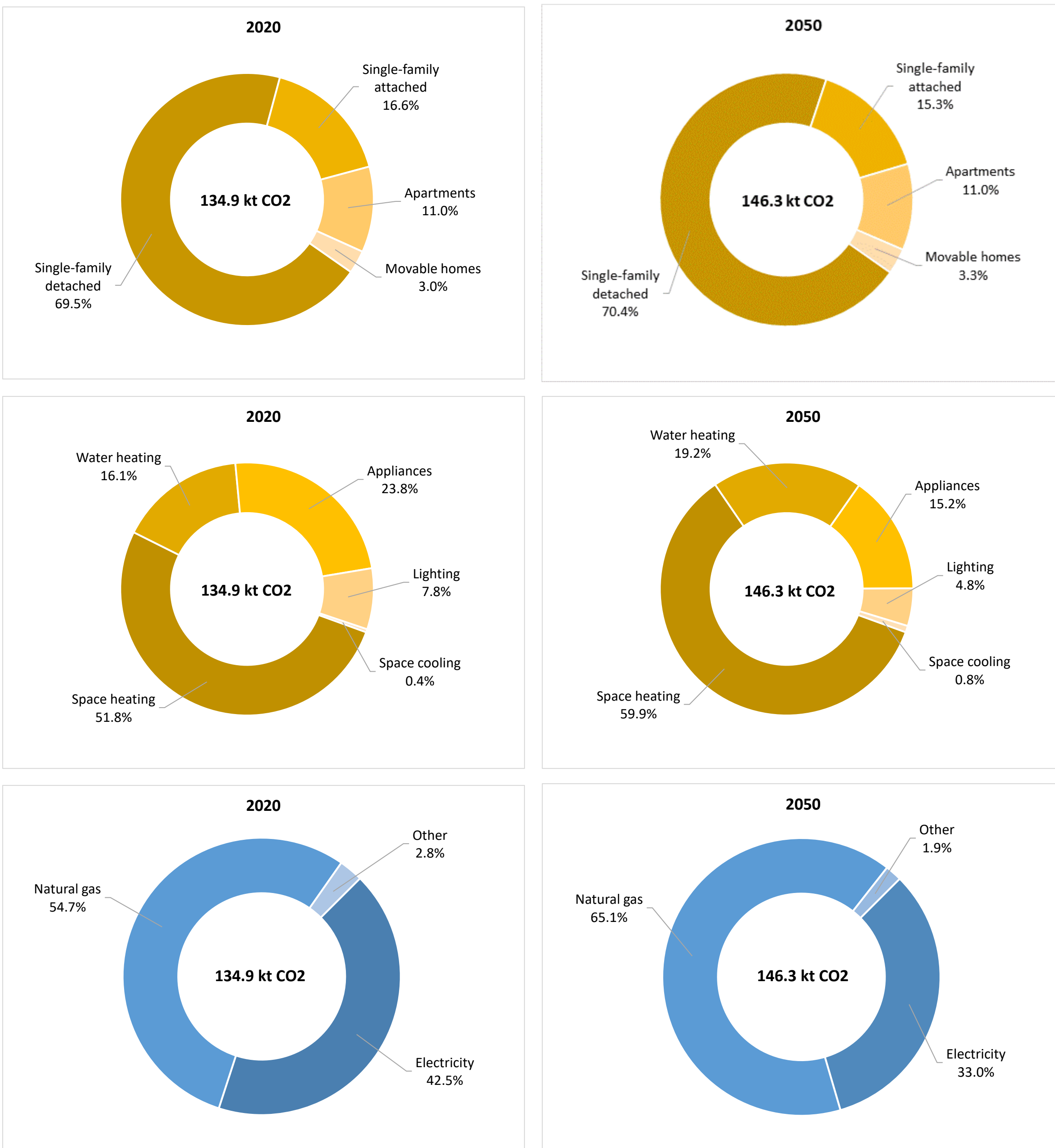
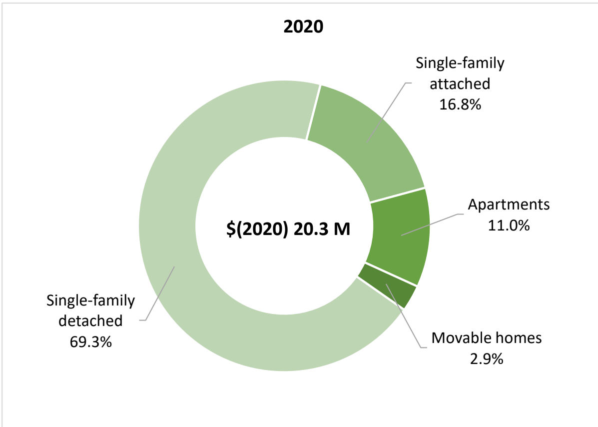


Figure 33: Projected residential buildings energy costs under the Reference Case for 2020 and 2050, by building type



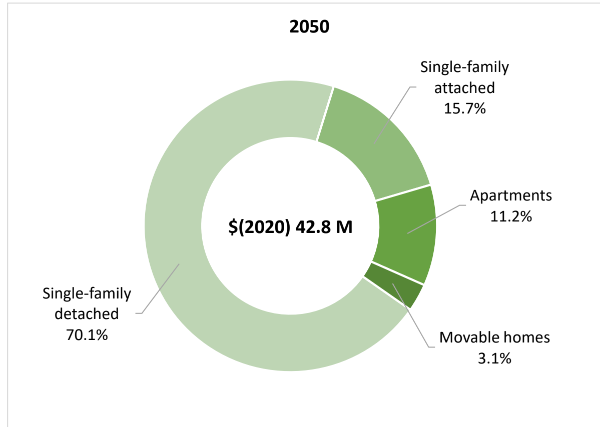
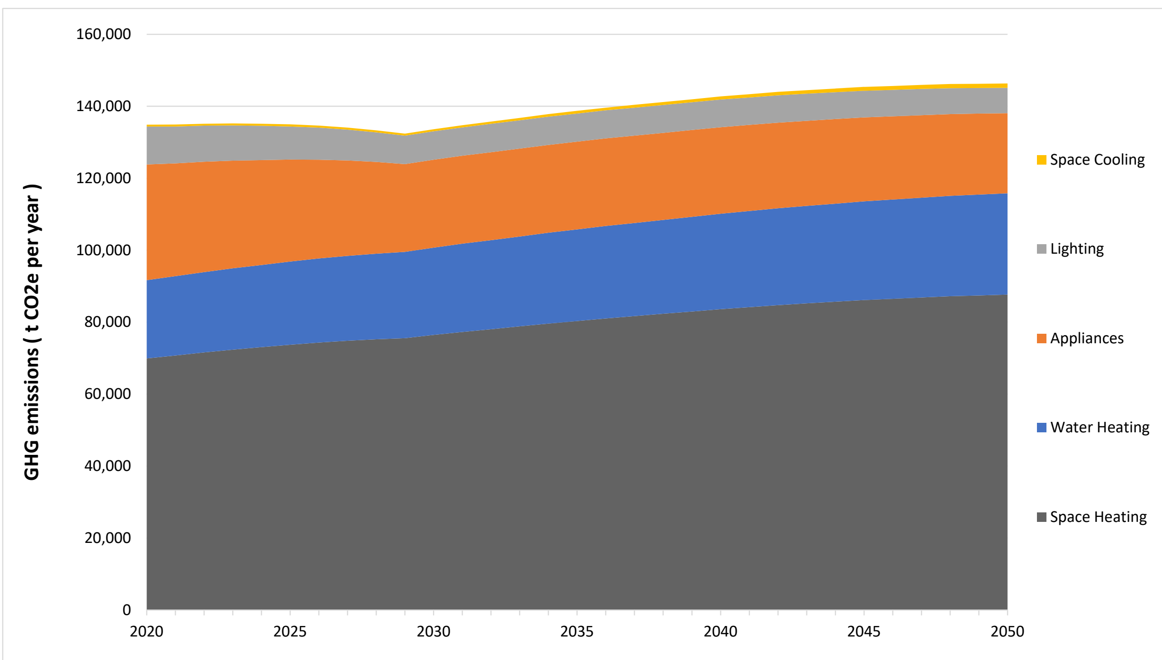


Figure 34: Projected residential buildings GHG emissions under the Reference Case for the period 2020-2050, by end-use activity



9 APPENDIX 5: C&I BUILDINGS SUMMARY FIGURES

Figure 35: Projected commercial and institutional buildings GHG emissions under the Reference Case for 2020 and 2050, by economic sector, end-use activity, and energy source

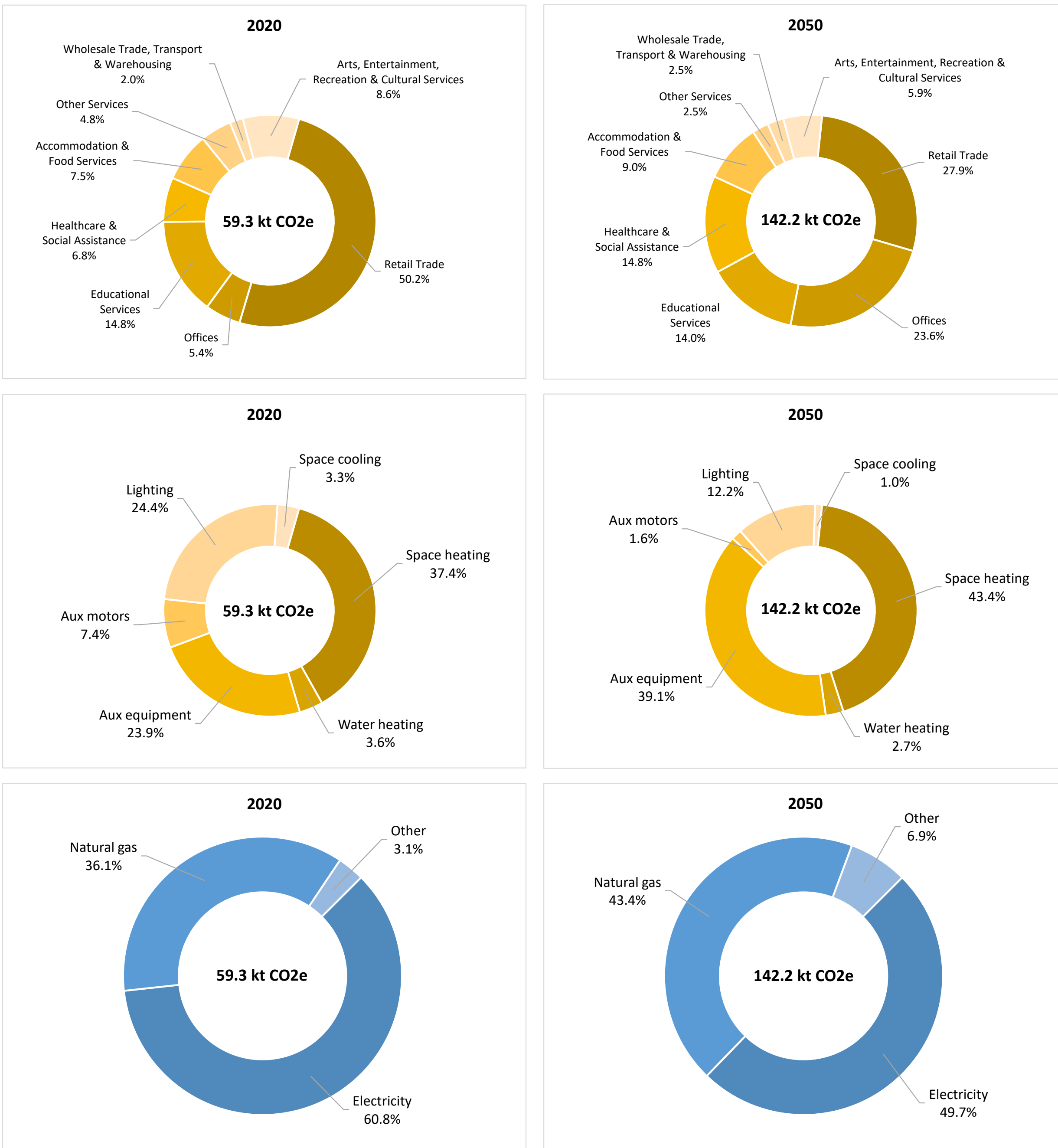


Figure 36: Projected commercial and institutional buildings energy costs under the Reference Case for 2020 and 2050, by economic sector

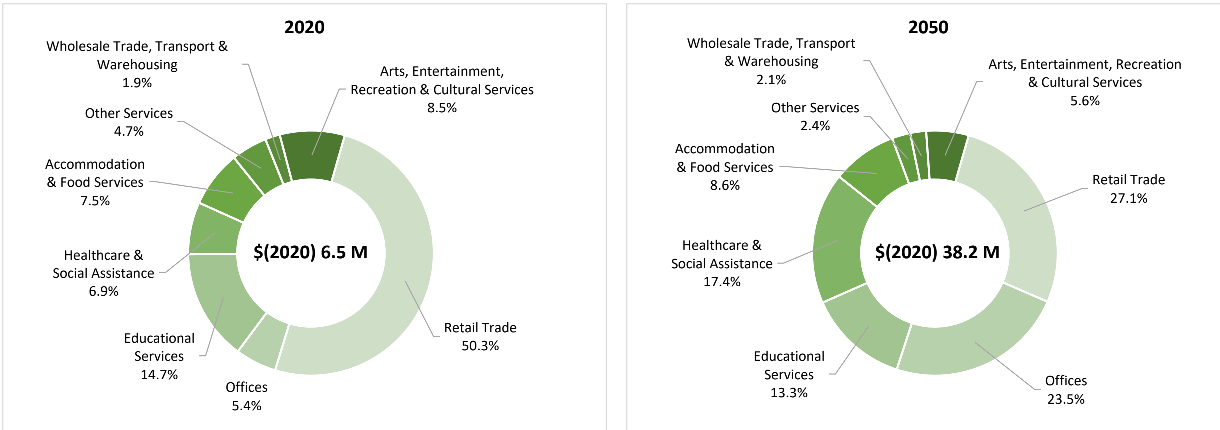
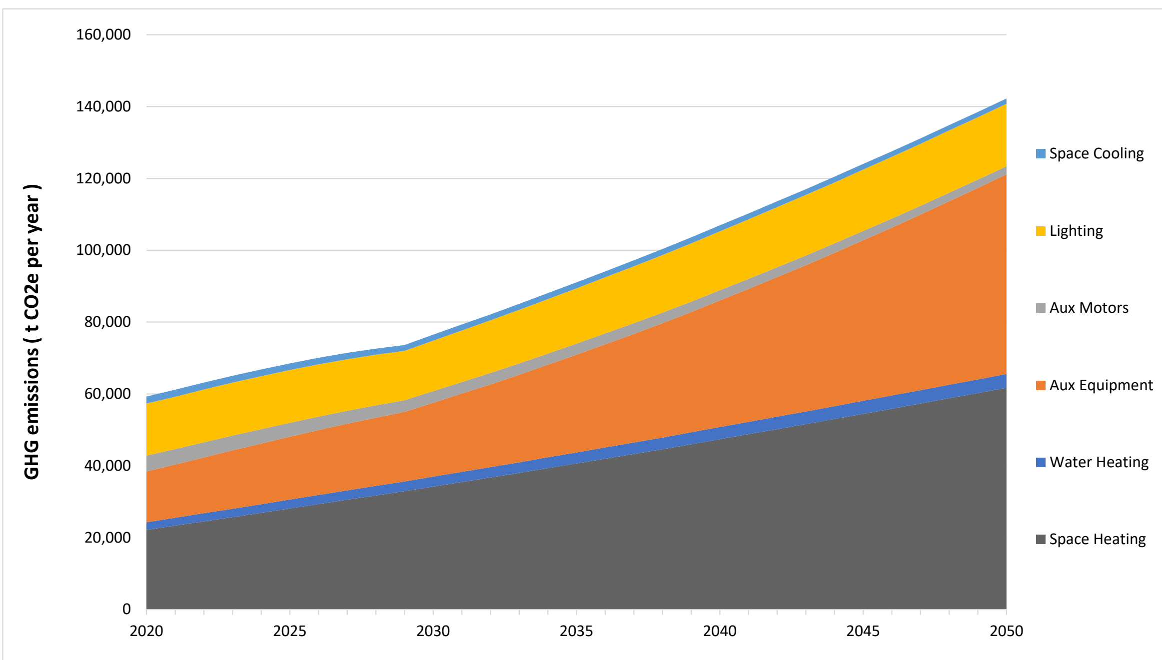
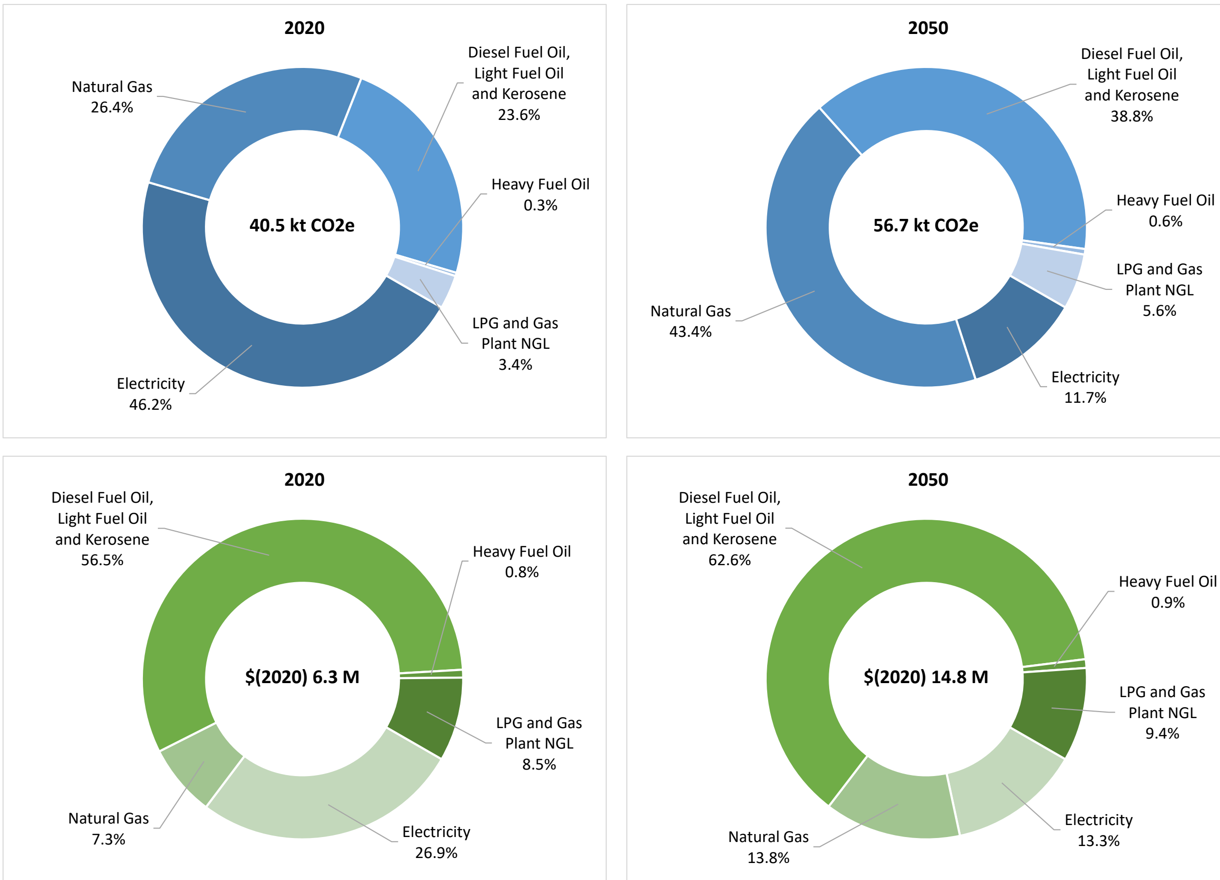


Figure 37: Projected commercial and institutional buildings GHG emissions under the Reference Case for the period 2020-2050, by end-use activity



10 APPENDIX 6: INDUSTRY SUMMARY FIGURES

Figure 38: Projected industry GHG emissions and energy costs under the Reference Case for 2020 and 2050, by energy source



ALL ONE SKY FOUNDATION is a not-for-profit, charitable organization established to help vulnerable populations at the crossroads of energy and climate change. We do this through education, research and community-led programs, focusing our efforts on adaptation to climate change and energy poverty. Our vision is a society in which ALL people can afford the energy they require to live in warm, comfortable homes, in communities that are resilient and adaptive to a changing climate.

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