City of Winnipeg

Community Energy Investment Roadmap

SSG

Winnipeg

Acknowledgements

Land Acknowledgement

Winnipeg is located in Treaty One Territory, the home and traditional lands of the Anishinaabe (Ojibwe), Ininew (Cree), and Dakota peoples, and in the National Homeland of the Red River Métis. Our clean drinking water comes from Shoal Lake 40 First Nation, in Treaty Three Territory. The electrical and natural gas systems that we rely on are located and operate across Manitoba, in Treaty 1, Treaty 2, Treaty 3, Treaty 4 and Treaty 5 Territory. The City of Winnipeg recognizes the important contributions of First Nations, Inuit, and Métis Peoples connected to the founding of our city and in the ongoing growth and prosperity of our communities.

Contributors to the Roadmap

CITY OF WINNIPEG TEAM

Lindsay Mierau
Darcy McGregor
Stephanie Whitehouse
Gurmeet Ghera
Jeanette Sivilay
Alara Brinton
Janelle Harper
Danny Powell
Becky Raddatz

CITY OF WINNIPEG INTERNAL WORKING GROUP

Chris Baker, Jennifer Bodnarchuk, Richard Bolton, Rob Carroll, Susanne Dewey Povoledo, Justin Dallmann, Lisa Gilmour, Linda Hathout, Rick Klassen, Jean-Luc Lambert, Tyler Markowsky, Ken McKim, Michelle Paetkau, Rod Penner, Mike Pyl, Bjorn Radstrom, Laura Rempel, David Tang, Ajaleigh Williams

WINNIPEG TECHNICAL ADVISORY GROUP

Josh Brandon, Dennis Cunningham, Levi Higgs, Tracey Hucul, Curt Hull, Durdana Islam, Mel Marginent, Lanny McInnes, Janetta McKenzie, Darrel Olson, Harry Schroeder, Dudley Thompson, Laura Tyler, Efficiency Manitoba, Climate Action Team, Green Action Centre, Sustainable Buildings Manitoba, Canadian Centre for Policy Alternatives, Winnipeg Chamber of Commerce, Manitoba Home Builders Association Canada, Green Building Council, International Institute for Sustainable Development, Assiniboine Credit Union, Climate Change Connection

SSG AND WHATIF?TECHNOLOGIES TEAM

Camilla Melrose, Lead Consultant, SSG

John Kong, Senior Modeler, whatIf? Technologies

Marcus Williams, Lead Modeler, whatIf? Technologies

Naomi Devine, Senior Consultant, SSG

Yuill Herbert, Principal, SSG

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A Note on COVID-19

The analysis in this document was completed during the COVID-19 pandemic, but does not include specific modelling to reflect the changes in work, travel, and lifestyles as a result of the pandemic. Even so, the analysis continues to be relevant not only because the climate crisis persists, but also because this document provides solutions that can stimulate the economy during the pandemic-induced recession. The solutions this report recommends range from retrofits to investing in renewable energy. They are designed to decrease emissions and costs and increase energy efficiency, while stimulating economic opportunity and creating new jobs. In the context of COVID-19, some key points to consider include:

- A global health crisis: The pandemic has radically transformed societies and economies, resulting in tragedy and disrupting work and home life around the world.
- The impacts of COVID-19 are unclear: The negative impact of COVID-19 on people, workplaces, and the economy, as well as the duration of those impacts presents many uncertainties. The recovery will be affected by a combination of factors such as the evolution of the pandemic, public health guidance on lifting COVID-19 health restrictions, the design of public policy responses and the continuing response by global institutions.
- The climate emergency remains an emergency[1]: While there was a short-term reduction in greenhouse gas (GHG) emissions, concentrations of GHG emissions in the atmosphere have continued to climb[2] and global temperatures continue to increase.[3] The pandemic has also disrupted international efforts to address climate change.
- There are challenges and opportunities: In the short term, the impacts of COVID-19 both challenge and reinforce actions outlined in this Roadmap.
- Substantively addressing climate change is more relevant than ever: Investments made now lock in emissions for decades. This Roadmap identifies investments that stimulate the economy and decarbonize Winnipeg by 2050.
- Alignment with green stimulus: As Canada initiates efforts to recover from the impact of COVID-19, there is an opportunity to stimulate the economy with investments that simultaneously address the climate crisis. This Roadmap describes an investment opportunity that will generate jobs, stimulate businesses, reduce GHG emissions, and provide benefits for Winnipeg.

[1] The Climate Clock highlights how little time remains to limit warming to the critical threshold of 1.5°C. See: https://climateclock.world/science

[2] For real time tracking of CO2 emissions, see: NOAA. Earth System Research Laboratories. Retrieved from: https://gml.noaa.gov/ccgg/trends/weekly.html

[3] NASA (2022). 2021 Tied for 6th Warmest Year in Continued Trend, NASA Analysis Shows. Retrieved from: https://www.giss.nasa.gov/research/news/20220113/

A Note on COP 26

The UN Conference of the Parties (COP 26) held in November 2021 in Glasgow was a pivotal moment for climate change, phase shifting GHG mitigation from the margins to the mainstream. More than 100 heads of states joined 37,000 delegates for two weeks of negotiations. While there were many developments, some of the major highlights are as follows:

- 1.5 degrees is the target: The Glasgow Climate Pact focuses on a strengthened commitment to limiting global warming to 1.5 degrees.[4] This target requires accelerated action in the next decade.
- The electrification of transportation is inevitable: Dozens of governments and car companies from around the world signed up to phase out sales of gasoline and diesel cars within 20 years.[5] (Canada is committed to 2035).[6]

- Phasing out fossil fuel production: For the first time, a coalition of states committed to a just process of phasing out fossil fuel production.[7] This was in response to an analysis by the International Energy Agency that found no new oil and gas development is required to achieve net-zero emissions by 2050.[8] A parallel initiative, the Fossil Fuel Non-Proliferation Treaty,[9] gained momentum whereby commitments were made to end international funding for fossil fuel projects[10] and to phase down coal.[11] A similar effort was initiated to advance

[4] UNFCCC. (2021). Glasgow Climate Pact. Retrieved from: https://unfccc.int/documents/310475

[5] Government of the UK (2021). COP26 declaration on accelerating the transition to 100% zero emission cars and vans. Retrieved from: https://www.gov.uk/government/publications/cop26-declaration-zero-emission-cars-and-vans/cop26-declaration-on-accelerating-the-transition-to-100-zero-emission-cars-and-vans

[6] Government of Canada (2021). Building a green economy: Government of Canada to require 100% of car and passenger truck sales be zero-emission by 2035 in Canada. Retrieved from: https://www.canada.ca/en/transport-canada/news/2021/06/building-a-green-economy-government-of-canada-to-require-100-of-car-and-passenger-truck-sales-be-zero-emission-by-2035-in-canada.html

[7] Beyond Oil and Gas Coalition. (2021). Retrieved from: https://beyondoilandgasalliance.com/

[8] IEA (2021). Net Zero.by 2050. A Roadmap for the Global Energy Sector. Retrieved from: https://www.iea.org/reports/net-zero-by-2050

[9] FFNPT. (2021). The Fossil Fuel Non Proliferation Treaty. https://fossilfueltreaty.org/

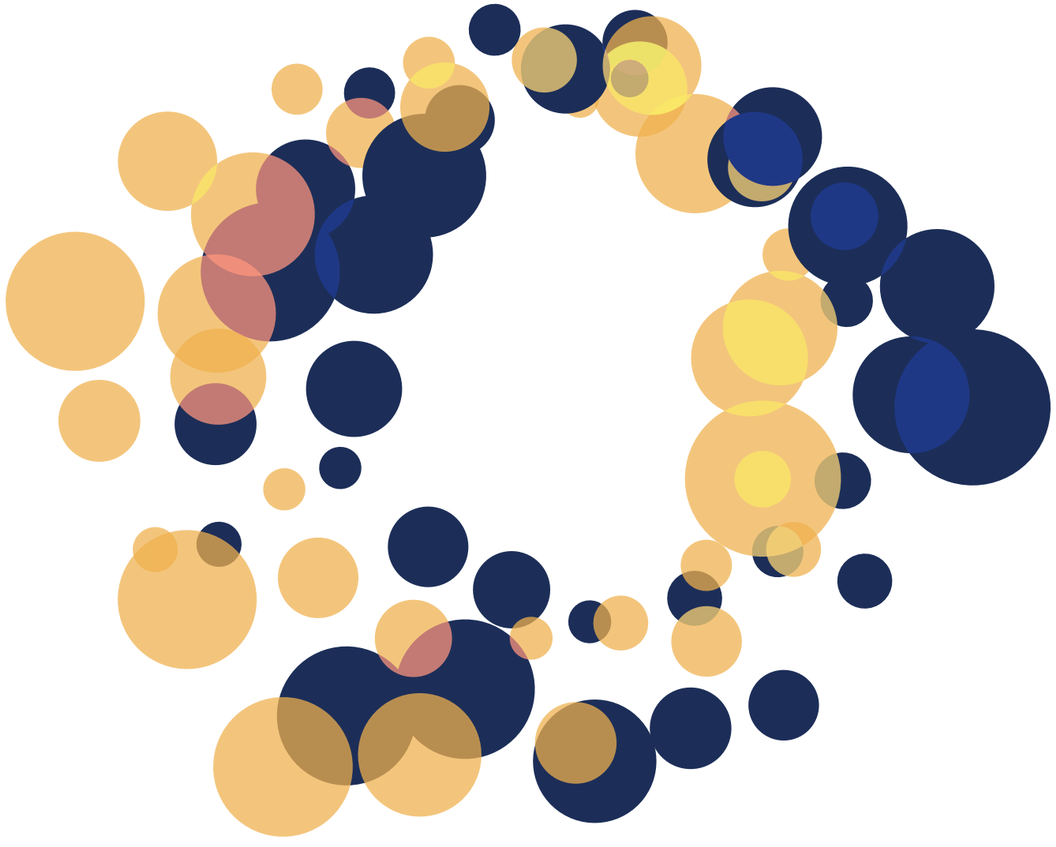
[10] Kottasová, I et al. (Nov. 4, 2021). Historic breakthrough': 20 countries say they will stop funding fossil fuel projects abroad. Retrieved from: https://www.cnn.com/2021/11/03/world/countries-agree-to-end-fossil-fuel-financing-abroad-cop26-climate/index.html

[11] Powering Past Coal Alliance (2021). Retrieved from: https://www.poweringpastcoal.org/

heat pumps under the banner of the Clean Heat Forum.[12]

- Countries will increase their ambition next year: Countries agreed to increase their targets by next year in order to improve the chance of limiting global warming to 1.5 degrees.
- Business, and in particular, finance is mobilized unlike ever before: Under the umbrella of the Glasgow Financial Alliance for Net Zero,[13] financial institutions including banks, insurers, pension funds, asset managers, export credit agencies, stock exchanges, credit rating agencies, index providers and audit firms have committed to science-based targets. This includes achieving net-zero emissions by 2050 and delivering their fair share of 50% emission reductions this decade.

City of Winnipeg's Community Energy Investment Roadmap (CEIR) aligns the City with these and other developments in the national and global effort to halt climate change.



[12] Global Alliance for Buildings and Construction (2021). Clean Heat Forum. Retrieved from: https://globalabc.org/news/globalabcs-clean-heat-forum-accelerating-heating-decarbonization-buildings-launched-cop26

[13] GFANZ. (2021). Amount of finance committed to achieving 1.5°C now at scale needed to deliver the transition Retrieved from: https://www.gfanzero.com/

Abbreviations

ABV.	DESCRIPTION
BAP	Business as planned scenario
BAU	Business as usual scenario
CEIR	Community Energy Investment Roadmap
CO2	Carbon dioxide
CO_2e	Carbon dioxide equivalents
CDD	Cooling degree days
CoW	City of Winnipeg
CH4	Methane
COP	Conference of the Parties (under the United Nations Framework on Climate Change)
DE	District energy
EV	Electric vehicle
EUI	Energy use intensity
GJ	Gigajoule
GHG	Greenhouse gas emissions
GPC	Global Protocol for Community Scale Greenhouse Gas Emissions Inventories
GWP	Global warming potential
HDD	Heating degree days
ICI	Industrial, commercial, and institutional buildings
kt	kilotonne
NBC	National Building Code
NECB	National Energy Code for Buildings
NPV	Net present value
NZS	Net-Zero Scenario
O&M	Operations and maintenance
RNG	Renewable natural gas
PV	Photovoltaic
SCC	Social cost of carbon
TEDI	Thermal energy demand intensity

Key Concepts

CONCEPT	DESCRIPTION
City vs city	City is the corporation of the City of Winnipeg; city is the city writ large including people, businesses, and governments
Net-Zero Scenario	A representation of the transformation of the city to achieve net-zero emissions
Roadmap	The policies and actions required to implement the Net-Zero Scenario

Units

GHG emissions

1 $ktCO_2e$ = 1,000 tCO_2e

Energy

1 MJ= 0.001 GJ

1 TJ= 1,000 GJ

1 PJ= 1,000,000 GJ

1 GJ= 278 kWh

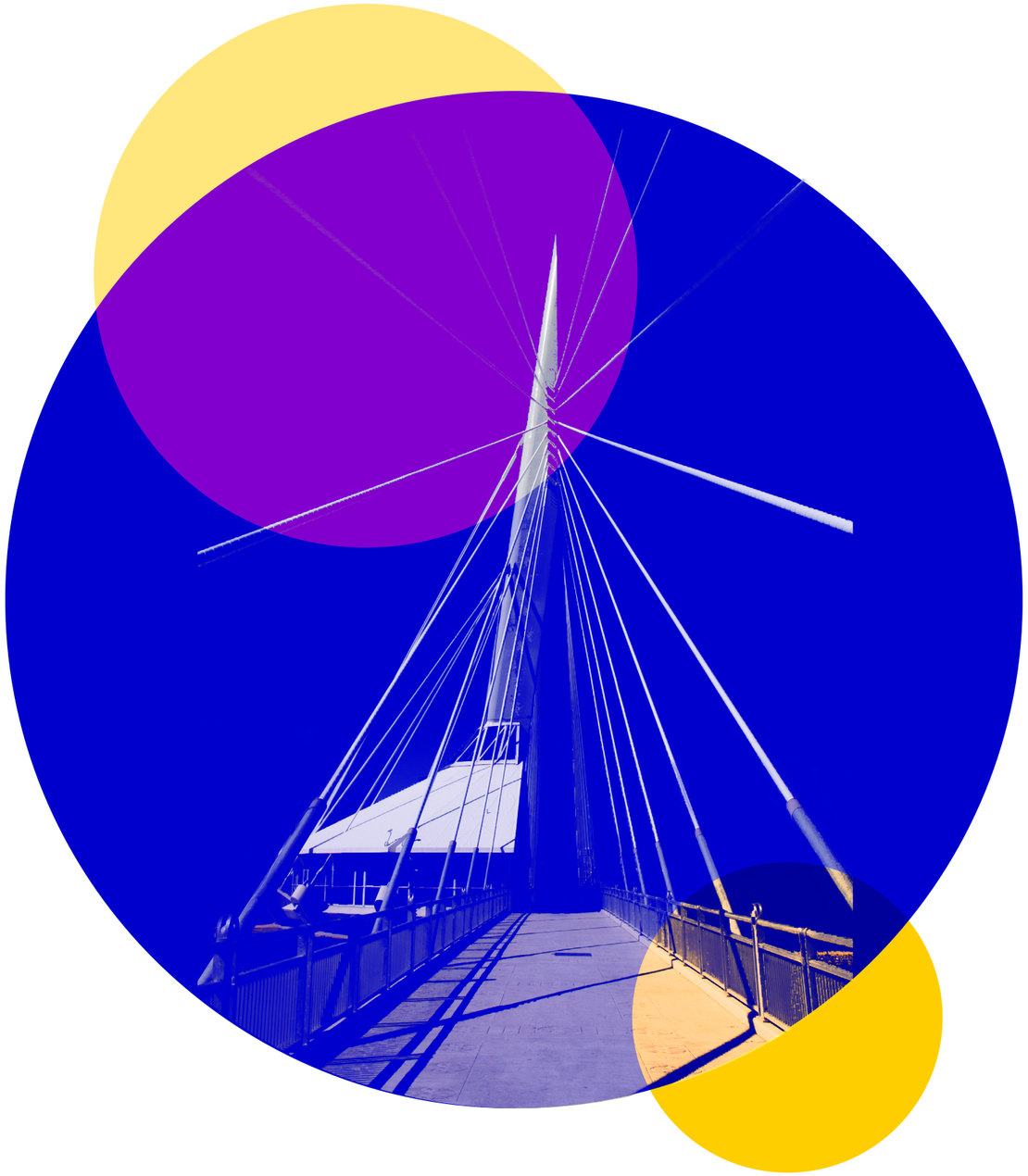
1 MWh= 1,000 kWh

1 GWh=1,000,000 kWh

Contents

Acknowledgements	2
Summary	10
Introduction	15
The Journey to a Net-Zero Winnipeg	22
The Costs and Opportunities	35
How to Achieve Our Goals	52
This is Only the Beginning	72
Appendices	73

Summary



Summary

The Community Energy Investment Roadmap (CEIR) is the City of Winnipeg's technical, evidence-based Roadmap to achieve the GHG emissions target to net-zero emissions by 2050. The CEIR illustrates the scale of the transformation required to meet the City's climate goals set out first in the City of Winnipeg Climate Action Plan and updated in the OurWinnipeg 2045 development plan (subject to Third Reading by Council). The CEIR touches on every aspect of the city, from land-use planning to waste management, from transportation to housing and from the electrical system to urban forests.

The CEIR is a technical analysis that:

- Identifies a Roadmap for actions and investments to decarbonize the city; it does not specify policies, resources, or mechanisms to operationalize these actions.
- Informs the development of strategic City policies, infrastructure plans, and investments by establishing targets and objectives for each sector.
- Establishes annual GHG emissions targets against which progress can be tracked.
- Represents an economic development roadmap for the city by identifying opportunities for new and existing businesses.
- Highlights the cost and benefits of actions, laying a foundation for the development of regulations, policies, and incentives to prioritize and accelerate action.

The CEIR uses state-of-the-art modeling to evaluate a Business as Usual (BAU) and a Net-Zero Scenario (NZS). The NZS is the basis of the roadmap that guides the city to net-zero emissions by 2050. Achieving this objective will involve the mobilization and coordination of every city department, business, non-profit organization, household, and other levels of government. The proposed actions will be enabled by market trends toward electric vehicles, decentralized electricity generation and renewable energy. The CEIR shows achieving net-zero emissions by 2050 will require unprecedented leadership by the City, other levels of government, residents and businesses.

The actions highlighted by the CEIR align with the six pillars of OurWinnipeg 2045: leadership and good governance; environmental resilience; economic prosperity; good health and well-being; social equity; and city building. These actions can inform the proposed Strategic Priorities Action Plan process.

In the era of accelerating climate change, every tonne of GHG emissions matters and this emissions reduction lens will need to permeate throughout City decision-making processes. The roadmap identified in the CEIR will ensure that the City of Winnipeg's response to climate change is transformational, equitable, and effective.

Key Insights

1. Climate action is a good investment.

The implementation of the NZS requires a societal investment of $23 billion over 28 years (from 2022–2050, undiscounted), averaging ~$800 million per year. This investment pays for itself two times over, generating savings of $53.7 billion from avoided carbon costs, reduced energy costs, and avoided maintenance costs and revenues of nearly $5 billion until 2050. These investments

also generate savings which continue beyond 2050 and are not included in these results. The net benefit to the community is $35.6 billion over 28 years, a climate dividend[14] that averages $1.2 billion per year. From an economic perspective, climate action is a no-regret policy with many opportunities for new and existing businesses.

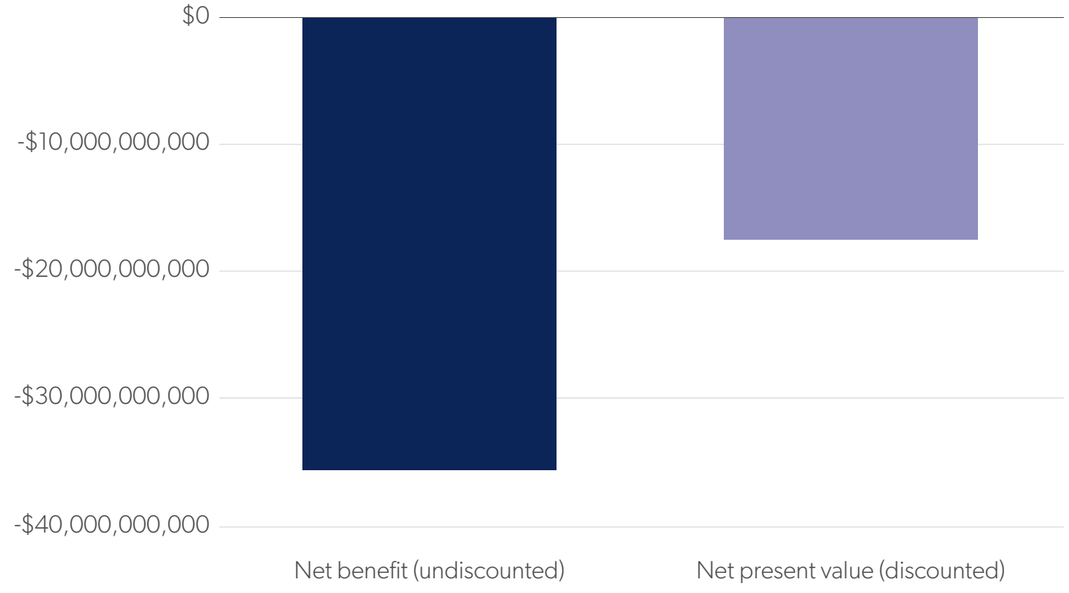


Figure 1. Net benefit and present value of the NZS, undiscounted and discounted[15]

2. Households save money

Household expenditures on energy—natural gas, electricity, gasoline, and diesel—decline in the NZS. The NZS involves shifting away from natural gas and gasoline to electricity, using high efficiency space heating and cooling with heat pumps, and improving the efficiency of homes. The carbon price adds to the cost of using fossil fuels for heating and transport. In the NZS, an average household in 2050 spends 56% less on fuel and electricity than they would have in the BAU scenario. These savings can be used to finance the incremental capital expenditures required to achieve the GHG targets. As examples, reduced heating costs can be used to finance a heat pump and reduced transportation costs can be used to finance an electric vehicle.

3. Many benefits that generate financial returns have not been included in the analysis or quantified.

The NZS generates a broad range of societal benefits with direct and indirect financial benefits, in addition to the financial analysis described in this report. For example, electrifying transportation improves air quality, thereby delivering health benefits and reducing health care costs. Building retrofits improve indoor air quality in dwellings and

[14] A climate dividend is the financial benefit that comes along with decarbonizing the City.

[15] A full explanation of these values is found in the Costs and Opportunities section of this report.

office space which can reduce health care costs and absenteeism at work. Reduced air pollution from the combustion of fossil fuels (on roads, in houses, and in electricity generation) will reduce health impacts, such as asthma and chronic obstructive pulmonary disease. Increased walking and cycling will reduce heart disease. The NZS also results in new employment opportunities- 103,000 person-years of employment over the BAU between 2022 and 2050. The economic value of the societal benefits has not been quantified in dollar terms, but the analysis demonstrates that the CEIR advances multiple city and societal objectives in addition to achieving deep GHG emissions reductions.

4. Electricity is the lynchpin of the Net-Zero Scenario (NZS).

Manitoba has the cleanest electricity in Canada. From a GHG emissions perspective, switching heating and transportation systems from fossil fuels to electricity is the primary strategy in reducing GHG emissions and achieving the net-zero target. The NZS is premised on a resilient and flexible electrical distribution system that enables households and businesses to install heat pumps and to charge vehicles, and to generate and source clean electricity.

5. Building retrofits reduce the impact on the electrical grid.

Combined with local solar generation and battery storage, building retrofits reduce annual electricity consumption to create space on the electrical grid for electrifying heating and transportation. Counterintuitively, as heating and transportation are electrified, annual electricity consumption does not increase in the NZS. The combination of replacing electric baseboards with heat pumps and retrofitting homes and buildings generate electricity savings, or negawatts.[16] The negawatts are then used to power heating and transportation. Building retrofits are also the key strategy for stimulating employment, addressing energy poverty, and improving living conditions for vulnerable populations.

6. Implementation strategies can be designed to address equity.

Decisions on the type, order, and magnitude of any actions implemented will impact not only emissions reductions, but also how people experience physical, social, and economic impacts of climate change and climate policy. Systemic injustice places greater risk from climate impacts on vulnerable communities. As a result, an equity lens must be applied to decision-making on both the approach to implementation and the costs of inaction.

Many actions outlined in this Roadmap will benefit low-income and equity-seeking groups. For example, the NZS reduces transportation costs for households and increases accessibility to destinations. This is particularly beneficial for households that are primarily dependent on personal autos or public transportation. Achieving the NZS can also reduce energy poverty, when a household's energy costs represent a disproportionate share of their income. Since the NZS involves investments, the mechanisms for financing the investments could generate higher returns for investors, which could exacerbate inequality. It is therefore important to consider the impacts on various groups when designing policies to support implementation.

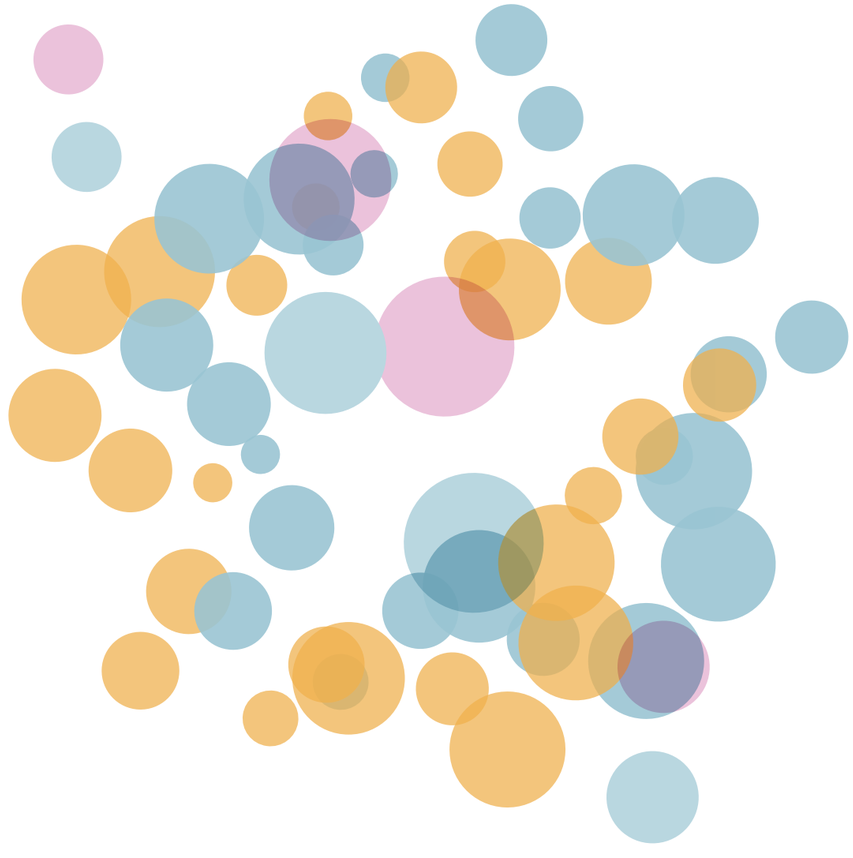
[16] Note that the impact on peak electricity demand was not assessed and would require a deeper analysis.

7. A Climate Test will avoid malinvestments

The timeline is tight and the pathway ambitious. Any investments or policies that the City undertakes which result in increased emissions will become stranded investments that are costly to undo, or malinvestments. To ensure the City's policies and expenditures align with the NZS pathway, the City can implement a climate test, where each investment is evaluated to identify its contributions to decreasing or increasing emissions. In the case an evaluation results in increased emissions, the project or policy should not proceed.

8. A whole-city approach to climate action

The next generation of climate action planning focuses on the systematic transformation of the built environment, as opposed to a long list of actions. In particular, this means embedding the consideration of climate into every policy and expenditure in alignment with the NZS, a whole-city approach. This approach requires a cultural and organizational transformation so the city itself is a climate mitigation mechanism, applying tools such as a climate lens and an annual carbon budget.



Introduction

Introduction

The Climate Emergency

Climate change is a crisis. The World Economic Forum identified the lack of climate action as the greatest risk of 2022.[17] Human-induced climate change threatens economic growth, health and public safety, infrastructure, livelihoods, and the world's biodiversity and ecosystems. As local and global greenhouse gas (GHG) emissions increase, the Earth continues to warm at an unprecedented rate. The impacts of climate change are local and tragic, characterized by new terms such as heat dome and atmospheric river.[18]

In December 2015, the Paris Agreement was adopted at COP21 by 196 countries. The Paris Agreement set a goal to limit global warming to well below a 2°C and preferably to a 1.5°C increase, above pre-industrial levels.[19] While the ambition of targets was increased at the Glasgow Climate Summit, current plans and policies are not on track to achieve this target.[20]

Global emissions declined in 2020 due to the COVID-19 pandemic, but have rebounded and the world is heading for 3°C or more of warming.[21] This degree of warming threatens human health, economic well-being, and the survival of the natural systems that humans and eight million other plant and animal species—already increasingly at risk—depend upon.[22] In response, many cities and governments have declared climate emergencies.[23]

The City of Winnipeg

The City of Winnipeg is situated in Southern Manitoba at the confluence of the Red and Assiniboine rivers. The city is more densely populated in the city core and the immediate surrounding ring, which contains several historic neighborhoods and areas of commerce. The Winnipeg downtown district is considered the fastest-growing area of the city and borders most of the major universities and colleges, along with major employment/offices and a residential region. The total area of the city is close to 500km^2, due to outward development which has been unconstrained from geographical barriers or planning interventions, such as an urban growth boundary.[24]

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[17] World Economic Forum (2022). The Global Risks Report 2022. https://www3.weforum.org/docs/WEF_The_Global_Risks_Report_2022.pdf

[18] While the impacts are being experienced across Canada, BC experienced the most extreme impacts in 2021. For more details, see: Baum and McClearn (2021). From fire to 'atmospheric river': Why B.C. is trapped in a world of climate extremes. Retrieved from: https://www.theglobeandmail.com/canada/article-first-fire-now-floods-why-bc-is-trapped-in-a-world-of-climate-extremes/ [paywall]

[19] United Nations Framework Convention on Climate Change. (2015) The Paris Agreement. Retrieved from: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

[20] Climate Action Tracker (2021). COP 26 Glasgow Initial Assessment. Retrieved from: https://climateactiontracker.org/documents/1002/CAT_2021-11-11_Briefing_GlasgowSectorInitiatives.pdf

[21] New UNEP Synthesis Provides Blueprint to Urgentaly Solve Planetary Emergencies and Secure Humanity's Future. 18 Feb. 2021. https://unfccc.int/news/new-unep-synthesis-provides-blueprint-to-urgently-solve-planetary-emergencies-and-secure-humanity-s

[22] Ibid.

[23] A list of climate emergency declarations from jurisdictions around the world can be found here: https://climateemergencydeclaration.org/

[24] "Sustainable Street Patterns in the Suburbs" 2019. Metalnikov, Anton. University of Manitoba.

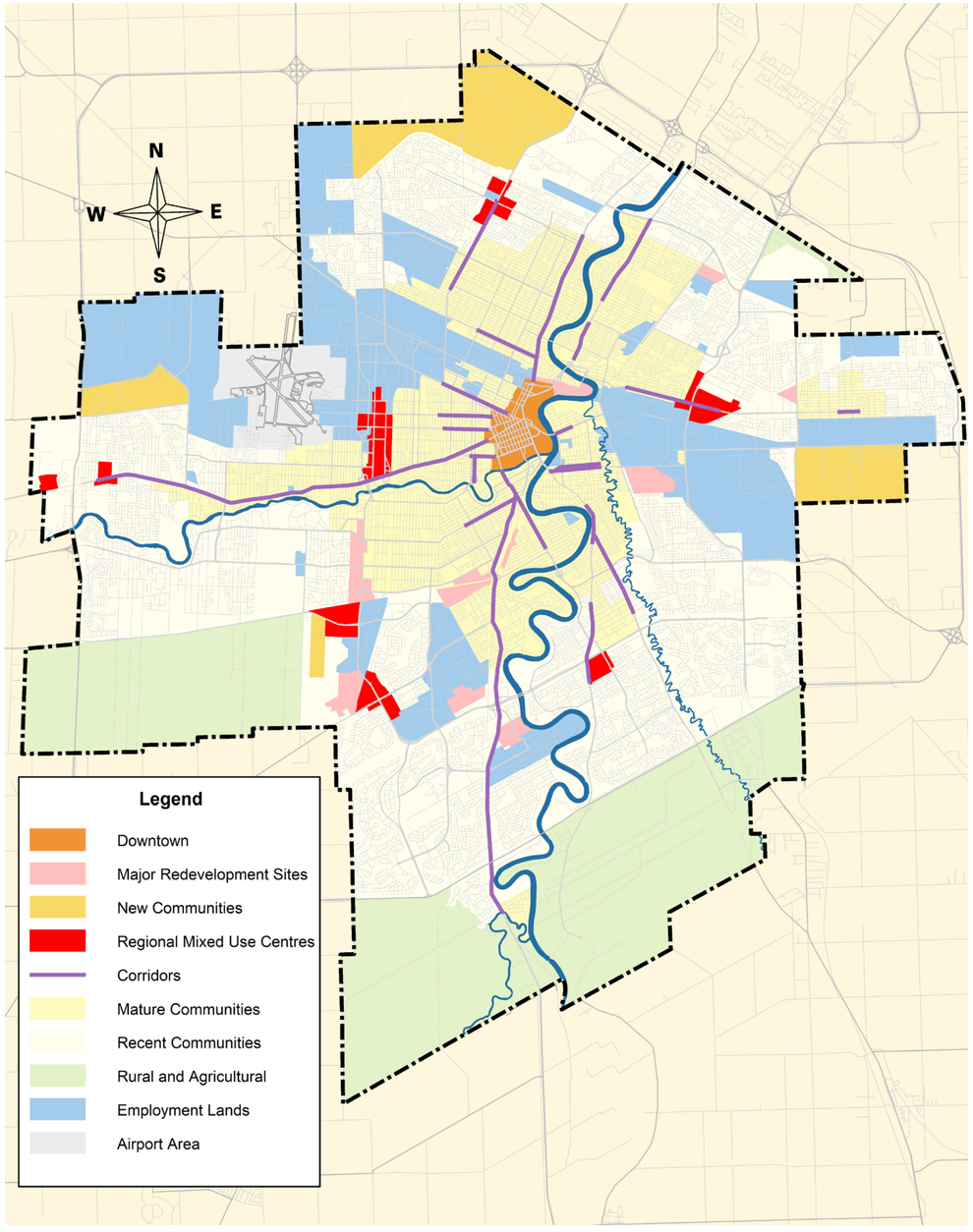


Figure 2. Current Winnipeg map showing policy boundaries.[25]

[25] Winnipeg Urban Structure. Our Winnipeg. Retrieved in 2020. Urban Structure - OurWinnipeg - City of Winnipeg

Between 2011 and 2016, the population of Winnipeg grew by 6.3%, from 663,617 people to 705,244.[26] The growth has continued to an estimated 763,900 in 2019 and is projected to grow to 819,2000 in the next 5 years.[27] By 2050, Winnipeg's population is expected to reach nearly 1 million people, an increase of 36% (Figure 3).

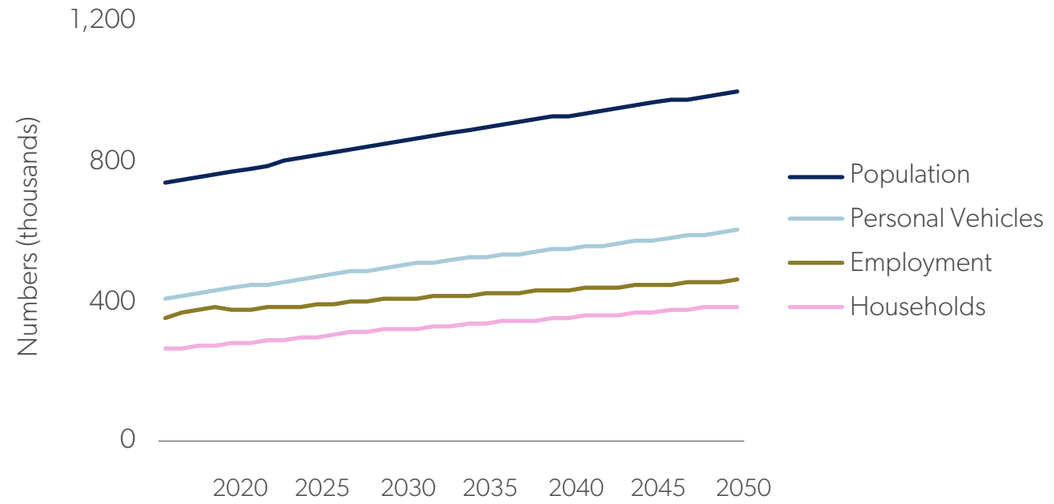


Figure 3. Population, personal vehicles, employment, and number of households from 2016-2050.

Winnipeg's Climate is Changing

Winnipeg is already experiencing the impacts of global warming. Since 1950, average annual temperatures in Western Canada have increased by about 2°C (twice the global average) and average winter temperatures have increased by about 4°C.[28] Moving forward, Winnipeg is expected to experience a further rise in annual average temperature, along with wetter springs, falls, and winters and drier summers.

Mean temperature is projected to increase by 2.4°C between 2021 and 2050. Hot days with a temperature of more than 30°C are projected to increase from an average of 14 per year to 31 per year. At the same time, cold days with a temperature of less than -30°C are projected to decrease from an average of 12 per year to 4 per year.[29]

The number of heating degree days (HDD) in a year is an indicator of the demand for thermal conditioning of buildings, or energy needed for heating. HDD have been falling and are projected to continue decreasing due to a warming climate, resulting in less thermal heating demand (Figure 4). Conversely, the number of cooling degree days (CDD), an indicator of the demand for energy to cool buildings, is projected to rise from now to 2050, resulting in greater demand for air conditioning.

[26] Census Profile: Winnipeg. 2016. Retrieved from: https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/prof/details/page.cfm?Lang=E&Geo1=CSD&Code1=4611040&Geo2=CD&Code2=4611&SearchText=winnipeg&SearchType=Begins&SearchPR=01&B1=All&TABID=1&type=0

[27] City of Winnipeg. June 2020. City of Winnipeg Community Trends and Financial Analysis: Selected Statistics on Local Demography, Development, and Municipal Finance. Retrieved from: https://winnipeg.ca/cao/pdfs/CommunityFinancialTrends-2020.pdf

[28] City of Winnipeg. (May 2018). Winnipeg's Climate Action Plan. Retrieved from City of Winnipeg's website: https://winnipeg.ca/sustainability/PublicEngagement/ClimateActionPlan/pdfs/WinnipegsClimateActionPlan.pdf; DeBeer, C. M., Wheater, H. S., Carey, S. K., & Chun, K. P. (2016). Recent climatic, cryospheric, and hydrological changes over the interior of western Canada: a review and synthesis. Hydrology and Earth System Sciences, 20(4), 1573. doi:10.5194/hess-20-1573-2016

[29] Climate Atlas. (n.d.). Climate Atlas Report - Municipality: Winnipeg. Retrieved Nov. 2020 from: https://climateatlas.ca/report_v2/grid/646

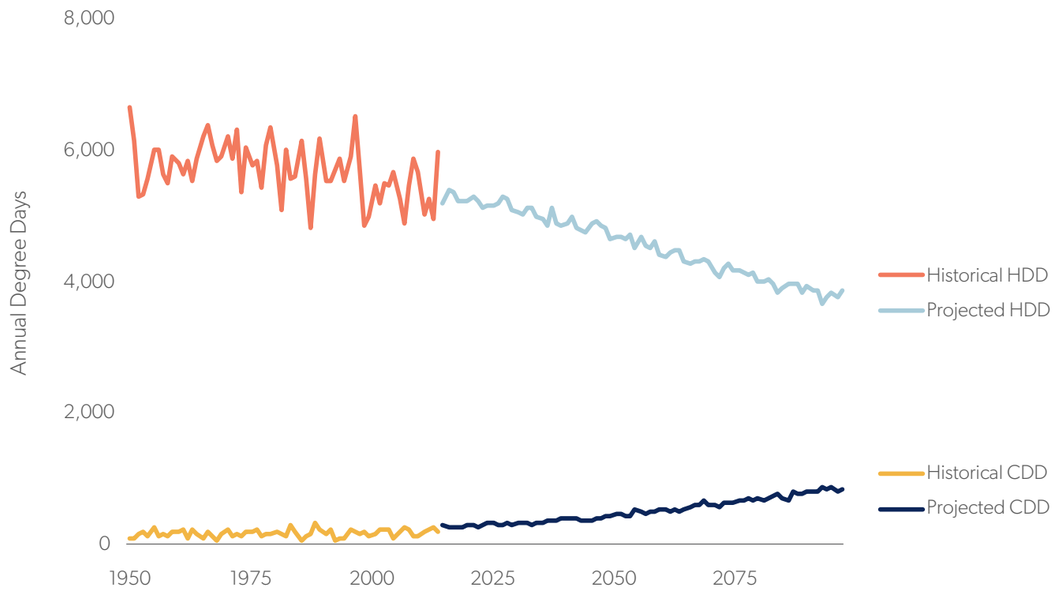


Figure 4. Heating Degree Days and Cooling Degree Days in the Winnipeg Area, projected to 2050.[30]

Precipitation is projected to increase marginally from 523 mm to 554 mm annually by 2050.[31] Precipitation is likely to increase during winter, fall, and spring and decrease during the summer. In addition, weather will likely be more variable from year to year.[32]

These changes will lead to increased droughts, as well as more extreme weather events, such as extreme storms and flooding.[33] Both droughts and wetter weather can pose problems for local agriculture.[34] Extreme weather will strain transportation infrastructure and buildings,[35] and the energy system. At the same time, new pests and invasive species may harm the local ecosystem[36] and agriculture. Warmer winters due to climate change are already making Winnipeg's ash trees—which compose much of the city's urban canopy—more vulnerable to the emerald ash borer, an invasive beetle species from China that

[30] Climate Atlas. (n.d.). Climate Atlas Report - Municipality: Winnipeg. Retrieved Nov. 2020 from: https://climateatlas.ca/data/city/465/cooldd_2030_85/line

[31] Ibid.

[32] City of Winnipeg. (May 2018). Winnipeg's Climate Action Plan. Retrieved from City of Winnipeg's website: https://winnipeg.ca/sustainability/PublicEngagement/ClimateActionPlan/pdfs/WinnipegsClimateActionPlan.pdf

[33] Ibid.

[34] Ibid.; Kives, Bartley. (Oct. 10, 2019). "'Unprecedented' wet fall Manitoba weather hurts crops, puts flood fighters into action". CBC. Retrieved from: https://www.cbc.ca/news/canada/manitoba/manitoba-crops-weather-climate-1.5316449

[35] City of Winnipeg. Winnipeg's Climate Action Plan.

[36] Ibid.

was discovered in the city in 2017.[37] The City predicts the beetles could kill up to 350,000 trees.[38]

These general trends tend to understate the disruption and damage caused by episodic extreme events, which are projected to continue to increase in Canada.[39] The 2021 summer forest fires and floods in Manitoba and British Columbia have demonstrated the extreme level of disruption from compounding events.[40] These are real life examples of the impact described by the Canadian Institute for Climate Choices:[41]

"The costs of climate change impacts on infrastructure also go beyond the price of physical damage and repair. When infrastructure is put out of commission or made less reliable by more frequent damage, the services that it provides—transportation, power, healthcare, communications, and shelter, to name a few—are also interrupted. We show that the costs of delays from climate-induced damage to roads and railways borne by transportation operators alone could be in the billions annually. In reality, however, these effects will reverberate through supply chains and industries, multiplying costs and reducing economic productivity. Further, damage from climate change, or the threat thereof, could have far-reaching implications for the stability of the financial system and the availability of capital and insurance."

Net Zero by 2050

Winnipeg's 2018 Climate Action Plan: Planning for Climate Change. Acting for People. provided GHG emissions targets for the City of Winnipeg, as well as a framework to attain them. The community-wide GHG reductions targets were:

1. 20% reduction in GHG emissions by 2030 relative to 2011 levels.

2. 80% reduction in GHG emissions by 2050 relative to 2011 levels

Guided by the latest science, the City of Winnipeg updated its GHG reduction target to net-zero emissions by 2050.[42] This target aligns with federal targets for emissions reductions announced at COP26, in November 2021.[43] The net zero by 2050 target has been included and approved by Council in the OurWinnipeg 2045 Development Plan.

Net zero means that Winnipeg either releases no GHGs, or offsets all the emissions it does release.[44] The Community Energy Investment Roadmap (CEIR) uses rigorous and detailed modelling of energy use, GHG emissions and financial impacts to Winnipeg, to identify a clear pathway that will enable Winnipeg to

[37] Botelho-Urbanski, Jessica. (May 18, 2018). "Climate change puts city's ash trees at greater risk from killer insects, researchers say". Winnipeg Free Press. Retrieved from: https://www.winnipegfreepress.com/local/climate-change-puts-citys-ash-trees-at-greater-risk-from-killer-insect-researchers-say-483086083.html

[38] CBC News. (Dec. 7, 2017). "Invasive emerald ash borer could kill more than 350,000 Winnipeg trees". CBC. Retrieved from: https://www.cbc.ca/news/canada/manitoba/winnipeg-emerald-ash-borer-1.4438061

[39] Insurance Institute (2020). Climate Risks: Implications for the Insurance Industry in Canada. Retrieved from: https://www.insuranceinstitute.ca/en/resources/insights-research/Climate-risks-report

[40] Austen, I. (2021). Sifting Through Mud, Flooded Canadians Fear Next Disaster. Retrieved from: https://www.nytimes.com/2021/11/29/world/canada/british-columbia-floods-storm.html

[41] Canadian Institute for Climate Choices. (2021). Underwater: The Costs of Climate Change for Canada's Infrastructure. Retrieved from: https://climatechoices.ca/wp-content/uploads/2021/09/Infrastructure-English-FINAL-Sep29.pdf

[42] City of Winnipeg (2021). OurWinnipeg 2045 Draft Plans Update. Accessed Dec 2021: https://winnipeg.ca/interhom/CityHall/OurWinnipeg/2045.stm

[43] Government of Canada (2021). Prime Minister Trudeau announces enhanced and ambitious climate action to cut pollution at the COP26 summitt. Accessed Dec 2021: https://pm.gc.ca/en/news/news-releases/2021/11/01/prime-minister-trudeau-announces-enhanced-and-ambitious-climate

[44] Canada has joined more than 120 countries in a pledge to move to a net-zero economy. For more information, see Canada's Climate Plan.

reach its climate goals.

Winnipeg has undertaken a robust modelling exercise to investigate energy consumption in the City and the resulting emissions today and into the future. This analysis informed the development of a pathway to net zero. Three scenarios for the period from 2016 to 2050 were assessed, each one with an increasing ambition. The final scenario, the Net-Zero Scenario (NZS) details the pathway to achieve the City's emissions target and how that pathway will shape the future of the city. The modelling process is described in greater detail in Appendix A.

Working Together

The development of the CEIR involved the participation of two working groups. The City Internal Working Group was composed of municipal employees whose work shapes and is shaped by climate change initiatives within the City. The Technical Advisory Group included a panel of Winnipeg-based experts from sectors including sustainable buildings, non-profits, and climate action.

Input from these two working groups helped to shape the actions and to ground these actions within the context of Winnipeg. In addition, these groups have provided valuable insight on how to implement these actions and provided access to essential data for use in the analysis.

The implementation of the CEIR will require participation and collaboration both within the City of Winnipeg and with stakeholders and community members across the city, the province, and the country. Many of the first steps to implementing the actions modelled in this study involve establishing working groups with industry, utilities, businesses, education centres, and community organizations. These first steps are essential to establish open communication, a spirit of experimentation, and clear pathways to success.

Meeting the net zero by 2050 goal identified in OurWinnipeg 2045, as modelled and detailed in the CEIR, will require immediate and decisive action from all members of society. Ensuring that all members of the community have the opportunity to participate fully in the low-carbon future is essential to the city's success.

The Journey to a Net-Zero Winnipeg

The Journey to a Net-Zero Winnipeg

The Winnipeg of Today

CURRENT ENERGY USE AND EMISSIONS IN WINNIPEG

Residents, businesses, industries, and the City use energy in Winnipeg to heat homes and buildings, to run appliances and machinery, and to operate vehicles. This involves the consumption of energy in a variety of forms, including electricity, natural gas, propane, gasoline, and diesel. The consumption of these fuels releases GHG emissions into the atmosphere.

In 2020, Winnipeg's total energy consumption was 103 million GJ. This energy consumption, plus emissions from the decay of waste in landfills and fugitive emissions from natural gas systems, resulted in a total of 4.79 million tonnes of CO_2e being produced by Winnipeg in 2020.

That is an average of 6.2 tCO_2e/person, or the equivalent of each person in Winnipeg driving a car for 25,000 km.[45]

The electricity grid in Manitoba relies primarily on low-emission hydroelectric generation, therefore, a GJ of electricity produces far less GHG emissions than an equivalent GJ of energy from fossil fuels such as natural gas and gasoline. As a result of this, fossil fuel-dominated transportation is responsible for nearly half (48%) of the total emissions in Winnipeg.

[45] Equivalency from the US EPA Greenhouse Gas Equivalencies Calculator. https://www.epa.gov/energy/greenhouse-gas-equivalenciescalculator

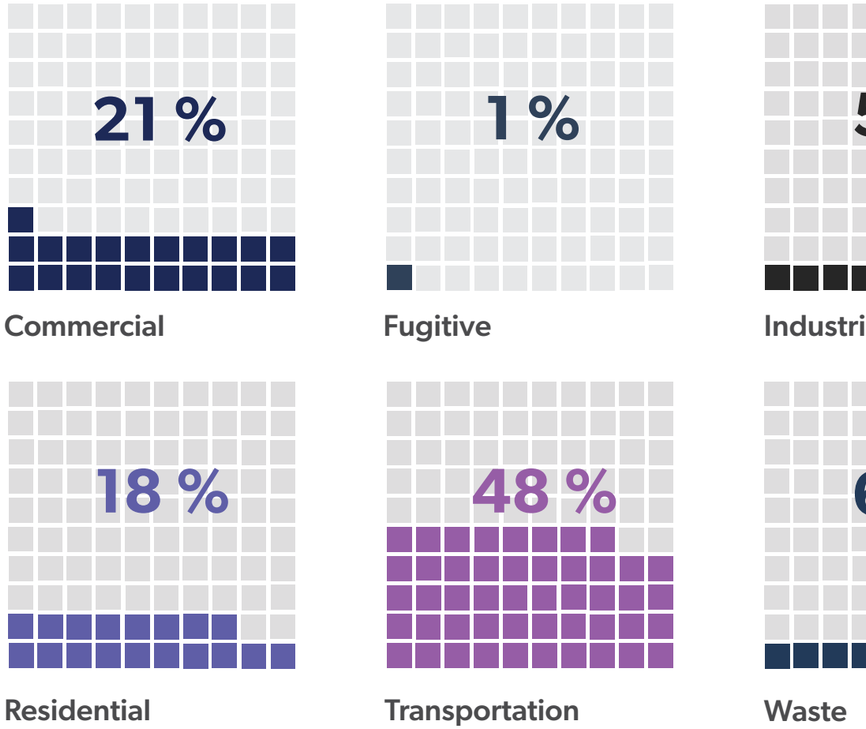


Figure 5. GHG emissions by sector for Winnipeg, 2020.[46]

BUSINESS-AS-USUAL SCENARIO

The Business-as-Usual (BAU) scenario illustrates energy consumption and GHG emissions if Winnipeg makes no major changes into the future. This scenario includes a projection of a warming climate, reducing the need for energy to heat buildings in winter, as well as an increased need to cool buildings in summer.

Additionally, the BAU captures improved efficiencies of gasoline- and diesel-powered vehicles and a small amount of building retrofits to improve energy efficiency.

As the population increases, overall energy consumption in Winnipeg also increases by 12% by 2050 in the BAU scenario (Figure 6).

[46] Fugitive emissions: unintentional emissions generated from a leakage of gasses or vapours from pressurized containers.

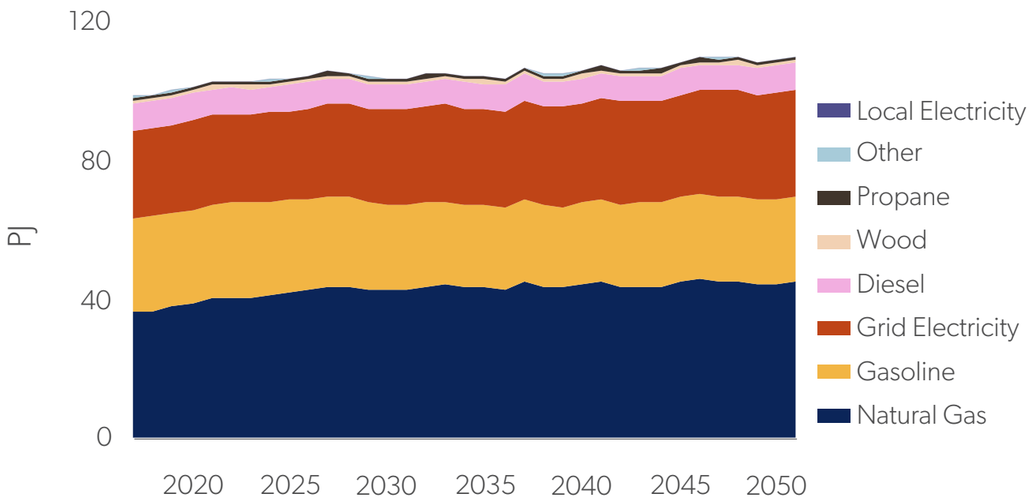


Figure 6. Energy use by fuel type, BAU scenario, 2016-2050

Similarly, GHG emissions increase by 9% between 2016 and 2050 under this scenario (Figure 7). The majority of the emissions come from fossil fuel use, including gasoline and diesel for transportation and natural gas for heating and industrial purposes.

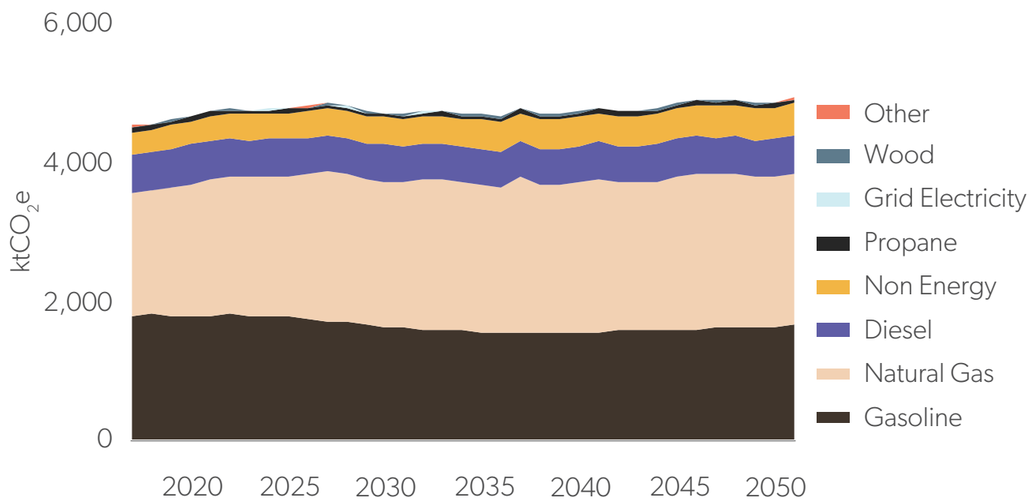


Figure 7. Emissions by fuel type, BAU scenario, 2016-2050

Per capita emissions are expected to decline slightly, from 6.2 tCO_2e/person in 2020, to 4.9 tCO_2e/person in 2050. Relative to the Canadian national average of 19.4 tCO_2e/person in 2019, Winnipeg is significantly lower, primarily because of the lack of major emissions-producing industries and the clean grid electricity.[47]

The Pathway to a Net-Zero Winnipeg

The pathway to dramatically reduce the GHG emissions produced by Winnipeg involves a multi-step approach to maximize efficiency, reduce the chance of overbuilding, and deep electrification. The modelling of the net-zero pathway for Winnipeg was divided into two steps (Figure 8):

First, a Business-as-"Planned"[48] (BAP*) scenario was developed that included changes expected from Federal and Provincial policies and regulations, as well as existing plans underway in Winnipeg to improve efficiency and reduce emissions.

Second, a net-zero scenario was added on top of the BAP* scenario, where fossil fuels are removed entirely from the city, systems are retrofitted and replaced with more efficient versions, and clean electricity is the primary fuel source.

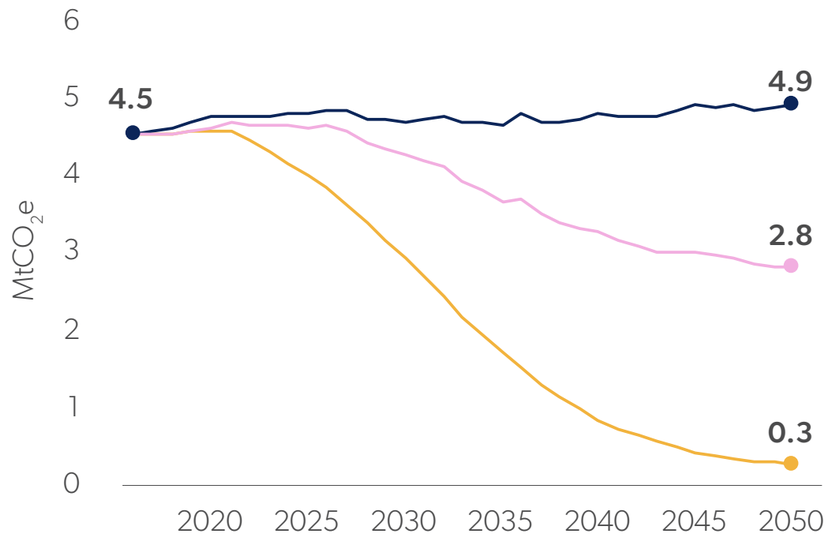


Figure 8. GHG emissions in Winnipeg from the BAU, BAP*, and NZ scenarios.

[47] Government of Canada, 2021. Greenhouse Gas Emissions. Accessed Dec 2021: https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/greenhouse-gas-emissions.html

[48] Note that this scenario included a switch from a moderate densification land use strategy, to a more ambitious scenario. This more ambitious scenario is not the current planning scenario used by the City of Winnipeg, but in order to maximize efficiencies from densification, this scenario was modelled for the net-zero pathway.

Efficiency First

The underlying approach to the NZS is to order the actions according to a priority of 'Reduce, Improve, Switch': reducing energy consumption is the first step, then maximizing energy efficiency improvements, and finally switching to low-carbon energy sources for the remaining demand. Each kWh of electricity saved through efficiency is a kWh that need not be generated. In an electrified future, each trip shifted from gasoline vehicles to transit or human-powered transportation modes constitutes an efficiency gain, which reduces the burden on the landscape to provide energy. Efficiency gains, therefore, also have land benefits.

THE BIG MOVES

There are five areas that need to make "Big Moves" when it comes to emissions reduction: buildings, transportation, local renewable energy, water, and waste. Implementing actions within these key areas can reduce GHG emissions as demonstrated in Figure 9.

Buildings: The majority of buildings, including homes, commercial buildings, municipal buildings, and industrial buildings undergo deep retrofits to reduce energy consumption.

New buildings are built to net-zero or PassivHaus standards, meaning they will be highly efficient and generate on-site electricity.

All buildings, whether new or existing, will switch from fossil fuels to electricity for heating, cooling, and water heating.

Transportation: All vehicles are zero emission, with municipal vehicles leading the way. The share of walking and bicycling trips increases by building more trails and bike lanes. Additionally, transit is expanded and decarbonized.

Local renewable energy: Solar panels are installed on new buildings as they are constructed and on existing buildings as they are retrofitted. Although wind power can be installed as appropriate, only solar generation was included in the modelling.

Water and waste: Overall waste generation is reduced and waste diversion to recycling and composting facilities is improved. Renewable natural gas is captured from waste sources and used to replace natural gas in some systems during the decarbonization process. Furthermore, water consumption is reduced with efficiency measures including leak detection and end-use equipment improvements.

Sector-by-sector actions are described in more detail in the Implementation portion of this report, as well as in Appendix A.

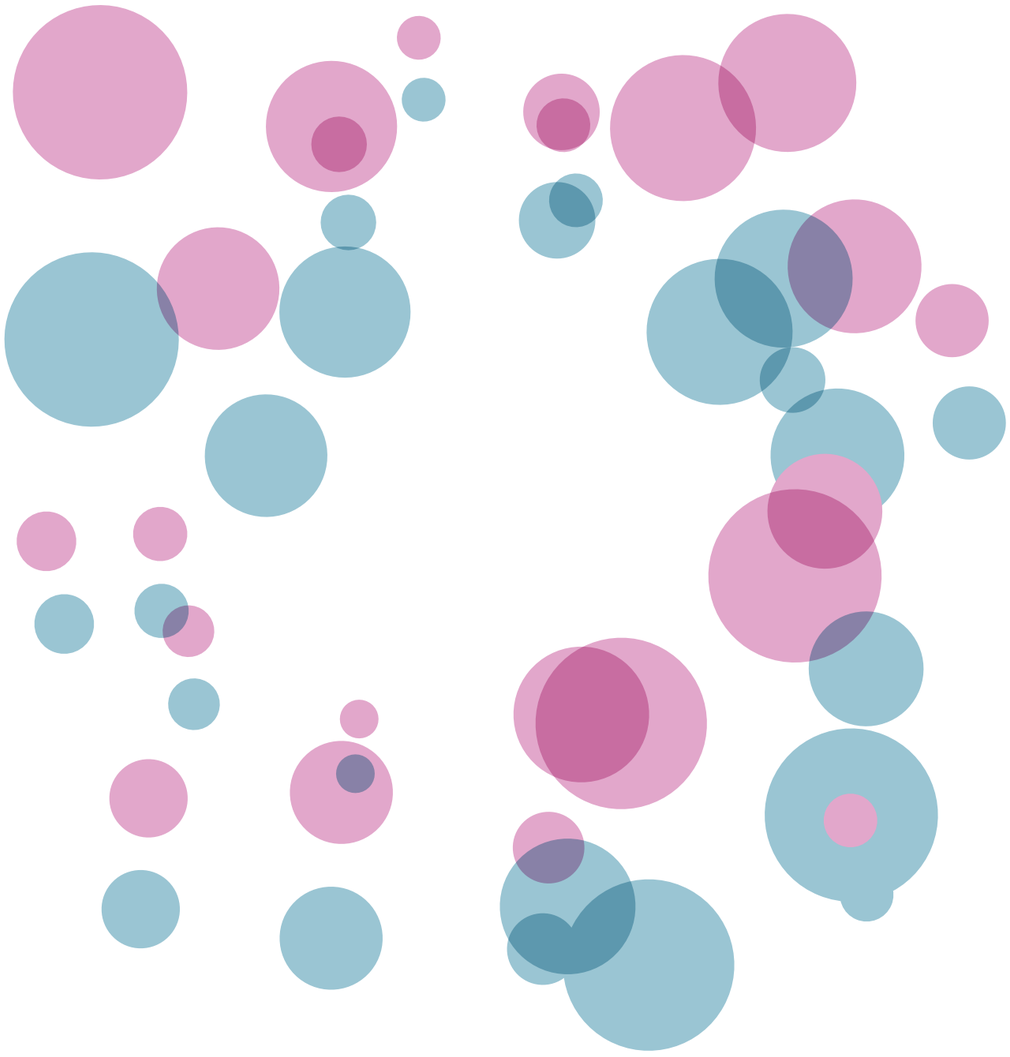
The result of making these changes, as shown in Figure 9 below, is a 94% decrease in GHG emissions by 2050 and an overall decrease in total energy demand by 62%. Residential, commercial, and municipal buildings are entirely decarbonized, while industrial emissions are reduced by 98%.

The electrification of transportation, the largest source of GHG emissions today, is a major driver in the overall decarbonization of the City. Even though a small amount of heavy machinery is still expected to use fossil fuels by 2050, it will be replaced with zero-emissions options as these machines are retired.

The replacement of natural gas as a heating source for homes and buildings with high-efficiency heat pumps removes the other major source of GHG emissions, with only minor emissions remaining in most sectors.

Emissions from landfills constitute the largest portion of the remaining emissions in the net-zero pathway. These emissions are a result of the biodegradation of organic materials, some of which may continue to emit GHGs for years or decades after they have been deposited.

The City of Winnipeg does not have direct control over all sectors and sources of emissions within the city, but through a combination of regulations, policies, incentives, moral suasion, and partnerships, it can enable deep emissions reductions in every sector.



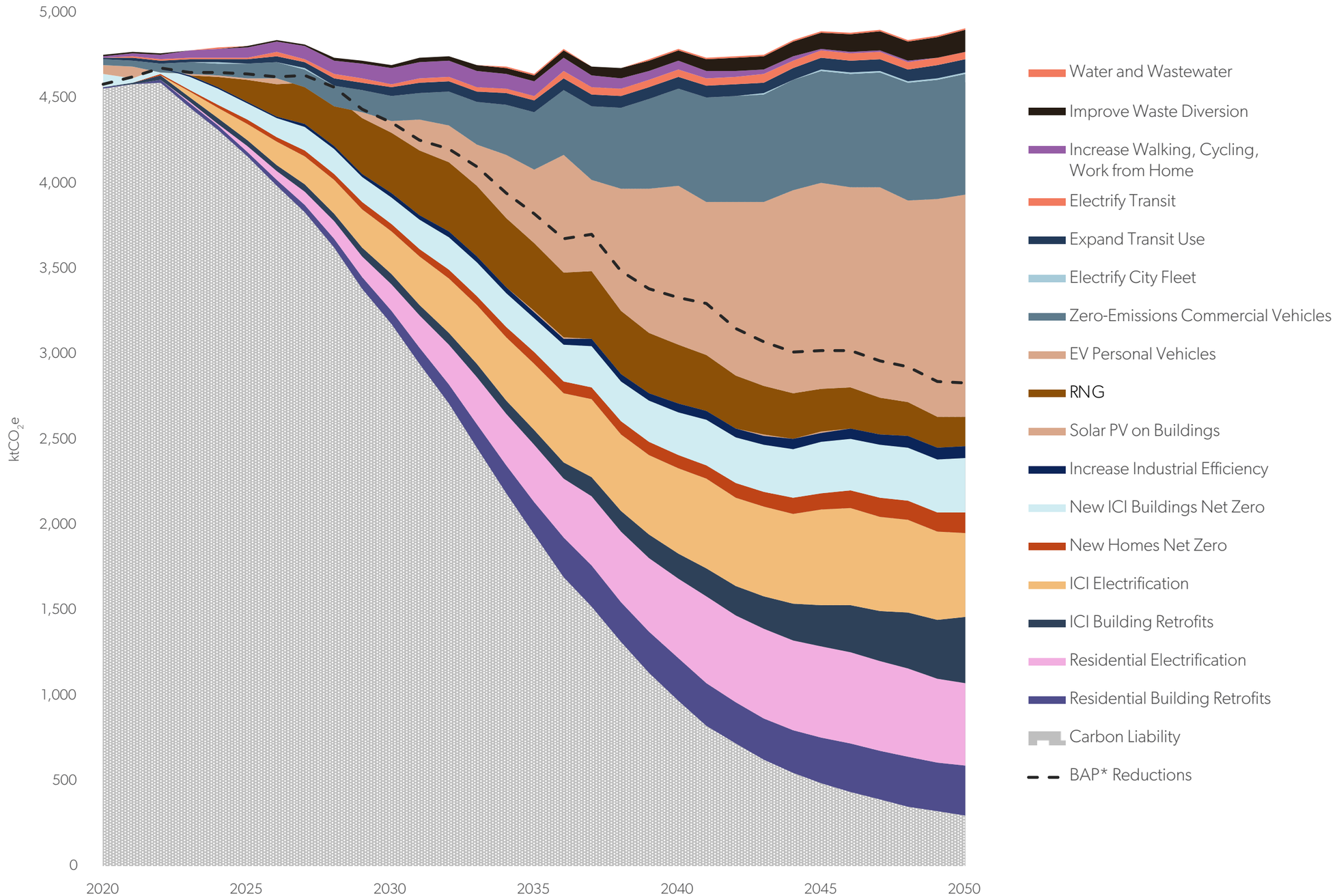


Figure 9. Wedge diagram showing the incremental GHG emissions decreases by action in the Net-Zero Scenario.

ELECTRICITY DOMINATES

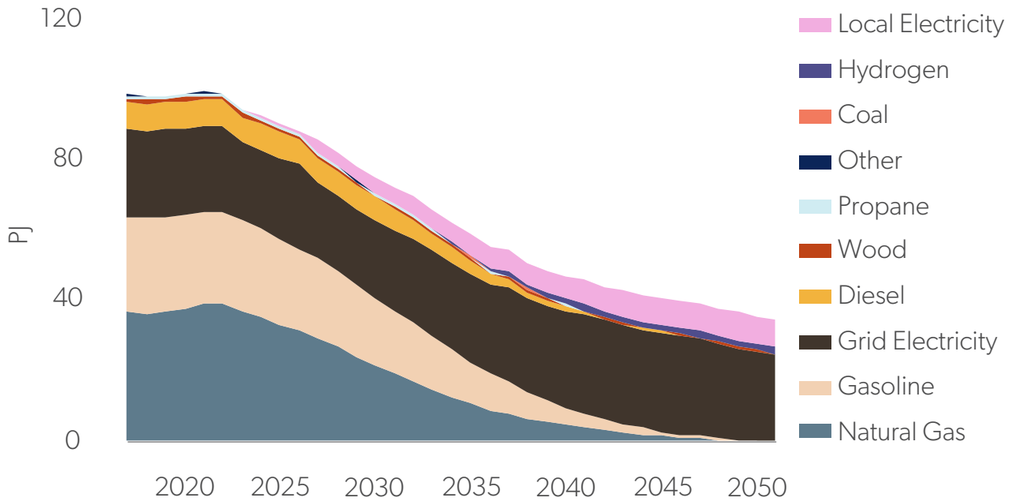
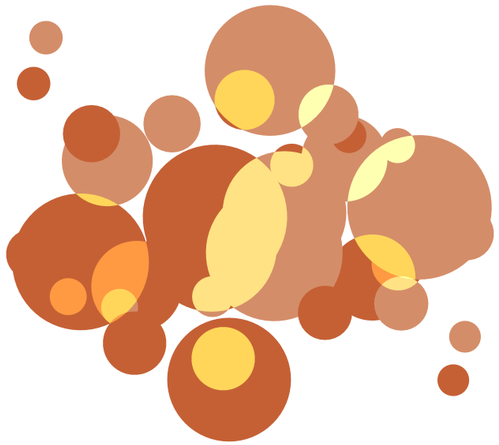


Figure 10. Energy by fuel type in the NZS, 2016-2050.

As fossil fuels are removed from the system, they are replaced by electricity and, to a lesser extent, by green hydrogen and renewable natural gas. Due to the efficiencies gained through deep building retrofits, improvements to new building efficiency standards, and electric vehicles, the total consumption of grid electricity remains unchanged between now and 2050. Electricity consumed from the grid is supplemented by local electricity generated using solar PV panels on buildings. These are installed on new buildings as they are built and existing buildings as they are retrofitted.

Without following the reduce-improve-switch paradigm and maximizing efficiencies from retrofits and equipment replacement, the total demand for electricity could increase, requiring a more substantial transformation of the electricity grid and distribution network.



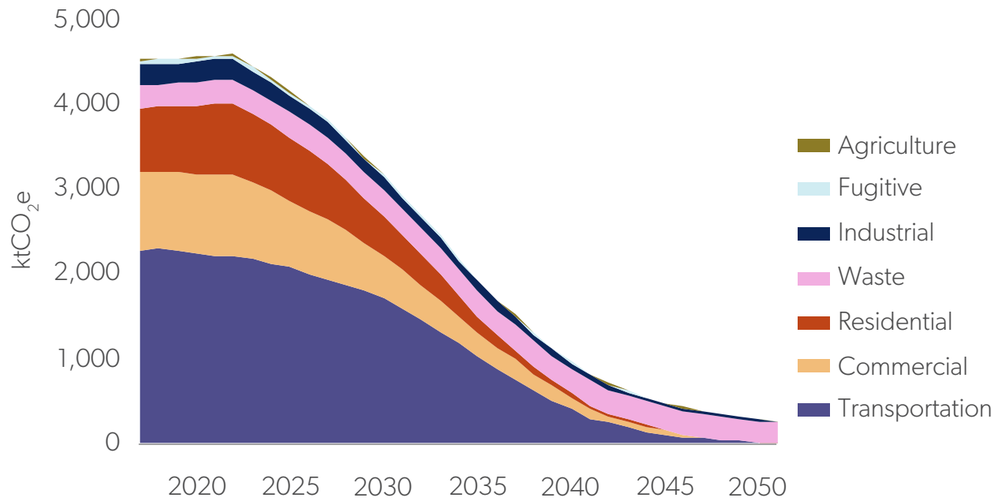


Figure 11. Total emissions by sector in the NZS, 2016-2050.

The remaining emissions in 2050 come primarily from landfills (Figure 11). Addressing this gap can be achieved through investments in landfill gas capture, improved waste management for future waste, and as a last resort, through the purchase of carbon offsets.

PER CAPITA EMISSIONS

2020	2050 BAU	2050 NZS
6.2 tCO_2e/person	4.9 tCO_2e/person ↓ 20% from 2020	0.8 tCO_2e/person ↓ 87% from 2020 ↓ 83% from 2050 BAU

Every tonne matters: cumulative emissions

The historical practice of carbon management has been to identify GHG emissions reduction targets for specific years, such as targets set for 2030 and 2050. The emerging paradigm, however, indicates that every tonne of GHG matters and, therefore, the trajectory of GHG emissions, not just the end point, needs to be managed.

A carbon budget provides a limit to the total GHG emissions a community or organization can produce. The budget is directly aligned with the remaining global carbon budget for 1.5°C of warming. Governments and cities around the world, such as the United Kingdom, the City of Oslo, and several Canadian cities, are implementing carbon budgets.

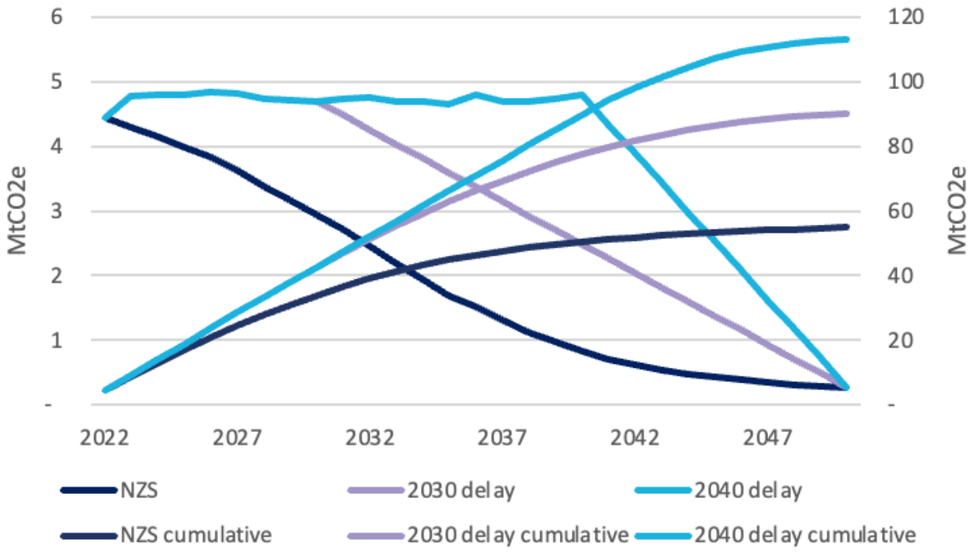


Figure 12. Impact of delaying emissions reductions until 2030 and 2040.

Figure 12 demonstrates how a carbon budget can act as a key climate action planning tool. Both pathways result in the same 2050 target; however, the cumulative reductions of Winnipeg's Net Zero Scenario (NZS) are slightly more than half that of the delay in reductions until 2040 and 40% lower than delaying action until 2030. Delay has three consequences: higher overall emissions, steeper reduction curves resulting in more disruption as assets are stranded, and the city forfeiting the economic value of the avoided carbon price and energy efficiency gains.

A Carbon Budget for Winnipeg

There is a finite amount of GHG emissions that can be released into the atmosphere to avoid catastrophic climate change. At the UN climate change conference in Glasgow, countries affirmed the importance of limiting global warming to 1.5 degrees to avoid the worst effects of climate change.

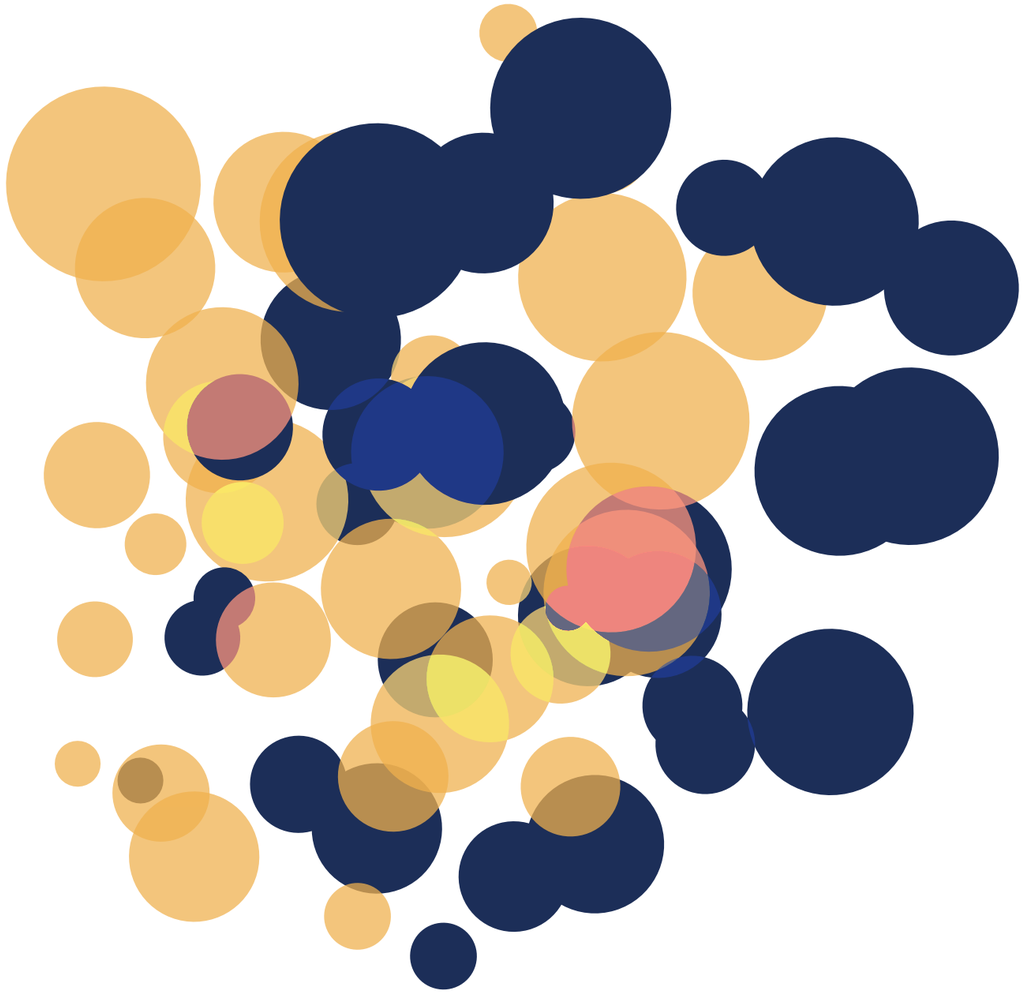
At current rates, the global 1.5 degree carbon budget will be used up in less than 8 years.[49] Summing up the emissions from each year in the NZS results in cumulative emissions of 55 $MtCO_2e$. At current levels of emissions, this total would be exceeded in 12 years. A longer duration at current rates is an indication that cumulative emissions in the NZS pathway exceed Winnipeg's fair share of the global 1.5 degree carbon budget. If the City is committed to limiting its emissions to a fair share, the gap between the 1.5 degrees carbon budget and the NZS pathway will need to be addressed by accelerated and more ambitious action, emerging or new technologies, carbon offsets and/or carbon removals.

The NZS also provides an indication of the remaining market share of fossil fuels, an important indicator for the energy transition. At current rates, the remaining natural gas and gasoline equals approximately 10 years of consumption.

[49] MCC (2021). Remaining Carbon Budget. Retrieved from: https://www.mcc-berlin.net/en/research/co2-budget.html

Table 1. Carbon and energy budgets.

BUDGETS (2021-2050)	TOTAL CUMULATIVE EMISSIONS	NUMBER OF YEARS LEFT AT CURRENT RATES	NATURAL GAS	GASOLINE
BAU	139 $MtCO_2e$		1,271 million GJ	710 million GJ
BAP	107 $MtCO_2e$		1,190 million GJ	354 million GJ
NZS	55 $MtCO_2e$	12	361 million GJ	310 million GJ
Remaining natural gas	361 million GJ	9		
Remaining gasoline	310 million GJ	12		



The Costs and Opportunities

The Costs and Opportunities

The transition to a low-carbon economy requires investment from residents, businesses, the City, and all levels of government. In many cases, the investments in the NZS require refocusing investments that are already planned or are necessary for maintaining existing infrastructure.

The financial impacts of CEIR provide important context for local decision-makers. GHG reductions are a critical response to the global climate emergency and the non-financial value (i.e. health and social benefits) of these reductions is not incorporated in the financial analysis. In addition, most measures included in CEIR provide social goods to the community, such as net job creation and positive health outcomes, which are also not reflected in the financial analysis. The CEIR aligns with other municipal strategies such as the City of Winnipeg Poverty Reduction Strategy.

A Quick Guide to Key Financial Concepts

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

Costs Are Relative to the Business-as-Usual Scenario

This financial analysis tracks projected costs and savings associated with low-carbon measures above and beyond the assumed 'business-as-usual' costs.

Discount Rate

The discount rate represents the concept of money today being of higher value than money in the future- the notion that ten dollars in hand is worth more than ten dollars five years from now. Hence, an investor considers a project financially beneficial if it generates a real rate of return equal to or greater than its discount rate.

The discount rate varies with the type of project, the duration of the investment, the risks involved, and the capital availability.

The social discount rate is the discount rate applied when assessing the value to society of investments made for the common good. It is inherently uncertain and difficult to determine. Some argue that a low or even zero discount rate should be applied in the evaluation of climate change mitigation investments[50]— that is to say we should not be discounting the future. A 2% pure-time discount rate means the life of someone born 35 years from now (with given consumption patterns) is deemed half as valuable as that of someone born now (with the same patterns).[51] In this project, we applied a 3% discount rate, which is low for business, but appropriate for community benefits, and is a central rate recommended by the Government of Canada.[52]

Net Present Value

The net present value (NPV) of an investment is the difference between the present value of the capital investment and the present value of the future stream of savings and revenue generated by the investment. Present value means that future dollars are discounted back to the current day. For example, the present value of an investment in year 1 and year 2 of $100 each would be $100+ $97= $197.

[50] Stern, N. (2006). The Stern review on the economic effects of climate change. Cambridge University Press.

[51] Stern, N. (2015). Economic development, climate and values: making policy. Proc. R. Soc. B, 282(1812), 20150820. https://doi.org/10.1098/rspb.2015.0820

[52] Environment and Climate Change Canada. (2016). Technical update to Environment and Climate Change Canada's social cost of greenhouse gas estimates. Retrieved from http://oaresource.library.carleton.ca/wcl/2016/20160502/En14-202-2016-eng.pdf

Financial Categories

Five aggregate categories are used to track the financial performance of the low-carbon actions in this analysis: capital expenditures, energy savings (or additional costs), carbon cost savings (assuming the carbon price reaches $170/tonne CO_2e in 2030 and is held constant thereafter[53]), operation and maintenance savings, and revenue generation (associated with renewable energy production facilities and some transit actions). Administrative costs associated with implementing programs, as well as any energy system infrastructure upgrades that may be required are excluded. Similarly, the broader avoided social costs from mitigating climate change are also not included.

Abatement Cost

The abatement cost of an action is the estimated cost for that action to reduce one tonne of GHG emissions, calculated by dividing the action's NPV by the total GHG emissions reductions (tCO_2e) resulting from that action. For example, if a project has an NPV of $1,000 and generates 10 tCO_2e of savings, its abatement cost is $100 per tCO_2e reduced. A project with a negative NPV saves money, while a project with a positive NPV costs money.

Amortization

The costs of major capital investments are typically spread over a period of time (e.g. a mortgage on a house commonly has a 25-year mortgage period). Amortization refers to the process of paying off capital expenditures (debt) through regular principal and interest payments over time. In this analysis we apply a 25-year amortization rate to all investments.[54]

Energy and Carbon Cost Projections

Energy cost projections underlie the financial analysis. These projections were derived from:

- Canada's Energy Future 2020, referenced against Manitoba Hydro current electricity prices;
- the US Energy Information Administration (propane); and
- Canada Energy Regulator (all other fuels).

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

An escalating carbon cost based on federal regulations was applied out to 2030, peaking at $170/$tCO_2e$ and was thereafter held constant.

[53] Assuming that the $170/tonne is held constant post-2030 is conservative, as the value of GHG emissions reductions will increase as the pressure to mitigate GHG emissions increases. If the carbon price increases post-2030, the financial value of the NZS will increase.

[54] To manage the complexity of the analysis, a blanket amortization of 25 years was applied across all actions in order to demonstrate the impact of financing the actions.

Climate Action Saves Money

Historically, there has been a discourse that climate action costs money and requires sacrifices. In the case of Winnipeg, this analysis finds the opposite. There are compelling economic reasons to implement a net-zero pathway as quickly as possible with no financial downsides.

Table 2. Summary of financial results, undiscounted (negative number = savings, positive number = cost) 2022-2050.

FINANCIAL ESTIMATE	NET-ZERO SCENARIO (UNDISCOUNTED)	NET-ZERO SCENARIO (3% DISCOUNT RATE)
Total incremental capital investment, 2021-2050	$23.0 billion	$16.0 billion
Total savings, 2020-2050	-$53.7 billion	-$30.8 billion
Total revenue, 2020-2050	-$4.9 billion	-$2.8 billion
Net benefit, 2020-2050	-$35.6 billion	-$17.5 billion
Capital cost (undiscounted) to reduce each tonne of GHG	$286/$tCO_2e$	
Abatement cost (NPV) per tonne of GHG	-$304/$tCO_2e$	
Annual household savings on energy, 2050 over 2016	-$2,500	
Investment $/person year of employment	$221,500	

The implementation of this Roadmap represents a total investment of $23 billion from 2022–2050, averaging ~$800 million per year (undiscounted), approximately 1% of Manitoba's GDP. As points of comparison, the Province's total GDP in 2019 was $63 billion with the construction industry representing $4.6 billion.[55]

This investment generates savings of $53.7 billion from avoided carbon costs, energy expense savings, and avoided maintenance costs between 2028 and 2050. Combined with the $4.9 billion revenue, the implementation of the Roadmap results in a $35.6 billion benefit to the community, a climate dividend that averages $1.2 billion per year. In order to illustrate this benefit in more tangible terms, if Winnipeg's population remained fixed at 763,000, the benefit would average just over $1,700 per person per year.[56] This benefit incurs to the community as a whole, including households, businesses and the municipality itself. The financial benefit would decrease if the investments are financed as a result of interest payments, while it would increase if the carbon price continues to rise post-2030 and/or if natural gas prices increase more rapidly than electricity prices.

[55] Statistics Canada (2021). Table 36-10-0402-01- Gross domestic product (GDP) at basic prices, by industry, provinces and territories (x 1,000,000). Retrieved from: https://www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=3610040201

[56] This calculation is to ground the total in more tangible terms. As these benefits are for the community as a whole, the savings will be distributed amongst businesses, the City and households.

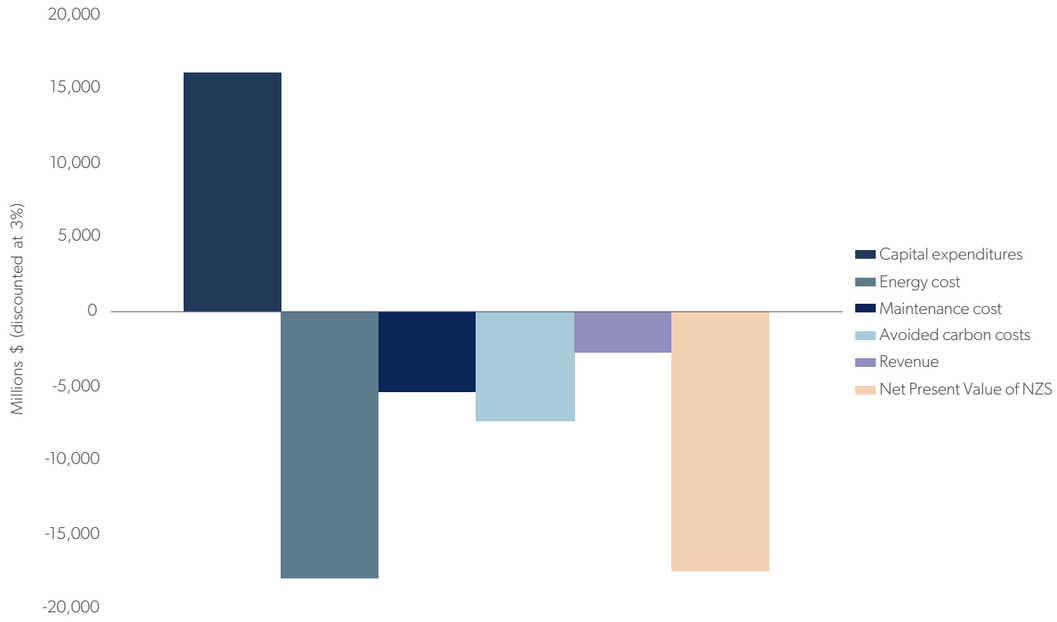


Figure 13. Present values of investments and returns for the net-zero scenario, discounted at 3% (costs are positive in this convention, and revenue and savings are negative), from 2021-2050.

The annual costs, savings, and revenue associated with fully implementing the actions in the NZS are shown in detail in Figure 14, with capital expenditures shown in full for the years in which they are incurred.

As is characteristic of low-carbon transitions, the capital expenditures in the early years of the transition are greater than the savings and revenues generated, but by 2027, the savings outweigh the costs.

Additionally, a life-cycle cost analysis may also show that the savings outweigh the costs in the longer term.

The peaks in capital investments shown in 2035, and to a lesser extent in 2026, are a result of how building retrofits were modeled, but do not necessarily represent how building retrofit activities will occur. To maximize efficiency gains, older, pre-1980 buildings are retrofitted first, followed by post-1980 buildings. The modelling illustrates an overlap of those two categories of buildings in 2035, giving an artificial peak for building expenses that would likely be spread over the adjacent years. In the implementation of the pathway, many of these investments would be amortized over the course of the project, which would smooth out the investments over time.

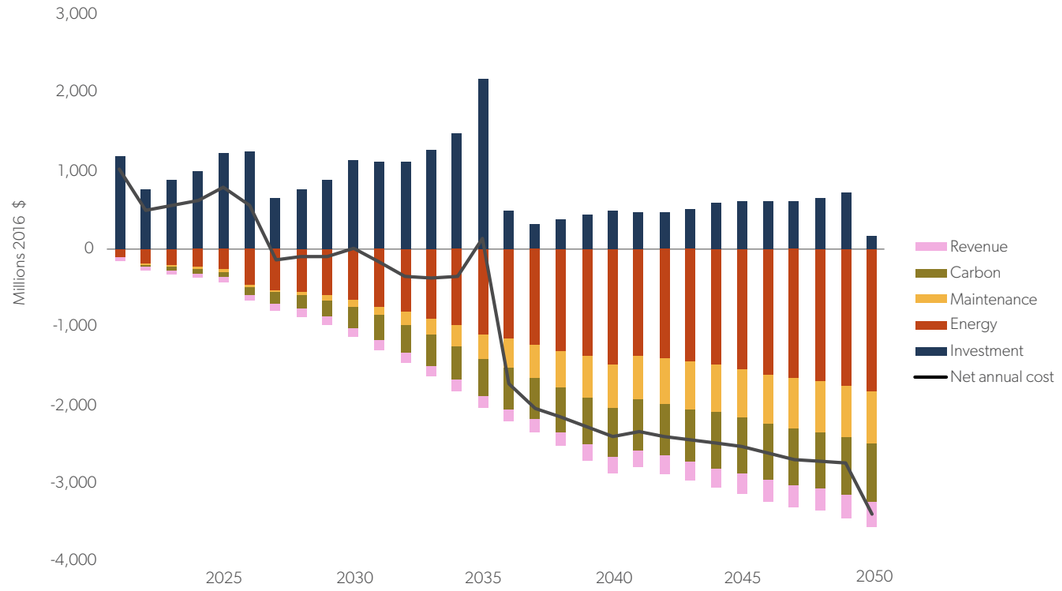
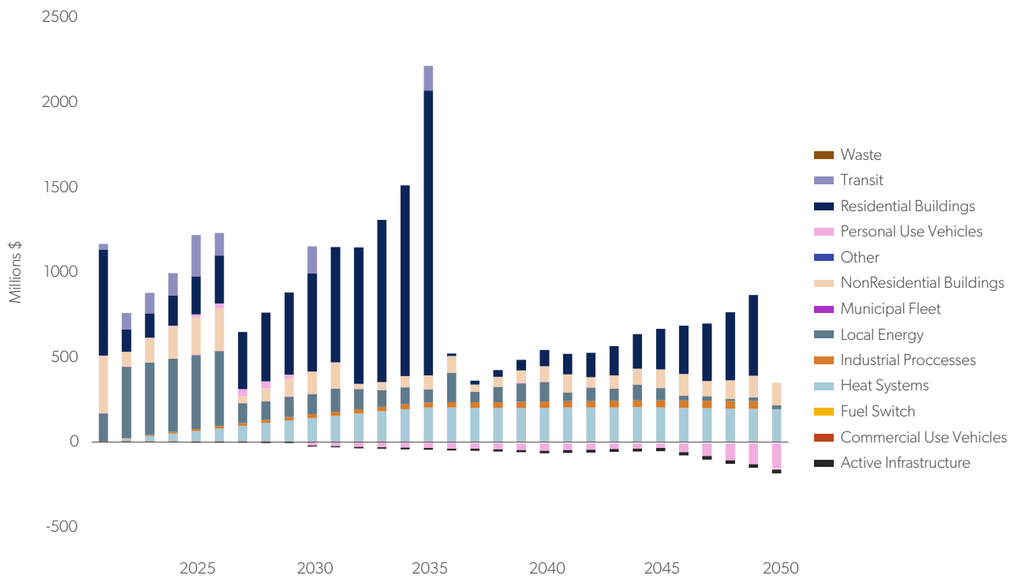


Figure 14. Year-over-year low-carbon scenario investments and returns, undiscounted.

The majority of investments are for building retrofits. The relatively clean electricity in Manitoba reduces the need for more investments in this sector compared to other provinces with more carbon-intensive grids. The incremental investment in transportation is negligible because the costs of electric vehicles are projected to reach parity with internal combustion engines as early as 2027. The reduced operation costs represent a major opportunity for cost savings going forward.

Figure 15 shows the capital investments on a cash basis and amortized over 25 years with 3% interest. This approach would presumably reflect actual approaches for financing the transition. Amortization has the effect of reducing the annual capital requirements by nearly half for peak investment years, with the result of repayments petering out beyond 2070.



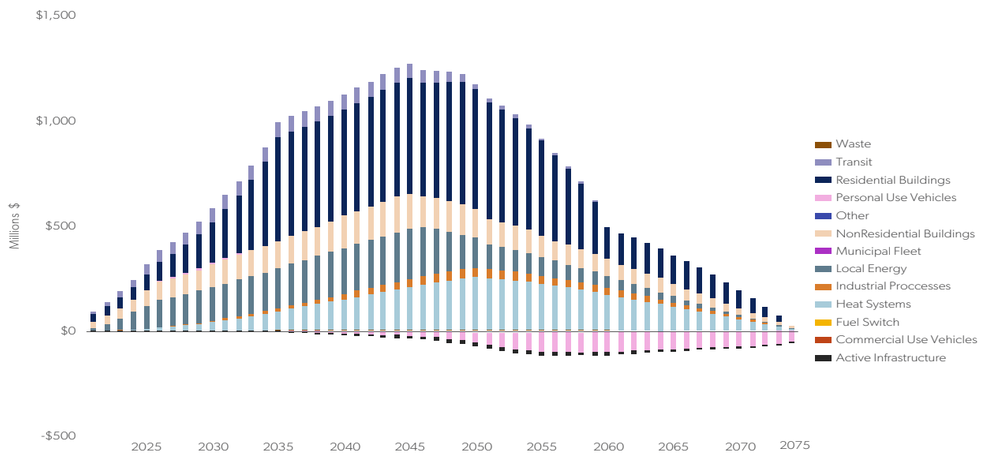


Figure 15. Two views on capital expenditures, in real time and annualized.

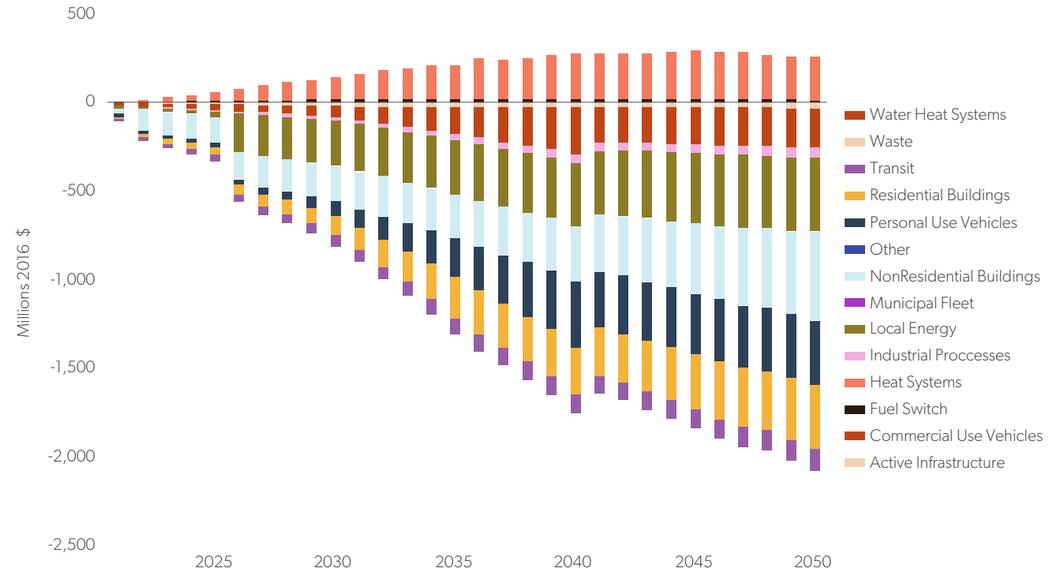


Figure 16. Energy savings by sector.

Figure 16 illustrates the financial benefits for each sector from energy savings, with the exception of expenditures on heat which increase as a result of fuel switching from natural gas to electricity (positive numbers represent an increase in energy costs). Total cost savings on energy are nearly $2 billion per year by 2050.

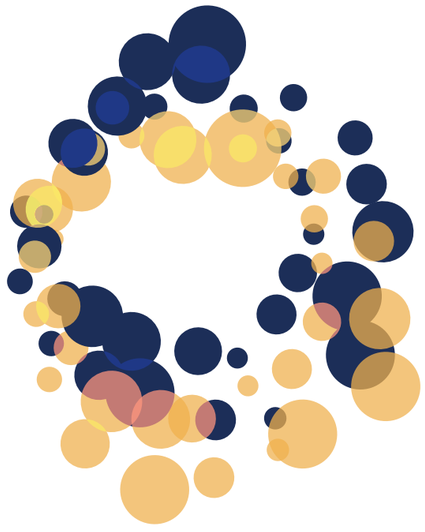
The Efficiency of Heat Pumps and Electric Vehicles

A cold-weather heat pump can generate 2-4 units of heat for each unit of electricity consumed.[57] In comparison, a high efficiency natural gas furnace generates 0.97 units for every unit of natural gas consumed. Similarly, an electric vehicle is five times more efficient than a gasoline one. These efficiencies, combined with avoided energy costs resulting from retrofits, result in financial savings.

Energy Savings for Households

Household energy expenditures (Figure 17)—natural gas, electricity, gasoline and diesel—are projected to decline by 24% in the BAU, from $8,150 in 2016, to $6,000 by 2050. These savings result from more efficient vehicles due to national fuel efficiency standards and decreased heating requirements as the climate becomes milder due to climate change. In the NZS, the savings are much greater, and household energy expenditures fall by 45% to $3,600 by 2050. Additionally, as the carbon price increases to $170/t$CO_2$e in 2030, the cost of using fossil fuels for heating and transportation increases, resulting in greater savings in the NZS. Depending on the business, policy, and financing strategies used in the implementation of the actions, these savings will be partly offset by the incremental capital expenditures required.

Household energy costs increase slightly at the start of the NZS as some natural gas is replaced with RNG in homes that have not yet been retrofitted. Furthermore, natural gas furnaces are replaced with electric heat pumps as part of the deep retrofits which minimize the heat required to ensure the homes are comfortable both in the summer and the winter.



[57] NEEA (2020). EXP07:19 Load-based and Climate-Specific Testing and Rating Procedures for Heat Pumps and Air Conditioners. Retrieved from: https://neea.org/img/documents/CSA-EXP07-Interim-Testing-Report.pdf

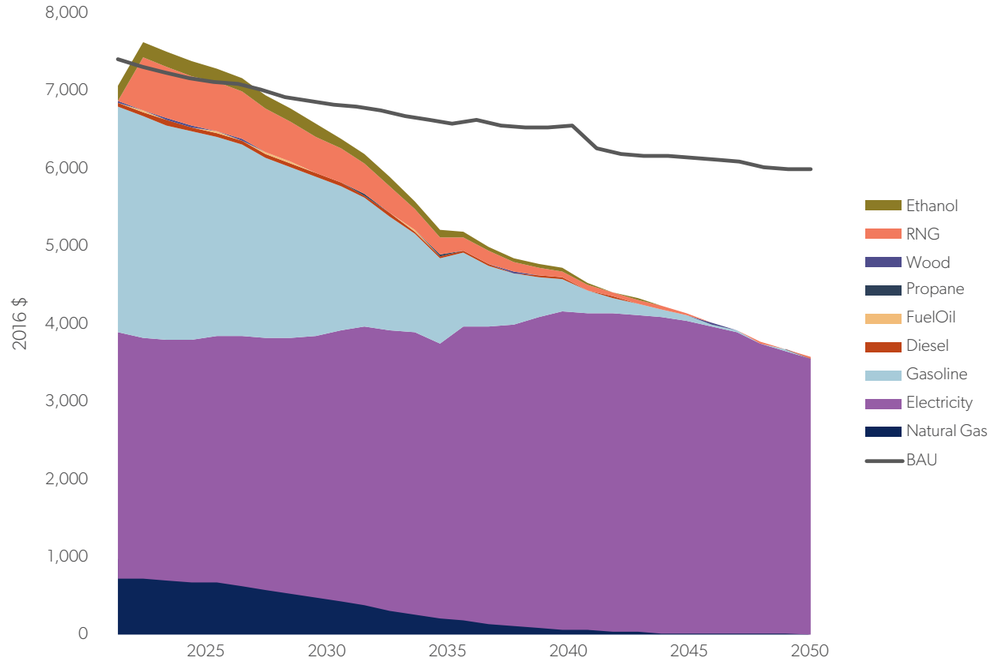
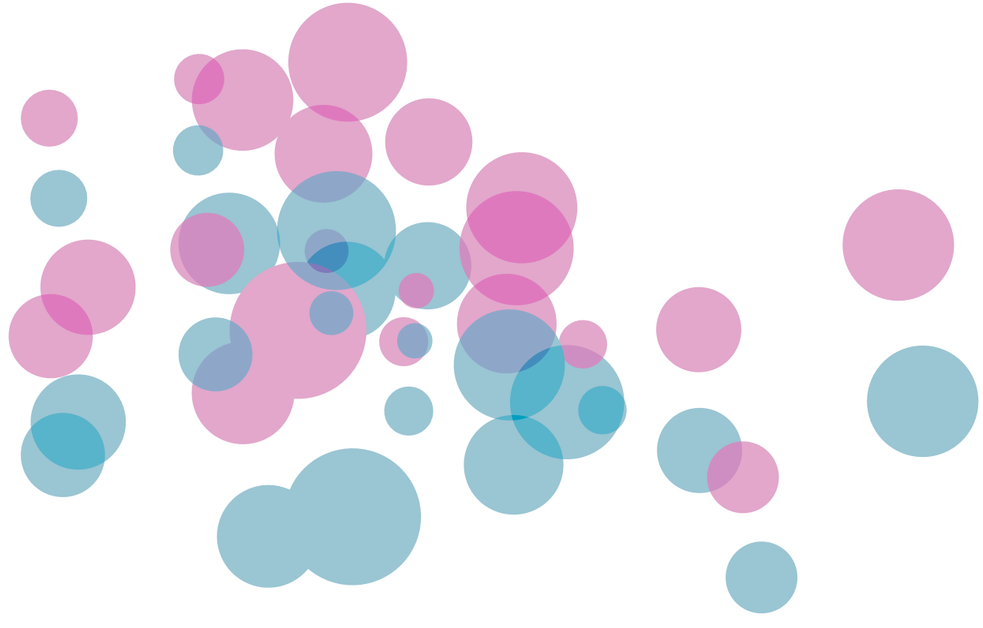


Figure 17. Household energy costs by fuel type for the net zero scenario, compared to the BAU.



The Toll of Energy Poverty

Households facing energy poverty or energy insecurity need to make difficult choices such as "pay the rent or feed the kids", "heat or eat", or "cool or eat".[58] In particular, energy insecurity disempowers low-income residents such as lone- parent households, older adults, persons with disabilities, and others with low or fixed incomes.[59] Energy insecurity leads to stresses such as utility-related debt, shutoffs, inefficient heating systems, antiquated appliances, and extreme home temperatures with significant health impacts.[60] Children may experience nutritional deficiencies, higher risks of burns from non-conventional heating sources, higher risks for cognitive and developmental behaviour deficiencies, and increased incidences of carbon monoxide poisoning.[61] Subsequent impacts include parents being unable to work in order to look after children, missed school days, and lost productivity.

Stimulating Job Creation

Transitioning to a low- or zero-carbon economy is expected to have four categories of impacts on labour markets: additional jobs will be created in emerging sectors, some employment will be shifted (e.g. from fossil fuels to renewables), certain jobs will be reduced or eliminated (e.g. combustion engine vehicle mechanics), and many existing jobs will be transformed and redefined. The low carbon scenario adds 103,000 'person-years of employment', over the BAU Scenario between 2020 and 2050 (Figure 18).

Building retrofits present the largest opportunity for new employment, presenting opportunities to partner with local education centres. This could include developing programs teaching the skills required to complete deep energy retrofits and install high-efficiency equipment. Winnipeg has the benefit of a large and sophisticated building sector, hence, developing partnerships to expand on local knowledge will help jump-start this activity.

In addition to building retrofits, improvements can simultaneously be made to accessibility features of public buildings, buildings, and common areas.

The modelling assumptions used for building retrofits resulted in an artificial peak in 2035, with an overlap between retrofits of pre-1980 and post-1980 buildings in that year. In reality, the renovations would be spread over the adjacent years, so building retrofit employment would not experience the peaks and losses as implied by Figure 18.

The sectors showing small losses in total person-years of employment are those which also show the most efficiency gains, including waste management and vehicle maintenance with the switch to electric vehicles.

[58] Cook, J. T., Frank, D. A., Casey, P. H., Rose-Jacobs, R., Black, M. M., Chilton, M., … Cutts, D. B. (2008). A brief indicator of household energy security: Associations with food security, child health, and child development in US infants and toddlers. PEDIATRICS, 122(4), e867–e875. https://doi.org/10.1542/peds.2008-0286

[59] Hernández, D. (2013). Energy insecurity: A framework for understanding energy, the built environment, and health among vulnerable populations in the context of climate change. American Journal of Public Health, 103(4), e32–e34. https://doi.org/10.2105/AJPH.2012.301179

[60] Hernández, D., & Bird, S. (2010). Energy burden and the need for integrated low-income housing and energy policy. Poverty & Public Policy, 2(4), 5–25. https://doi.org/10.2202/1944-2858.1095

[61] Ibid.

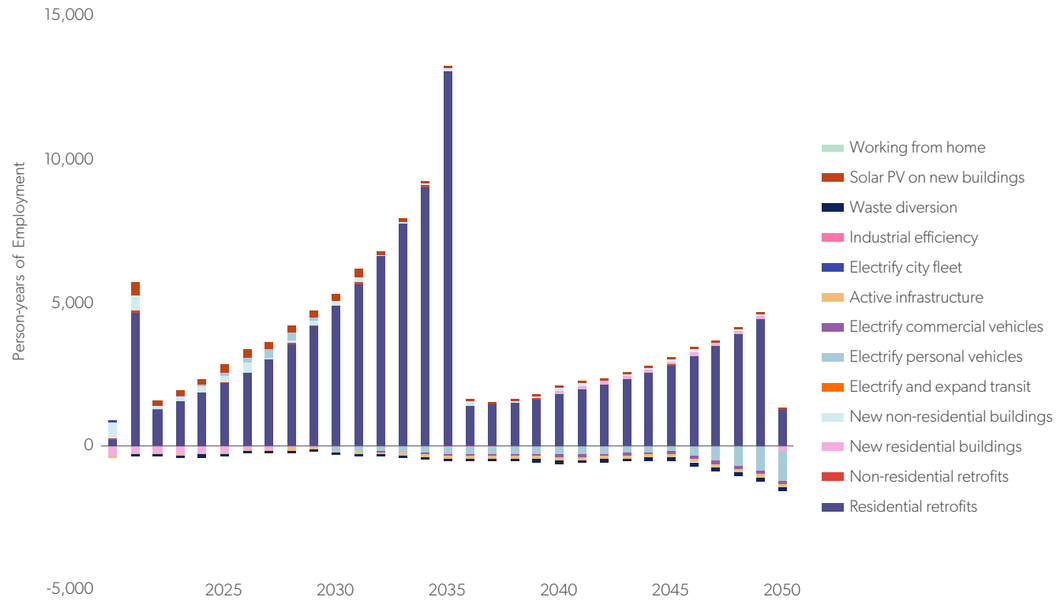


Figure 18. Annual person years of employment generated in the low carbon scenario.

Marginal Abatement Costs

The Marginal Abatement Cost (MAC) is the incremental cost of one tonne of GHG reductions. The lower the cost, the more affordable the action and in some cases, the action can be profitable. It is calculated by summing the net present value of capital costs and operating costs over the lifetime of the investments divided by the tonnes of GHGs reduced.

By providing individual costs for actions, MACs can imply that the actions are a menu from which individual actions can be selected. In fact, many of the actions are dependent on each other, for example, energy costs increase without retrofits. Another important message is that in order to achieve Winnipeg's target, all the actions need to be undertaken as soon as possible.

Using Abatement Costs to Guide Policy

Figure 19 illustrates an abatement curve of actions. Actions on the left save money and are therefore financially interesting to investors. Actions in the middle have a net present value that is either slightly negative or slightly positive and may require credit enhancements to be compelling. Finally, on the right, those actions which are NPV negative will require subsidies. A capital-constrained public sector must concentrate on the expensive projects while relying on the private sector for the rest. A capital-rich public sector can invest in projects that are more expensive and those which may generate more interesting financial returns.

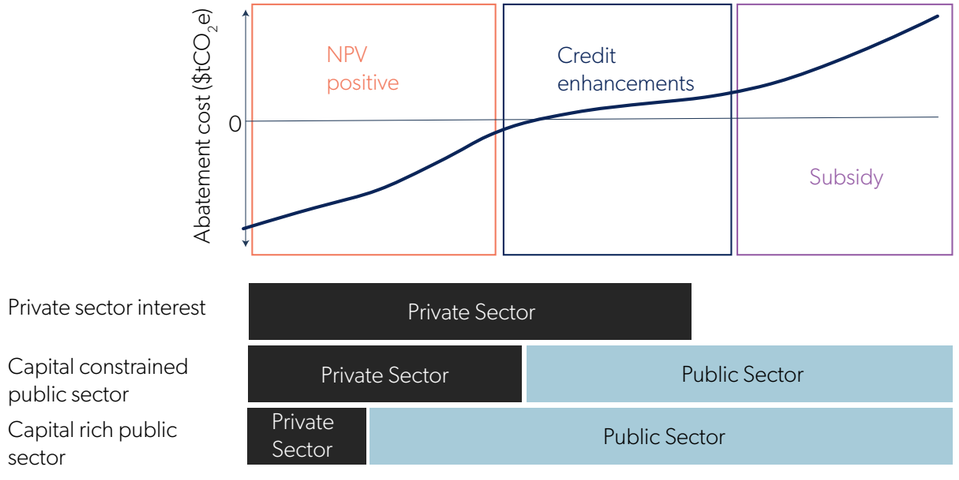


Figure 19. Aligning the abatement costs with investor interest.

Table 3, below, summarizes the marginal abatement costs for the modeled actions in Winnipeg's low-carbon future. The actions with green, or negative abatement costs generate financial returns over their lifetimes. A purple, or positive abatement cost, costs money over the span of the project. This comparison provides one way to view the costs and benefits of the implementation of emissions-reducing actions, but should not be the only metric used to measure an action.

Table 3. Marginal abatement costs for modeled actions

	CUMULATIVE EMISSIONS REDUCTION (KT CO_2EQ)	NET PRESENT VALUE	MARGINAL ABATEMENT COST ($ / T CO_2EQ)
New Dwellings Smaller	215	-$1,108,000,000	-$5,148
New Residential Buildings	1,656	-$781,000,000	-$472
New Non-Residential Buildings	6,118	-$4,283,000,000	-$700
Residential Retrofits	4,958	$3,493,000,000	$705
Residential Heat Pumps	9,122	$2,777,000,000	$304
Non-Residential Retrofits	3,935	-$3,804,000,000	-$967
Non-Residential Heat Pumps	10,495	$1,435,000,000	$137
Industrial Processes	1,081	-$176,000,000	-$163
Transit Electrification	940	-$52,000,000	-$56
Increase transit use	1,643	-$6,161,000,000	-$3,750
Active transportation	445	$565,000,000	$1,270
Working from home[62]	1,061	$434,000,000	$409
Electrify Personal Use Vehicles	16,792	-$8,915,000,000	-$531
Electrify Municipal Fleet	69	-$42,000,000	-$604
Electrify Commercial Use Light-Duty Vehicles	5,074	-$2,958,000,000	-$583
Electrify Commercial Use Heavy-Duty Vehicles	6,010	-$4,288,000,000	-$713
Solar PV on new residential buildings	2	-$250,000,000	-$120,980
Solar PV on existing buildings	15	-$2,032,000,000	-$131,384
Solar PV on existing ICI buildings	4	-$234,000,000	-$63,143
RNG	7,891	-$499,000,000	-$63
Waste diversion	1,489	-$187,000,000	-$126
Reduce water consumption	118	-$132,000,000	-$1,121
Wastewater efficiency improvements	9	-$3,000,000	-$297

Shown slightly differently, the Marginal Abatement Cost Curve (Figure 20) gives a visual representation of the financial implications and the emissions reductions associated with each action. The height of the bar indicates the size of the financial costs/savings and the width shows the potential GHG savings.

The action with the highest cost per tonne of CO_2e reduced is the expansion of active transportation infrastructure and the second-most expensive action is residential retrofits. Active transportation requires infrastructure investments in trail networks and bike lanes. It does not compensate for this with other direct financial revenues. Residential retrofits require costly building envelope improvements and the switch to heat pumps, while maximizing

[62] Working from home gives a negative NPV because of lost revenue from transit in commutes to and from workplaces.

efficiency and reducing GHG emissions, requires switching to electricity that is currently more expensive than natural gas. While these actions may not have immediate financial incentives, they provide other benefits though improved connectivity within the city, improved community health, and can help address inequality and social barriers within the community. Efficient homes are easier to heat, and an expansive active infrastructure network can ensure all community members can travel freely and safely throughout the city.

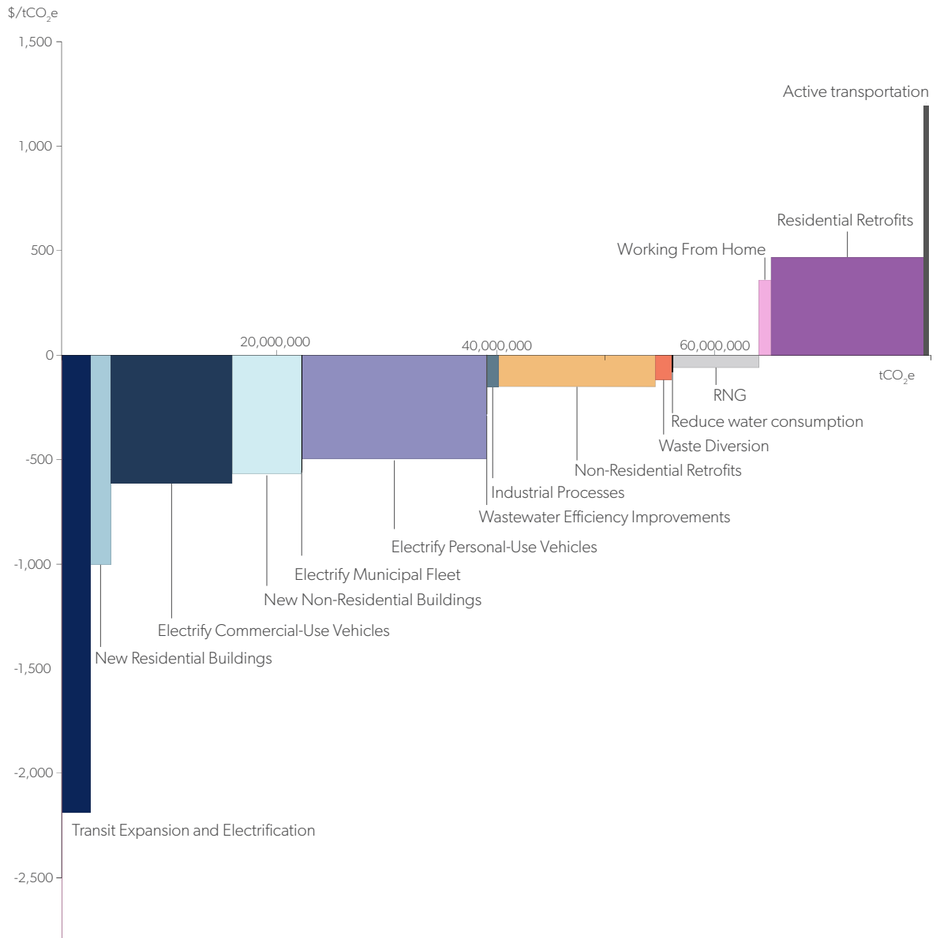


Figure 20. Marginal abatement cost curve for Winnipeg's low-carbon future.

THE COST OF INACTION

The impacts and costs of climate change will be determined by how quickly actions are implemented and by how deeply GHG emissions are reduced over the next few years, prior to 2030. This is because the cumulative GHGs emitted into the atmosphere determine the degree of global average temperature increase. Over the past several decades, the cost of inaction to address climate change by limiting and reducing GHG emissions has now locked the world into at least a 1.5 to 2.0°C temperature increase.

Already, the costs of weather-related disasters, such as floods, storms, and wildfires, have risen in Canada from an average of $8.3 million per event in the 1970s to $112 million per event between 2010-2019. This change represents a staggering 1,250% increase.[63] During the latter time period (2010-2019), total insured losses for catastrophic weather events totalled over $18 billion.

Climate change is driving a higher number of extreme weather patterns, resulting in more frequent and more expensive impacts than previous decades. For example, in the last decade, disaster costs have grown from about the equivalent of one percent of Canada's gross domestic product (GDP) growth to between five and six per cent of annual GDP growth.[64]

The value of the avoided damage from climate change can be calculated using the Social Cost of Carbon (SCC). When the SCC is applied to the cumulative emissions between 2020 and 2050, the cost of the damages is $30.5 billion. In comparison, the cost of the damages declines to $23.3 billion in the BAP scenario and to $11.7 billion in NZS, as illustrated in Figure 21.[65]

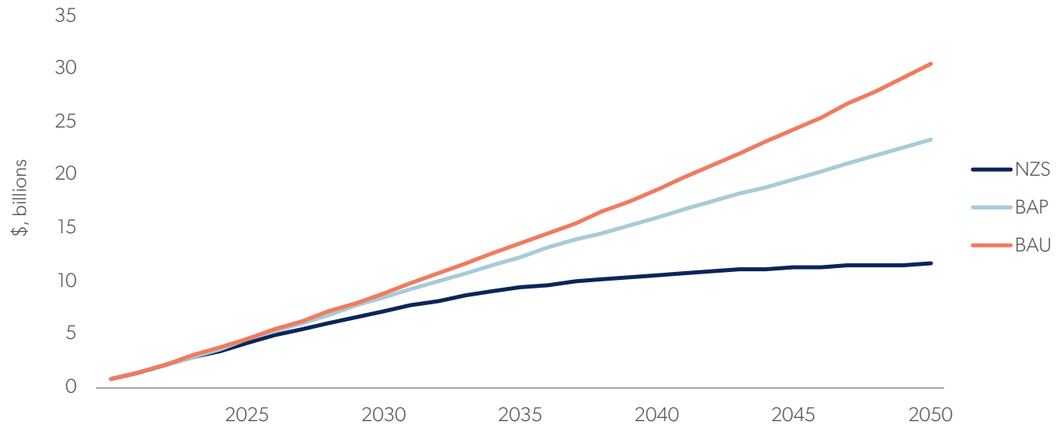


Figure 21. The Social Cost of Carbon (SCC) for the three scenarios, 2020-2050.

The cumulative financial benefits of implementing the NZS, with regard to the avoided damage costs of climate change, total $19 billion in comparison to the BAP scenario (Figure 22).

[63] Canadian Institute for Climate Choices. 2020. Tip of the Iceberg: Navigating the Known and Unknown Costs of Climate Change for Canada. Retrieved from: https://climatechoices.ca/wp-content/uploads/2020/12/Tip-of-the-Iceberg-_-CoCC_-Institute_-Full.pdf

[64] Ibid.

[65] All values used the 3% discounting rate, 95th percentile which reflects higher than expected economic damages from climate change. Interagency Working Group on Social Cost of Greenhouse Gases, United States Government (2021). Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990. Retrieved from: https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf

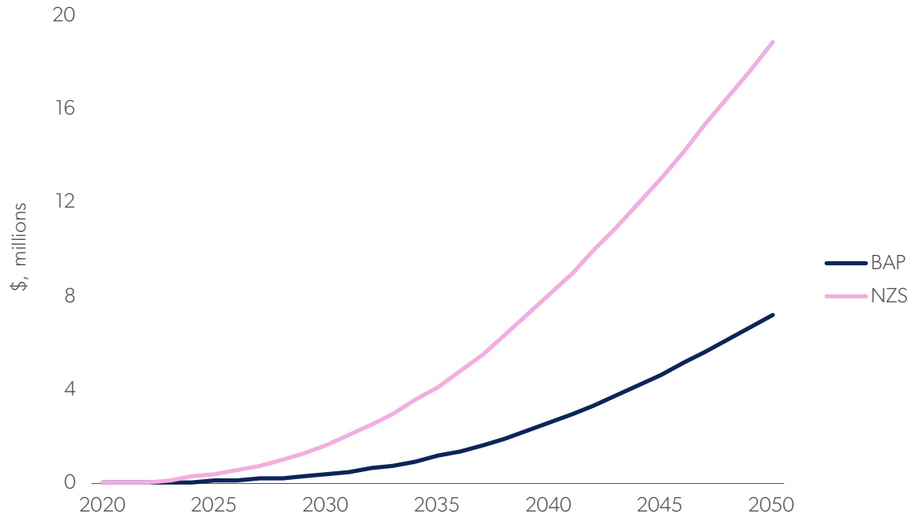


Figure 22. Cumulative benefit of Social Cost of Carbon (SCC), as an indicator of avoided damages of climate change for BAP and the NZS.

The Social Cost of Carbon

The social cost of carbon (SCC) has been used in regulatory processes in Canada and the US to reflect the impacts of climate change on society. The SCC attempts to add up the quantifiable costs and benefits of a tonne of carbon dioxide. While the estimates of SCC are highly uncertain, it is one of the best ways to reflect future damages to ensure that decision-making, which has implications for future emissions, accounts for those impacts. The SCC includes assumptions around future conditions including population size, economic growth, rate of climate change and the impact of climate change on those conditions, drawing on the results of integrated assessment models. The discount rate is also a significant assumption within the models. Discounting reflects the idea that people would rather have $100 now than $100 in ten years. From an ethical perspective, a higher discount rate indicates that future generations are worth less than current generations. As Stern pointed out in a subsequent article, "A 2% pure-time discount rate means that the life of someone born 35 years from now (with given consumption patterns) is deemed half as valuable as that of someone born now (with the same patterns)." The Government of Canada recommends 3% in circumstances where environmental and human health impacts are involved and 3% was used for Winnipeg's NZ modelling. In addition, the Government of Canada reports on estimated damage associated with lower probability, high-cost damages using the same 3% discounting rate. The SCC in this analysis reflects less likely impacts of increased temperatures that result in greater damage, as described within the 95th percentile of the SCC frequency distribution.

How to Achieve Our Goals

How to Achieve Our Goals

The City of Winnipeg has set the target of net-zero emissions by 2050 and the analysis above shows a pathway to achieving this goal. Moving from modelled actions to real-world change requires coordination and participation from all members of the community. The following is a discussion of the priority steps for the next five years for the City and for the community.

While not all elements of this plan are under the purview of the municipal government, the City can act as a leader, convener, organizer, and coordinator in many sectors. Below is a description of the modelled actions, the measurable targets from this modelling, and programs which enable the implementation of these targets.

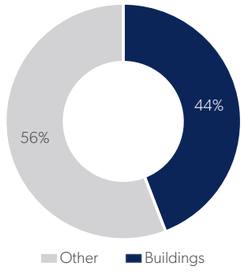
Affordable, Zero-emissions Buildings

GHG emissions from buildings, including homes, businesses, institutions, and industrial buildings, make up 44% of the total emissions from Winnipeg in 2020. The majority (93%) of the GHG emissions are from the use of natural gas for space heating and other industrial purposes. The remaining 7% of emissions come from diesel, propane, and a small amount of wood.

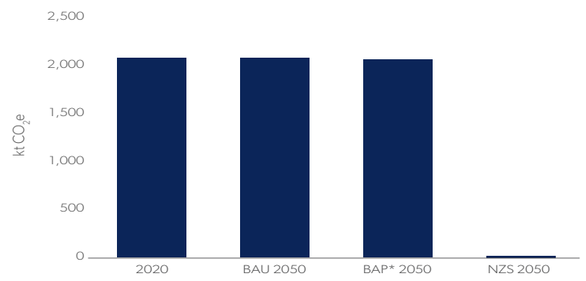
Switching from natural gas for space heating to efficient electric heat pumps, as well as eliminating the use of diesel and propane will result in the decarbonization of the buildings sector.

To reduce the demand for electricity with the complete electrification of the buildings sector, the first objective is to reduce the total energy demand through efficiency measures and deep retrofits to all buildings. By prioritizing the reduction of the total energy demand, the need for increased electricity generation is minimized.

EMISSIONS AND PATHWAY



2020 GHGs



The GHG reduction actions for the buildings sector are provided in Table 4. This section details the interventions needed to increase the efficiency of the building stock and the fuel switch from fossil fuels to electricity.

High performance buildings

Canadian cities are adopting the Passive House[66], Zero Carbon[67] and Net Zero Energy standards[68] or certification or level of performance as a basis for new construction and retrofits,[69] to implement GHG reduction targets. Designers and builders in Winnipeg have a long history of high-performance construction, which provide a foundation for the targets in the CEIR. Examples include Habitat for Humanity's net-zero homes, Sun Certified Builders' home at 482 Kylemore Ave. and Red River College's net zero Innovation Centre. One innovative approach, KITHOUSE, is offering net zero and Passive House kits. A housing cooperative, Bannerman Green Housing Co-op and Buffalo Crossing at Fort Whyte Alive are targeting Passive House certification.

Table 4. Summary of BAP* and NZS actions in the buildings sector.

		NET GHG REDUCTION (KT CO_2E) (RELATIVE TO BAU)	MARGINAL ABATEMENT COST ($ / TCO_2E REDUCED, NEGATIVE= SAVINGS)
NEW BUILDINGS			
1. Residential	Only 20% of new dwellings are single-detached by 2050.	215	-$5,148
	All new buildings are substantially more efficient and electric by 2030, using the NBC as a starting point: 2022: 2013 NBC 2024: 10% better 2026: 20% better 2030: 40% better	1,656	-$472
2. Commercial, Institutional, and Industrial	All new buildings are substantially more efficient and electric by 2030, using the NECB as a starting point: 2022: NECB 2020 2024: 25% better 2026: 50% better 2030: 60% better	6,118	-$700

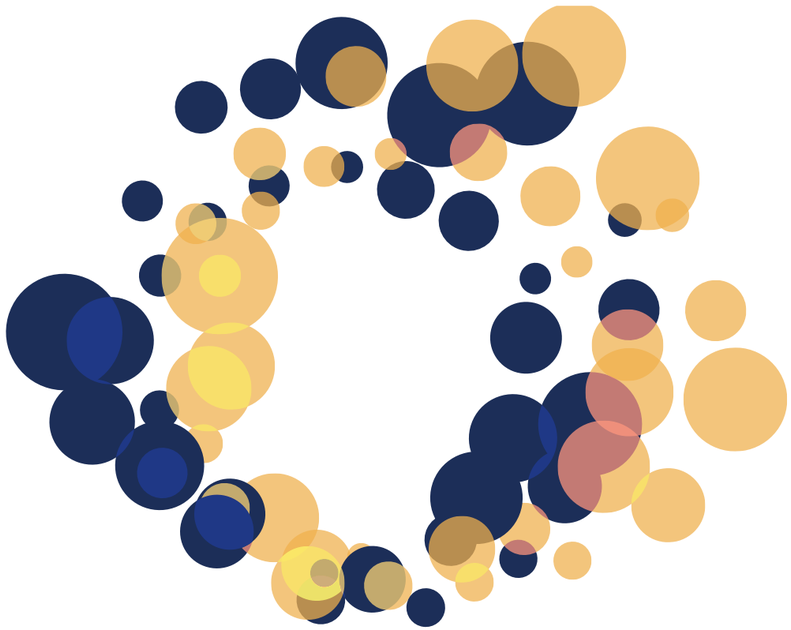
[66] For more details on Passive House certification, see: https://www.passivehousecanada.com/passive-house-building-certification/

[67] Details on Canada Green Building Council's Zero Carbon program can be found here: https://www.cagbc.org/zerocarbon

[68] CHBA's net zero home program can be found here: https://www.chba.ca/CHBA/HousingCanada/Net_Zero_Energy_Program/CHBA/Housing_in_Canada/Net_Zero_Energy_Program/NZE_Program_Landing_Page.aspx?hkey=4af3da17-b4da-42ef-bf20-261a9cfbe39f

[69] A project in Hamilton was the first residential tower retrofit in Canada to receive Passive House certification in Canada, achieving a 94% reduction in GHG emissions. For more information, see: https://www.reminetwork.com/articles/hamilton-tower-named-worlds-largest-residential-passive-house/

		NET GHG REDUCTION (KT CO_2E) (RELATIVE TO BAU)	MARGINAL ABATEMENT COST ($ / TCO_2E REDUCED, NEGATIVE= SAVINGS)
EXISTING BUILDINGS			
3. Residential	Starting in 2022, retrofit 100% of all existing dwellings built before 1980 by 2035, in order to improve thermal and electrical efficiency by 50%.[70] Starting in 2035, retrofit 100% of all remaining buildings by 2050, to improve thermal and electrical efficiency by 50%.	4,958	$705
	As homes are retrofitted, heat pumps are installed to provide all of the space heating and cooling needs. By 2050 all buildings have electric heat pumps.	9,122	$304
4. Commercial, Institutional, and Industrial (ICI)	Starting in 2021, all ICI buildings are retrofitted to increase efficiency by 50% by 2050.	3,935	-$967
	By 2050, 100% of all ICI buildings use electric heat pumps for space heating and cooling.	10,495	$137
5. Industrial efficiency	Starting in 2021, increase efficiency to reduce overall process-related energy consumption by 33% by 2050.	1,081	-$163



[70] Electrical efficiency is improved through replacement of appliances, lighting, and water heaters with more energy-efficient options.

TARGETS

The following is a summary of the five-year measurable targets the City can use to track progress towards the overall sector emissions reductions plan. These are the results of the modelled actions in Table 4.

Table 5. Targets for Buildings Sector

	2021-2025	2026-2030	2031-2040	2041-2050
% improvement to EUI/TEDI of new buildings relative to 2020	10%	40%	45%	50%
Number of dwelling units built prior to 2016 that are retrofit	13,607	29,130	74,206	41,065
Non-residential buildings constructed prior to 2016 that are retrofit	169	338	1,517	4,260
Non-residential floor area constructed prior to 2016 that is retrofit (m^2)	650,631	439,930	1,973,386	5,544,252

PROGRAMS

Winnipeg has an advanced and sophisticated green buildings sector. Working together to help plan, develop, and industrialize building retrofits will ensure the most effective transformation of Winnipeg's existing buildings. The following are the essential programs, policies and initiatives for the City of Winnipeg to implement in the next five years:

Program #1: Zero-Emissions New Construction

1.1 Zero-emissions building coalition: The City can convene developers, builders, consultancies, institutions, and non-profit organizations who are committed to advancing net-zero projects. This coalition can support the City by undertaking pilot projects and identifying strategies to accelerate net-zero projects.

1.2 Sustainable development checklist: As part of any development application, the City can require enhanced building process using an approach that requires evidence of improved energy and GHG performance prior to approval. A tiered approach to the performance requirement would result in a steady increase in required improvement of performance over time. A building performance label can also be tied to the checklist to highlight the best performing homes and buildings. The cities of Vancouver, Brampton and Toronto have similar programs and many others are under development.

1.3 Efficient development incentives: The City can identify mechanisms to acknowledge improved performance such as expedited permitting, reduced development charges, and other incentives.

1.4 Net-Zero Building Code: The Net Zero Ready Building Code will be released in early 2022.[71] The City can lobby the Province to not only adopt the code in 2022, but to endorse the highest tier as the minimum requirement by 2025.

[71] A net zero ready building is an energy efficient building that can provide all of its required energy through renewable generation on site.

Cold Weather Heat Pumps

Cold climates are seeing a resurgence of attention on heat pumps, as technological advances have improved its performance.[72] Heat pumps use electricity to harness energy from the surrounding air and pump that energy indoors in the form of heat—much like an air conditioner in reverse.

Program #2: Zero-Emissions Retrofits

The following four objectives will guide the CIty's efforts to scale up retrofits:

1. Harness the collective market power of the demand among home/building owners.
2. Mobilize the building industry to develop innovative technical solutions to substantially improve affordable housing buildings while residents continue to live in their homes.
3. Collaborate with financial organizations to fund projects by capturing energy savings.
4. Engage regulatory agencies to support facilitation of widespread adoption.

2.1 Residential retrofit stream: The City can take an integrated approach to building retrofits that includes an envelope upgrade, the installation of a heat pump, solar PV, energy storage, and an EV charging station according to the specific circumstances of the building. The City can also develop a plug and play approach where the City, or a trusted third party, acts as the coordinator of the retrofits. This includes coordinating funding programs from the Canada Mortgage and Housing Corporation, determining grants and utility incentives, identifying approved contractors and suppliers, and organizing bulk procurement.

2.2 Low income retrofit stream: In collaboration with a working group on energy poverty, the City will identify ways to ensure building retrofits are available to those who are most vulnerable to fluctuations in energy and home heating costs. It will focus particularly on social and rental housing.

2.3 Large buildings stream: This stream will develop a customized program for multi-story retrofits including a financing strategy similar to Toronto's Better Buildings Partnership.[73] This stream will also advance green leases[74] to address the split incentive challenge between landlords and tenants.

2.4 Carbon co-operative: The City will support the development of a carbon co-operative as a novel approach to building retrofits. Based on a UK model, the carbon co-op is a novel approach to overcoming the barriers to retrofits where networks of community members coordinate and participate in retrofits.[75]

2.5 Neighbourhood retrofit pilot: As a pilot project, the City can coordinate the retrofit of an entire neighbourhood at once in order to achieve efficiencies through bulk purchasing, a simple project planning and stimulating the bulk retrofits, similar to the EnergieSprong model. The EnergieSprong model provides a turn-key retrofit service to existing buildings to convert them to net zero or net zero-ready when renewable energy becomes available.[76] Energiesprong retrofits can be completed in 10 days and have been successful in updating social housing without requiring upfront capital from tenants.[77] The Sundance Co-operative in Edmonton is an early example of this type of project.[78]

2.6 Embodied carbon and refrigerants: Embodied carbon refers to the emissions associated with the production of the materials used in buildings. The City of Winnipeg can build on Vancouver's approach[79] to require consideration of embodied carbon as part of rezoning applications. A second consideration is for refrigerants used in heat pumps, which can emit potent GHGs. The City can preferentially procure and specify refrigerants with low global warming potential.[80]

2.7 Workforce development program: Capacity and expertise is a major barrier for zero-emissions buildings and deep retrofits. The City can work with the University of Manitoba, the Province of Manitoba, Red River College, unions and trades organizations, and industry experts in developing a program to scale up the workforce in alignment with the City's targets.[81] Ensuring access to all members of the community to training and education programming is essential in ensuring the energy transition is equitable.

[72] RMI (2020). Heat pumps: A practical solution for cold climates. Retrieved from: https://rmi.org/heat-pumps-a-practical-solution-for-cold-climates/

[73] City of Toronto (2021). Better Buildings Partnership. Retrieved from: https://www.toronto.ca/business-economy/business-operation-growth/green-your-business/better-buildings-partnership/

[74] Green leases incentivize both landlords and tenants to implement energy savings and GHG emissions reductions. For more information, see: RMI. Net-zero energy leasing. Retrieved from: https://rmi.org/our-work/buildings/pathways-to-zero/net-zero-energy-leasing/

[75] For more information, see the Carbon Co-op's website at: https://carbon.coop/

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

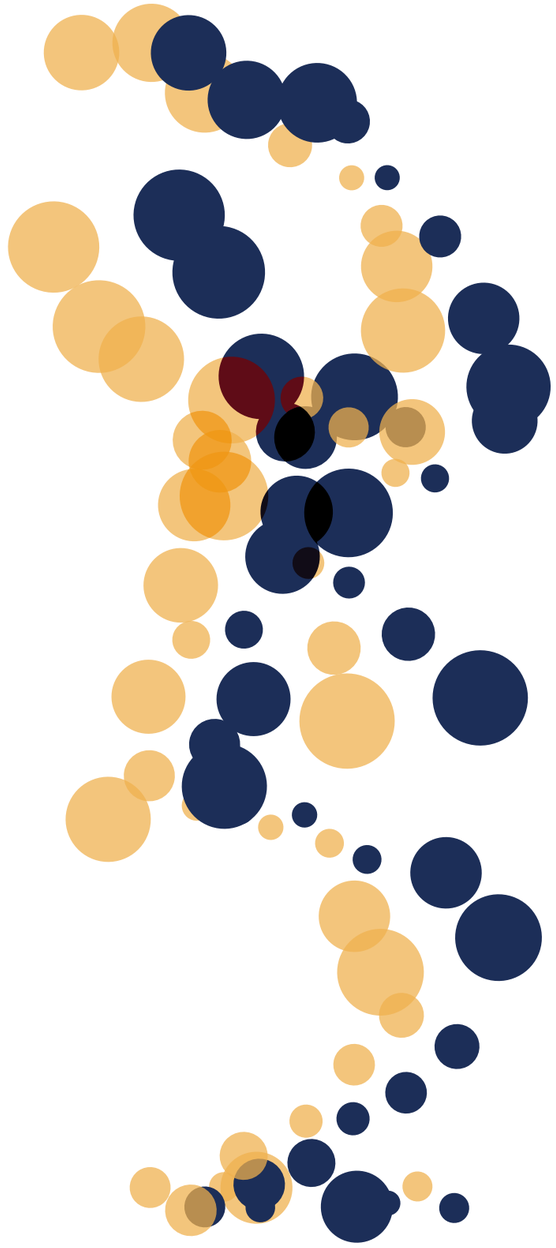
[77] Rocky Mountain Institute (n.d.). "How-to-Guide: Net-Zero Retrofit Technical and Cost Benchmark Studies." Rocky Mountain Institute. https://www.rmi.org/rmi_techno_economic_study_how_to_guide/.

[78] For more information on the Sundance Project, see: https://sundancecoop.org/sundance-retrofit-project/

[79] City of Vancouver (2016). Zero Emissions Building Plan. Retrieved from: https://vancouver.ca/files/cov/zero-emissions-building-plan.pdf

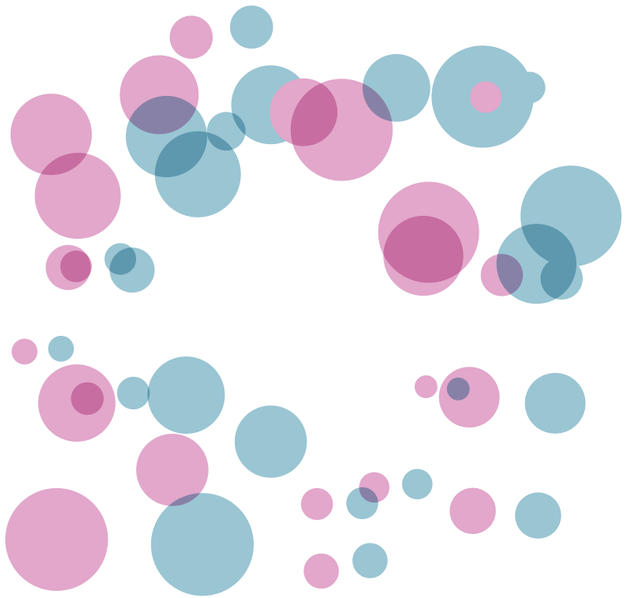
[80] EPA (2015). Transitioning to Low-GWP alternatives in Residential & Light Commercial Air Conditioning. Retrieved from: https://www.epa.gov/sites/default/files/2015-09/documents/epa_hfc_residential_light_commercial_ac.pdf

[81] For an example of a green workforce development strategy, see: https://www.nyserda.ny.gov/All-Programs/Clean-Energy-Workforce-Development



Industrialization of Retrofits

In both Europe and North America, the industrialization of retrofits is an increasingly common solution to rapidly retrofit the building stock in order to achieve GHG reduction targets. Energiesprong, a Dutch public-private partnership, has pioneered a semi-industrialized net-zero energy retrofit package and applied this approach to approximately 5,000 low- and mid-rise multifamily retrofits, with roughly another 100,000 units of multifamily demand aggregated across Europe.[82] Similar projects are under development in New York State, California, and Massachusetts.[83] The European Union currently has advanced retrofit industrialization programs underway.[84] The City of Seattle has developed a mechanism to transform deep retrofits into power purchase agreements, described as Energy Efficiency as a Service (EEaS) contracts. A pilot project for 30 commercial buildings is currently underway.[85] Efficiency Canada has identified policies to scale up retrofits in Canada including integrated design and project delivery, prefabrication of building facades and HVAC systems, mass customization tools that manage distinct building characteristics with greater ease, and aggregation of retrofit projects into single portfolios.[86]



[82] Egerter, A., & Campbell, M. (2020). Prefabricated zero energy retrofit technologies: A market assessment (DOE/GO-102020-5262, 1614689). https://doi.org/10.2172/1614689

[83] The hub of the US work is a project called REALIZE: https://rmi.org/our-work/buildings/realize/

[84] An example of one project that is a partnership of major industries is BRESAER: http://www.bresaer.eu/

[85] A description of the City of Seattle's program is available here: https://www.bdlaw.com/publications/seattle-launches-energy-efficiency-as-a-service-program-encouraging-deep-energy-efficiency-building-retrofits/

[86] Haley, B and Torrie, R. (2021). Canada's Climate Retrofit Mission. Retrieved from: https://www.efficiencycanada.org/wp-content/uploads/2021/06/Retrofit-Mission-FINAL-2021-06-16.pdf

Zero-Emissions Transportation

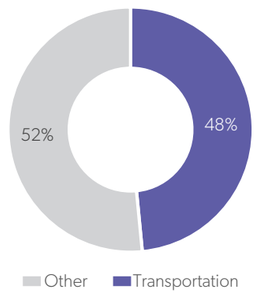
Transportation is the largest source of GHG emissions in Winnipeg. Personal vehicle use, commercial operations, transit, heavy transportation, and off-road vehicle use was responsible for 48% (2.3 Mt CO_2e) of emissions in 2020. Personal vehicles accounted for the majority of these emissions (43% from light trucks and SUVs, and 33% from cars), while heavy trucks made up a further 18% of the emissions.

Transportation emissions also come from many small sources, it takes into account every personal vehicle, every snowblower or lawn mower and every bus. The decarbonization of transportation requires coordination across the entire city to encourage the mass electrification of all vehicle types.

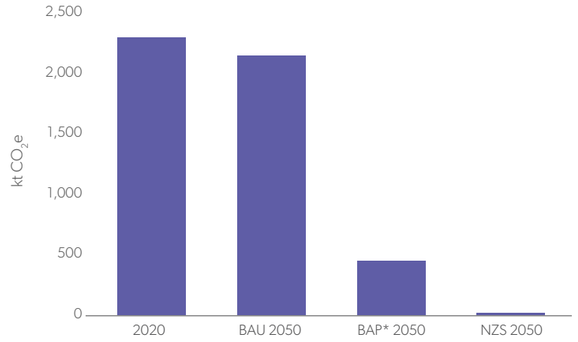
The federal government has announced it will require 100% of car and passenger truck sales to be zero-emission by 2035.[87] However, the decarbonization of heavy vehicles and large-scale transportation of goods will require further leadership and innovations across the industry.

Through the use of electric personal vehicles and zero-emissions heavy vehicles, as well as active transportation and trip avoidance, transportation emissions can be reduced almost entirely.

EMISSIONS AND PATHWAY



2020 GHGs



The GHG reduction actions for the transportation sector are provided in Table 6. This section details the interventions needed to reduce the number of trips made by personal vehicles and to switch fuel source from fossil fuels to electricity.

[87] Government of Canada. (2035). Building a green economy: Government of Canada to require 100% of car and passenger truck sales be zero-emission by 2035 in Canada. Retrieved from: https://www.canada.ca/en/transport-canada/news/2021/06/building-a-green-economy-government-of-canada-to-require-100-of-car-and-passenger-truck-sales-be-zero-emission-by-2035-in-canada.html

Table 6. Summary of BAP and NZS actions in the transportation sector.*

		NET GHG REDUCTION (KT CO_2E) (RELATIVE TO BAU)	MARGINAL ABATEMENT COST ($ / $TC0_2E$ REDUCED, NEGATIVE= SAVINGS)
TRANSIT AND ACTIVE TRANSPORTATION			
6. Transit electrification	100% of fleet is electric or zero-emissions by 2035	940	-$56
7. Increase transit use	The use of transit is increased, according to the Transit Master Plan (15% of trips are made by transit by 2030)	1,643	-$3,750
8. Active transportation	By 2050, 50% of <2km trips are made by walking and <5km trips are completed by cycling or other human-powered modes of transportation	445	$1,270
9. Working from home[88]	Implement smart commute / home-based work to reduce annual vehicle trips by 9% per person and trip length by 6% per person.	1,061	$409
VEHICLE TRANSPORTATION			
10. Personal vehicles	100% of new personal-use vehicles are electric by 2035	16,792	-$531
11. City fleet	The municipal vehicle fleet is 100% electric by 2035	69	-$604
12. Commercial vehicles	100% of new light-duty vehicles are electric by 2035	5,074	-$583
	By 2040, all heavy-duty vehicles (semi-trucks) are zero-emissions (shown as green hydrogen) Light-duty commercial vehicles are 100% electric by 2050 (taxis)	6,010	-$713

[88] The costs associated with this action are from the revenue list from transit use with reduced commuting to and from workplaces.

TARGETS

The following is a summary of the five-year measurable targets the City can use to track progress towards the overall sector emissions reductions plan. These are the result of the modelled actions in Table 6.

Table 7. Targets for Transportation Sector Actions.

	2016	2025	2030	2040	2050
Share of total personal vehicles which is electric	0%	1%	15%	76%	100%
Share of total energy used for transit which is electric	0%	50%	75%	100%	100%
Mode share (NZS)	82% cars 9% transit 7% active 3% other[89]	78% cars 10% transit 10% active 2% other	73% cars 12% transit 13% active 2% other	64% cars 14% transit 19% active 1% other	56% cars 16% transit 27% active 0% other

Transforming transportation in Winnipeg requires collaboration and partnerships across the city. The identification and removal of barriers to the adoption of electric and zero-emissions vehicles will require education and leadership. Active transportation networks ensure cycling and walking is safe and accessible for all members of society. And by changing how and where people work, the need for long daily commutes can be reduced.

PROGRAMS

Program #3: The Built Environment

3.1 Urban Planning and land use policies to encourage densification will leverage the ability to expand services that help the community reduce their emissions. This includes using transit, increasing active transportation, and choosing to live in denser neighbourhoods. Building dense, accessible neighbourhoods allows all members of the community to benefit from the opportunities presented within the CEIR.

3.2 15-Minute Super Blocks: The City can apply the concept of super blocks, or a variation of it, which is an urban planning approach where vehicle traffic is limited only to major routes in designated neighbourhood areas.[90] Travel within the super block is by walking or cycling and each super block neighbourhood is connected by transit. Limiting vehicular traffic reduces noise and air pollution in the spaces where people live. At the same time, it provides land for naturalization of urban areas, which can help control urban heat islands through vegetated shading. This can be combined with the principle of "15-minute cities", that allow residents to access all key services, such as grocery stores, medical care, and coworking spaces within a 15 minute walk. Spatial analysis can be used to guide the development of these neighbourhoods while ensuring residents can access more centralized services using active transportation networks and transit.

[89] The "other" category refers to trips made by school buses. These serve as a place-holder only, with no emissions, energy, or costs assigned.

[90] López, I., Ortega, J., & Pardo, M. (2020). Mobility Infrastructures in Cities and Climate Change: An Analysis Through the Superblocks in Barcelona. Atmosphere, 11(4), 410.

3.3 Neighbourhood climate action plans: New and existing neighbourhoods can develop localized climate action plans that align with broader City goals that empower them to take action. In Ontario, secondary plans are increasingly required to develop community energy or climate action plans.

3.4 Parking strategy: The City can reduce or eliminate parking fees for zero- emissions vehicles as an immediate strategy to incentivize EVs. Another parking strategy is to remove parking minimums for development approvals in order to encourage density and active transportation.

Program #4: Active Transportation

4.1 Walking and cycling infrastructure: Infrastructure and maintenance is critical to ensuring that people feel safe to walk and cycle. When people feel safe, cycling increases and demand for bicycles and infrastructure increases, creating a virtuous feedback loop. Electric bikes (e-bikes) are transformational for increasing the number of people who are comfortable cycling and increasing the trips that can be taken by bicycle. Every vehicular trip shifted to active transportation represents avoided investments that will be required in the electrical grid to support vehicle electrification. This financial value can contribute to justifying investments in active transportation. Since walking and cycling is more accessible to low-income individuals, investing in walking and cycling advances equity. The best practice is to target ~$20 per capita to walking and cycling infrastructure.[91] For context, the City planned to invest $150 million in road renewal in 2021.[92] Similar investments would allow for significant improvements to the active transportation infrastructure.

4.2 Clean air zones: Clean air zones are a strategy to reduce air pollution and GHG emissions. Zero-emissions vehicles are either charged a discounted fee or no fee at all for downtown access. This fee is typically applied to all residential and commercial vehicles. North American cities such as Vancouver[93] and Toronto are currently evaluating clean air zones or similar approaches. Municipalities in the UK have already successfully implemented clean air zones.[94]

4.3 Behaviour change: Shifting away from vehicular travel requires a cultural shift and behaviour change. Given the impact of electrification of vehicles on the electricity grid and the health benefits, the city can work with relevant partners to help people make lifestyle changes to shift to electric vehicles, transit, walking and cycling in the context of other incentives.[95] City of Edmonton's Change for Climate[96] is an example of this type of program.

4.4 Flexible work locations: The COVID-19 response has highlighted the ways in which workspaces can be flexible and successful. Leveraging this information will help reduce the need for large office spaces, vehicle parking, and private transportation. Additionally, by supporting the development of coworking spaces within the city, Winnipeg can develop neighborhood hubs that build connections within the community and make working close to home available to more of the city. Zoning changes can support live-work

[91] Cradock, A. et al. (2019). Evidence to Inform a Cycling and Walking Investment Strategy. Retrieved from: https://cdn1.sph.harvard.edu/wp-content/uploads/sites/84/2019/05/Evidence-to-Inform-a-Cycling-and-Walking-Investment-Strategy_2019_04_30.pdf

[92] City of Winnipeg. (2021). Multi-year budget: 2021 Update. Retrieved from: https://winnipeg.ca/Interhom/Budget/2021-budget/default.stm#5

[93] City of Vancouver (2021). Transport Pricing Strategy. https://vancouver.ca/streets-transportation/transport-pricing.aspx

[94] For detailed information on clean air zones, see: https://www.gov.uk/guidance/driving-in-a-clean-air-zone

[95] The Sustainable Travel Towns initiative is an example of a successful program that support a cultural shift on transportation. For more details, see: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/738305/ppr776-sustainable-travel-towns-final-report.pdf

[96] City of Edmonton (n.d.). Change for Climate. Retrieved from: https://changeforclimate.ca/

arrangements for households. This strategy can also unlock space currently used for parking for housing, parks or other uses.

Program #5: Enhanced Transit

5.1 Enhanced transit: The City can fully implement the Transit Master Plan encouraging its use to ensure transit options are accessible to the whole Winnipeg community, decreasing the need for private vehicle trips where possible. Transit services are being revolutionized by on-demand services, autonomous vehicles, and the impact of COVID-19. The transit system can incorporate E-bikes and other micro-mobility systems and reduce fare costs or enable for free transit.[97]

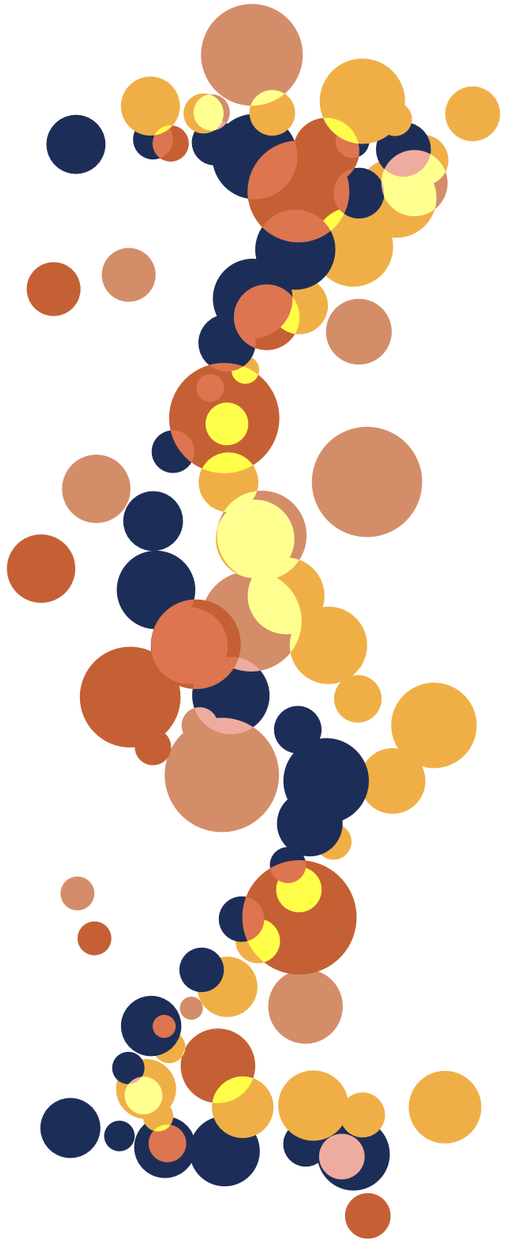
5.2 Zero emissions transit: The City can develop a coordinated approach to decarbonizing transit, including a policy for no new fossil-fuel powered vehicle purchases unless Council makes an exception.

Program #6: A Clean Fleet

6.1 EV charging infrastructure: Unlike gas stations, charging stations do not require storage tanks and careful zoning for watershed protection. They can be installed in parking lots, alongside street parking, and at facilities such as libraries, restaurants, and gyms. Ownership of the charging stations can be dispersed, allowing local businesses to install chargers for their customers, providing financial benefits from the chargers on their properties. The City can coordinate with Manitoba Hydro on an EV charging partnership to ensure availability of infrastructure and electrical capacity.

6.2 Zero-emissions transportation education program: The switch to EVs raises questions for many within Winnipeg, with concerns about pricing, availability, winter performance, range, and availability of charging infrastructure. By coordinating education programs to encourage and incentivize zero-emissions, the City can encourage the switch from gasoline- and diesel-powered vehicles, to more sustainable options.

6.3 Fleet transformation coalition: The City



[97] City of Toronto's Net Zero Strategy envisions free transit in the City.

can convene major vehicle fleet owners to develop an expedited electrification strategy, in coordination with the Vehicle Technology Centre. The strategy can include procurement coordination, leasing strategies, charging station deployment, and pilot projects for heavy vehicles and technologies such as green hydrogen. Winnipeg Transit will be deploying hydrogen vehicles in 2023, and the City can be a hub for green hydrogen transportation in the City.

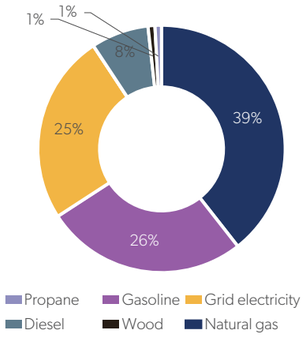
Clean Energy for Everyone

Manitoba has one of the cleanest electricity grids in Canada. By switching from fossil fuels to electricity, the City of Winnipeg can decarbonize most sectors. Currently, natural gas is the primary fuel used for heating while gasoline and diesel are used for transportation. To eliminate the emissions associated with these fuels, heating and transportation must be electrified.

Due to the clean electricity grid in Manitoba, the rationale for the cost and effort of installing renewable electricity systems does not make sense from the standpoint of simply reducing GHG emissions. However, the pathway to electrification will increase the total demand for electricity in Winnipeg. By supplementing the current electricity grid with solar generation, the need to build new grid-scale generating capacity is reduced. Additionally, by diversifying the sources of electricity and adding energy storage, Winnipeg will become more resilient to disruptions in electricity supply.

It is important to note that while the CEIR models rooftop solar generation, site-specific analysis will be needed to identify the most appropriate renewable electricity generation method for a given location. This could be ground-mount solar or wind generation, but for modelling purposes, wide-spread rooftop solar was chosen as it is a versatile technology that works in many situations and does not require the use of greenfield sites.

ENERGY SOURCES AND PATHWAY



2020 Energy

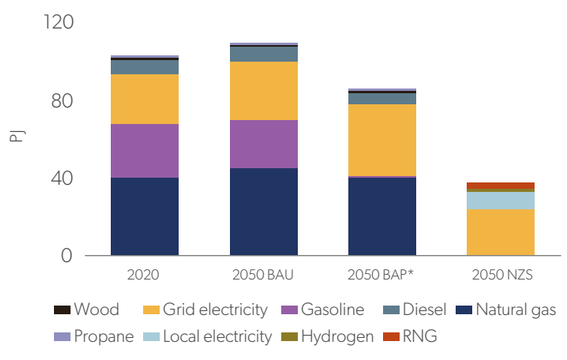


Table 8 shows the key actions required to increase solar generation capacity, and eliminate the need for fossil fuels in Winnipeg.

Table 8. Summary of BAP and NZS actions in the energy sector.*

		NET GHG REDUCTION (RELATIVE TO BAU)	MARGINAL ABATEMENT COST ($ / TCO_2E REDUCED, NEGATIVE= SAVINGS)
CLEAN ENERGY			
13. Solar PV on existing buildings	Starting in 2022, install solar PV on existing buildings, achieving on average 50% of building electric load, scaling up to 50% of existing buildings by 2050.	15	-$131,384
14. Solar PV on new ICI buildings	As of 2031, all new ICI buildings have 50% of their annual load covered by solar PV	4	-$63,143
15. Solar PV on new residential buildings	As of 2031, all new homes have 50% of their annual load covered by solar PV	2	-$120,980
16. RNG	By 2050, biogas production: - 75% methane recovery and conversion to biogas	7,891	-$63

TARGETS

The following is a summary of five-year measurable targets the City can use to track progress towards the overall sector emissions reductions plan. These are the results of the modelled actions in Table 8.

Table 9. Selected Targets for Energy Sector Actions.

	2016	2017-2025	2026-2030	2031-2040	2041-2050
Renewable energy: Rooftop solar PV installed (MW)	0	203	1,303	685	338
Natural gas displacement with RNG (% of natural gas displaced)	0%	10%	30%	65%	100%

PROGRAMS

Program #7: A Renewable Energy Economy

7.1 Renewable Energy Action Group: The City can convene a renewable energy action group with the objective of identifying actions to expedite renewable energy and storage installations in the City. Participants could include renewable energy installers, Manitoba Hydro, University of Manitoba, Red River College and others.

7.2 Rooftop solar PV: The City can set up single desk permitting in coordination with Manitoba Hydro to expedite solar PV installations. Expanding the local generating capacity of Winnipeg will increase the city's resilience to electricity supply disruptions and provide additional capacity to support the electrification of buildings and transportation. The PV installations can be integrated into the building retrofit and new construction programs.

7.3 Parking lot solar PV: Parking lots are a land

asset that is compatible with large scale urban solar installations.[98] The City can partner with Manitoba Hydro and parking lot owners to advance solar installations where appropriate.

7.4 Household and neighborhood energy storage: The City can support small and medium-scale energy storage projects for households and neighbourhoods in coordination with Manitoba Hydro. The installations can target low-income neighbourhoods to increase resiliency.

7.5 Community solar gardens: To facilitate solar access for households where it is inaccessible due to physical or financial reasons, solar gardens can be constructed in appropriate locations as a new energy service provided by the City or a renewable energy co-operative.

7.6 Renewable Energy Co-operatives: Renewable energy co-operatives are a powerful mechanism to increase community capacity, build expertise and excitement and create new investment opportunities for communities. They are also a key strategy in reducing climate anxiety as they empower communities to take action. The City can provide grants to support the establishment of renewable energy co-operatives and sites for installation.[99]

7.7 Zero-Emissions District Energy: District energy can be used to transfer renewable energy from concentrated sources to diffuse consumers. For example, district energy can be constructed from waste heat in sewer lines,[100] industrial operations, or from fields of ground source heat pumps, and ambient district energy systems enable energy trading between buildings. For example, a building with excess heat can share that heat with buildings that require heat by depositing the heat in the low temperature network. The City can explore a district energy system for specific areas of concentrated heat demand.

7.8 Renewable Natural Gas (RNG): RNG from wastewater can be used as a zero-emissions fuel to replace natural gas during the decarbonization transition. RNG can be made from biogas captured during the treatment of wastewater, landfills, and other biogenic sources such as wood waste. It can be used for targeted energy requirements that are otherwise difficult to electrify.

Program #8: Clean Industry

8.1 Industrial efficiency action team: The City can convene Economic Development Winnipeg, researchers, industry representatives, and climate leaders to identify lighthouse projects that will radically improve the efficiency of, and reduce GHG emissions from, industrial operations. Example projects could include district energy based on waste heat from industrial facilities or a green hydrogen project.[101]

[98] Coniff, R. (2021). Why Putting Solar Canopies on Parking Lots Is a Smart Green Move. Retrieved from: https://e360.yale.edu/features/putting-solar-panels-atop-parking-lots-a-green-energy-solution

[99] A detailed guide on how to support renewable energy cooperatives is available here: https://www.rescoop.eu/toolbox/community-energy-a-practical-guide-to-reclaiming-power

[100] The City of Toronto is coordinating with the University Health Network to extract heat from sewage in a major facility. For more information, see: https://www.uhn.ca/corporate/News/Pages/UHN_reducing_emissions_with_huge_new_wastewater_energy_system.aspx

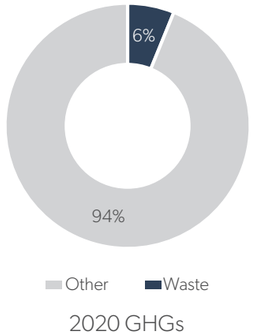
[101] The CIty of Selkirk has initiated a number of green hydrogen projects. For more information, see: City of Selkirk (2022). Another Green Energy Project Looks to Call Selkirk Home. Retrieved from: https://www.myselkirk.ca/blog/2022/01/19/charbone/

Waste Management

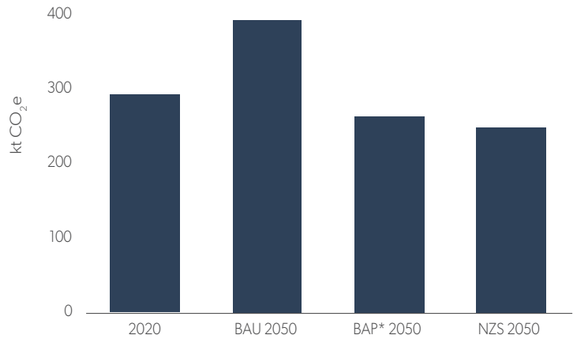
Emissions from waste in Winnipeg come from both municipally operated and private landfills. Organic matter in landfills decays over time, and can continue to release GHGs long after it is deposited in the landfill. The most effective strategy in reducing these emissions is to reduce the amount of waste entering them. This can be achieved through a combination of waste reduction and waste diversion to composting and recycling facilities.

Emissions from waste accounted for 6% of the total GHG emissions in 2020. In the BAU scenario, this increases as a result of the growing population and the nature of the decay of organic material in landfills. GHG emissions from waste are not entirely eliminated in the NZS and highlight the need for coordinated efforts with private landfills to manage.

EMISSIONS AND PATHWAY



2020 GHGs



The first steps to reduce emissions from waste, and to reduce the overall waste production in Winnipeg are shown in Table 10.

Table 10. Summary of BAP* and NZS actions in the waste sector.

		NET GHG REDUCTION (RELATIVE TO BAU)	MARGINAL ABATEMENT COST ($ / TCO_2E REDUCED, NEGATIVE= SAVINGS)
CLEAN ENERGY			
17. Waste Diversion	75% residential diversion, 80% ICI and construction/demolition waste	1,489	-$126
18. Reduce water consumption	By 2050, implement a 25% reduction in water consumption and pumping energy demand (behaviour change, leak detection system, greywater reuse, etc)	118	-$1,121

		NET GHG REDUCTION (RELATIVE TO BAU)	MARGINAL ABATEMENT COST ($ / TCO_2E REDUCED, NEGATIVE= SAVINGS)
CLEAN ENERGY			
19. Increase wastewater efficiency	By 2050, implement a 25% reduction in wastewater production and and pumping/ treatment energy demand (behaviour change, leak detection system, greywater reuse, etc)	9	-$297

TARGETS

The following is a summary of the five-year measurable targets that the City can use to track progress towards the overall sector emissions reductions plan. These are the results of the modelled actions in Table 10.

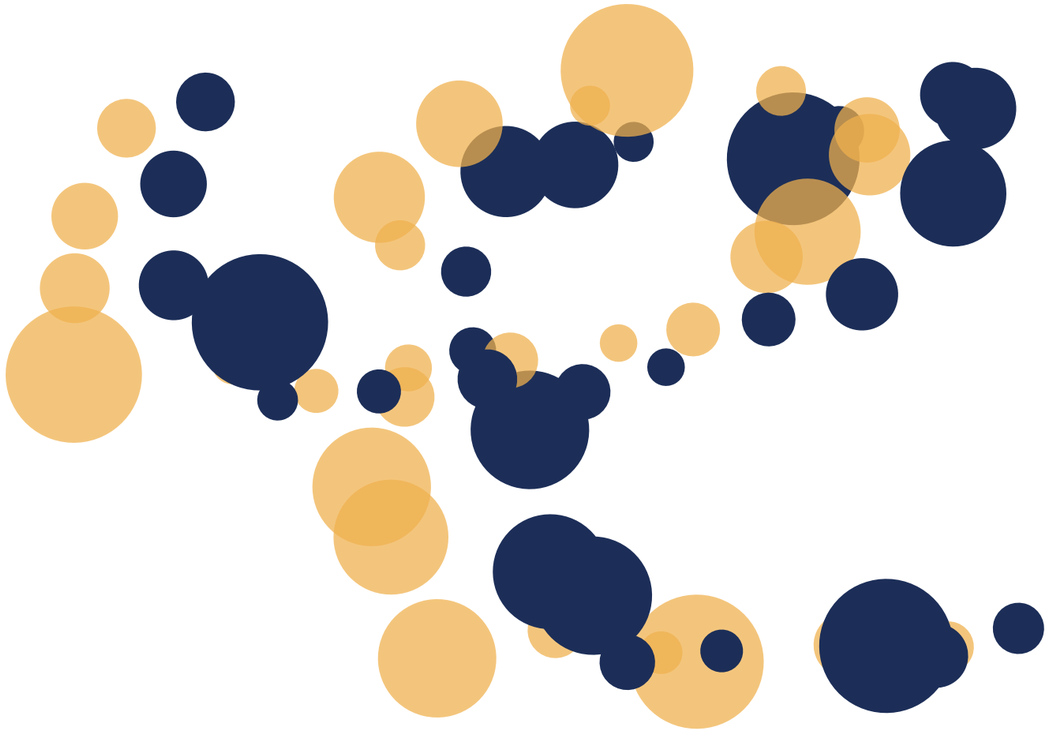


Table 11. Targets for Waste and Sustainable Consumption Sector Actions, NZ40.

	2016	2025	2030	2040	2050
Overall waste diversion rate	24%	33%	42%	60%	78%
Waste generation (tonnes per capita)	0.38	0.38	0.38	0.38	0.38
Increase efficiency of water pumps (w.r.t. 2022)	0%	3%	7%	16%	25%

PROGRAMS

Program #9: Zero Waste

9.1 A Circular Economy Strategy: The City will develop a circular economy strategy that focuses on the ideas of zero landfill waste and using waste as a resource.

9.2 Landfill GHG Action Group: The City can convene a zero-emissions landfill strategy for the landfills serving Winnipeg. A component of the strategy will focus on the generation of RNG from landfill gas and/or from an organics diversion program.[102]

9.3 Zero emissions water and wastewater: The City can evaluate and implement opportunities to increase efficiency in its pumping stations and other waste, water, and wastewater infrastructure facilities.

A Whole City Approach

The City of Winnipeg has the opportunity to demonstrate leadership in the transition to a green economy. The decarbonization of Winnipeg requires full participation from the entire society, though not all of these decisions will be under the purview of the municipal government. The City can, however, leverage its physical, financial, and human assets to facilitate the implementation of all aspects of the CEIR.

PROGRAMS

Program #10: Carbon Management

10.1 Develop an annual carbon budget: A carbon budget is a mechanism to align financial budgets with GHG targets in order to operationalize the GHG targets of the City. A carbon budget process ensures all departments and expenditures are aligned with GHG reductions.

10.2 Apply a climate lens for expenditures and policies: A climate lens is a policy that aligns investments and policies with the climate targets. Staff can ensure that all proposals are "tested" against climate targets and revised accordingly.

10.3 Addressing the emissions gap: While the NZS pathway guides the decarbonization of the City, it is not enough to align with a 1.5 degree trajectory. A core action for the City is therefore to identify and implement opportunities to: (a) accelerate planned action; (b) support carbon removals; and (c) purchase carbon offsets. The City can accelerate action when there is momentum in certain sectors (for example electric vehicle adoption) or when the financial returns are higher than anticipated. The second two options are more uncertain. Carbon removals are currently an unproven and expensive technology. Carbon offsets

[102] The City of Toronto's program at Dufferin Solid Waste Management Facility is a good example. See: City of Toronto (n.d.). Turning Waste into Renewable Natural Gas. Retrieved from: https://www.toronto.ca/services-payments/recycling-organics-garbage/solid-waste-facilities/renewable-natural-gas/

are a mechanism for purchasing emissions reductions, but this represents a cost that does not generate returns and the integrity of carbon offsets is difficult to validate.

Program #11 Zero-Emissions Operations

11.1 Annual GHG and energy use reporting: The City can undertake annual reporting on energy, costs, and emissions. The annual report can also include a review of programs to determine the ones that are successful and the ones that need to be adjusted to be more effective.

11.2 An Expanded Office of Sustainability: The Office of Sustainability will need staff to develop pilot projects, to build relationships with working groups, and to work within the City to decarbonize municipal operations. Each program area will need to be supported by staff with subject matter expertise.

11.3 A Zero-emissions fleet: The City can develop a strategy to decarbonize its fleet by purchasing only zero-emissions light duty vehicles by 2023 and heavy-duty vehicles by 2026. A key aspect of this effort will be providing appropriate charging and fuelling infrastructure for these vehicles.

11.4 Zero-emissions buildings: The City can commit to only constructing net-zero buildings beginning in 2023 and develop a decarbonization strategy to retrofit its existing building stock.

Program #12 Communications

12.1 Community Climate Advisory Committee: A Community Climate Advisory Committee is a powerful mechanism for selecting and building community support for challenging climate actions.[103] The committee can provide advice to the City on climate actions and serve as a forum for initiating or coordination community-level programs.;

12.2 Story-telling: A communications roadmap can highlight successes of the implementation, building momentum and enthusiasm. Key strategies include web-based stories, podcasts, learning laboratories, and peer-learning groups.

[103] For more information on climate assemblies, see: https://climateassemblies.org/

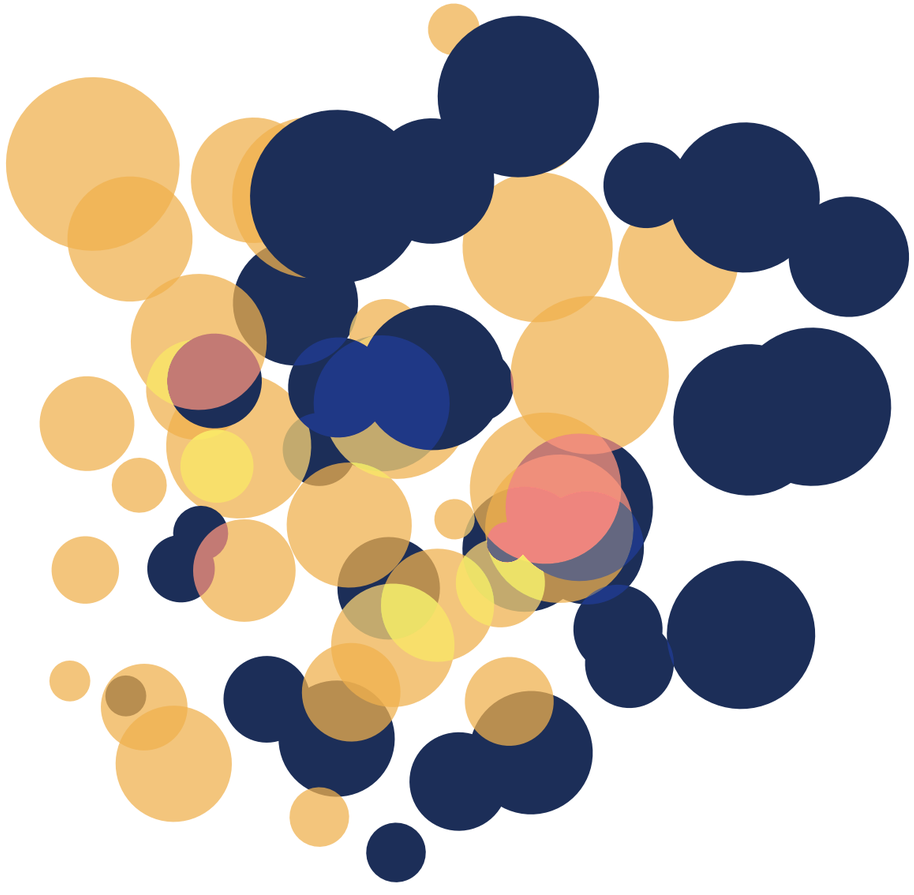
This is Only the Beginning

This is Only the Beginning

In the context of climate action, cities are, and must be leaders. This role takes many forms; custodian, facilitator, implementer, investor, convener, decision-maker, regulator, prompter and activator. The CEIR is an ambitious roadmap to achieve net-zero emissions by 2050, that relies on a whole City approach, in which each staff member and department advances the objectives and targets.

Climate action is about reducing greenhouse gas emissions, building a new economy, and improving quality of life. As is demonstrated by this analysis, the investments required to achieve the City's targets generate both financial returns and health benefits for the people of Winnipeg.

There is no time to waste.



Appendices

Appendix A: DMA + Assumptions

Appendix B: Modelling Results

Appendix C: Implementation Framework

Appendix D: GPC Tables

The appendices are contained in a separate document.