Achieving Real Net-Zero Emission Homes:

Embodied carbon scenario analysis of the upper tiers of performance in the 2020 Canadian National Building Code

Natural Resources Canada

BUILDERS FOR CLIMATE ACTION

About Builders for Climate Action

Builders for Climate Action is a project of the Endeavour Centre, a not-for-profit sustainable building school based in Peterborough, Ontario. Builders for Climate Action is growing a coalition of builders, designers, developers, policy-makers, researchers and manufacturers to tackle the serious impact of buildings on our climate. We want to offer future generations our best efforts to reign in the worst effects of climate change through smart, coordinated and effective action to address emissions in the sector.

Authors

The research team for Builders for Climate Action is:

- Chris Magwood, Director of Research and Programs
- Javaria Ahmed, Embodied Carbon Analyst
- Erik Bowden, Embodied Carbon Analyst
- Jacob Deva Racusin, New Frameworks

Acknowledgments

The research team would like to thank the team at Natural Resources Canada for their initiation and support for this project:

- Alex Bigonesse, Technical Advisor, Office of Energy Efficiency
- Christopher McLellan, P.Eng, MASc., Senior Technical Advisor, Office of Energy Efficiency
- Patric A. Langevin, M.Arch, Project Leader, Local Energy Efficiency Partnerships (LEEP)

Citation

Magwood, C., Ahmed, J., Bowden, E., Racusin, J. (2021). ACHIEVING REAL NET-ZERO EMISSION HOMES: Embodied carbon scenario analysis of the upper tiers of performance in the 2020 Canadian National Building Code

Table of Contents

Executive Summary

Canada has committed, under the Paris Agreement, to reduce GHG emissions by 40-45% below 2005 levels by 2030 and become net-zero by 2050. In 2016, the Pan-Canadian Framework on Clean Growth and Climate Change (PCF) identified the building sector as one of the major contributors to GHG emissions in Canada. To date, the central tactic for addressing emissions from Canadian home building has been the introduction of energy efficiency tiers in the National Building Code of Canada, with each of the five tiers representing a significant reduction in energy use for the homes, with an anticipated correlation to operational carbon emissions (OCE) reductions.

Since the release of the PCF, accounting for the GHG emissions from the production of home building materials—often called "embodied carbon" but more accurately described in this report as material carbon emissions or MCE—has indicated that this emission source may outweigh the impact of OCE for several decades and be the leading cause of GHGs in the sector. Three recent studies of MCE for residential buildings indicate an emissions intensity of approximately 250 kilograms of carbon dioxide equivalent per square meter of floor area (kg CO_2e/m^2). If this average is accurate and applied to new low-rise homes built in Canada each year, the MCE of Canadian homes would be 14.1 Mt CO_2e/year. This is equivalent to the annual emissions from 3.1 million Canadian vehicles or 3.6 coal-fired power plants. Such a substantial volume of emissions requires examination in light of Canada's emission reduction targets.

This report investigates the relative impacts of OCE and MCE in low rise Canadian homes. Three housing archetypes were provided by Natural Resources Canada (NRCan), along with HOT2000 energy modeling data for these all-electric homes at Tiers 3, 4 and 5 of the National Building Code of Canada in five Canadian cities (Vancouver, Prince Albert, Toronto, Québec City and Halifax). MCE was estimated for each home using NRCan's Material Carbon Estimator tool, co-developed by the study's authors. This tool uses data from Environmental Product Declarations (EPDs) to calculate the global warming potential (GWP) of each material required for construction. Four tiers of material selection were used, ranging from the highest to the lowest GWP in each material category. In total, 196 models were created for comparison.

Results varied widely, from a high of 758 kg CO_2e/m^2 to a low of –84 kg CO_2e/m^2 (representing net carbon storage, rather than emissions) for the Tier 5 two-storey. The very wide range of results indicates that material selection can impact the total emissions of a new home by as much as 842 kg CO_2e/m^2 without changing the design or performance of the home. These results establish the significant emissions impacts of MCE, but they also point to a solution by demonstrating the feasibility of creating new homes with a net-zero MCE impact, and indeed net carbon storage. Insulation, exterior cladding and concrete were identified as the material categories with the highest impact on overall MCE.

The OCE for the modeled homes varied depending on the carbon intensity of the local electrical grid. The OCE results were very similar for the three cities—Vancouver, Toronto and Québec—which have relatively low-carbon electrical grids, resulting in emissions at every tier of energy efficiency well below 1 tonne of CO_2e per home per year. For the two cities with more emissions-intensive electrical grids, Prince Albert and Halifax, the annual emissions are much higher, ranging from 7.7 to 23 tonnes of OCE per year.

Each step up the energy code tiers tends to increase a home's insulation thickness. This either increases the building's MCE for carbon emitting insulations or decreases overall MCE for carbon storing insulations. The increase of 93 kg CO_2e/m^2 in MCE between Tier 3 to Tier 5 for the high carbon material selection (HCM) model presents a cautionary warning that the pursuit of energy efficiency without consideration of material emissions can cause dramatic increases in overall emissions.

Emission reductions achievable by addressing MCE outweigh reductions in OCE from higher tiers of the NBC. The average OCE reduction per home across tiers 3 to 5 in all archetypes in the three cities with low-carbon electrical grid cities was 0.08 tonnes of CO_2e per year, while the reduction in cities with high-carbon electrical grids was 6.5 tonnes. Average MCE reductions were 86 t CO_2e between the high and moderate models, 34 t CO_2e between the moderate and best available models and 10 t CO_2e between the best available and best possible models. The ideal scenario is demonstrated by the Québec City two storey home at Tier 5 with the best possible materials having OCE of just 0.02 t CO_2e and MCE of -21 t CO_2e setting an example for the kinds of homes required to meet Canada's climate targets.

An exploration of the material costs for the two material categories with the highest MCE impact—insulation and exterior cladding—showed no direct correlation between MCE and cost. In some cases, the material with the best MCE had low costs while the material with the worst MCE had the highest costs. Sometimes the inverse was true.

This report identifies a number of challenges and opportunities. The findings align well with the Greening Government Strategy to encourage innovation and adoption of low-carbon material supply chains and stress the importance of developing tools, methodologies and training to achieve a zero-emission housing sector while supporting economic development. Though this study focused on new construction, it was suggested that MCE should be considered an equally important factor in developing retrofit strategies for the sector, to ensure the government does not offer incentives that will significantly increase MCE in the attempt to reduce OCE.

The key recommendation from this study is to consider adopting a unified metric for measuring and regulating emissions in the homebuilding sector that combines all three emissions factors into a single metric: Carbon Use Intensity (CUI). The current regulatory framework addresses only energy efficiency and ignores MCE and fuel source emissions. Canada will not be able to assist the home building sector to truly achieve net-zero carbon while energy efficiency remains the only metric. CUI would be the total of material carbon emissions plus operational carbon emissions, determined by multiplying the anticipated energy use of the home by the emissions intensity of the energy fuel source.

A Canadian home can have a high Material Carbon Intensity of 758 kg CO_2e/m^2 or a low of -84 kg CO_2e/m^2 (representing net carbon storage, rather than emissions). The very wide range of results indicate that material selection can impact the total emissions of a new home by as much as 842 kg CO_2e/m^2 without changing the design or performance of the home.

1. Context

Canada has committed, under the Paris Agreement, to reduce GHG emissions by 40-45% below 2005 levels by 2030 and become net-zero by 2050 (Canada, 2021). In 2016, when the Pan-Canadian Framework on Clean Growth and Climate Change (PCF) was put into practice, the building and construction sector was identified as one of the major contributors to GHG emissions in Canada (Wetzel, 2019).

Since then, the National Building Code, as well as some provincial building codes, have adopted benchmarks for reducing GHG emissions and increasing building efficiency (Canada, 2018).

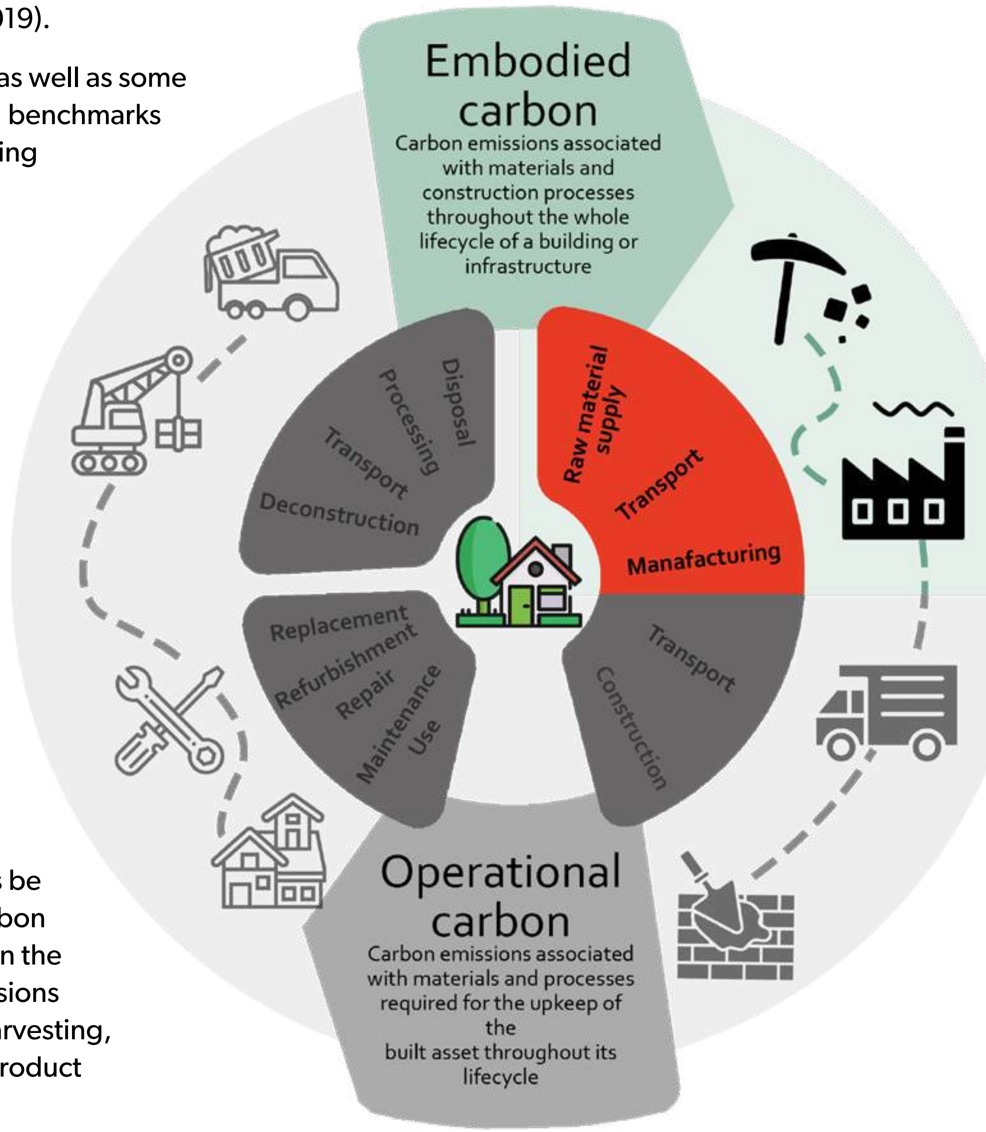


Figure 1 Life cycle of a house showing both embodied and operational carbon sources and need for whole life consideration (Adapted from the World Green Building Council report, Bringing Embodied Carbon Upfront (Adams et al., 2019)

However, even if all operational carbon emissions (OCE) from Canadian buildings reach net-zero, the substantial volume of emissions from the production of materials used to build Canadian homes will continue to be a leading source of housing sector emissions. These material-related emissions are commonly known as “embodied carbon," but would perhaps be more accurately labeled as “material carbon emissions” (MCE). This project focuses on the MCE aggregate of greenhouse gas emissions from processes involving raw material harvesting, transportation, and manufacturing of a product (figure 1, red highlight).

Currently, no Canadian building codes or regulations consider the GHG impacts of MCE. This may prove to be a critical lost opportunity in Canada's GHG strategy if, as early studies indicate, MCE becomes a larger contributor to a building’s total life cycle impact than its operational emissions over the next few critical decades. This oversight may prove to be all the more dramatic because reaching higher levels of energy efficiency with the use of high MCE materials is currently poised to drive higher net carbon emissions than reductions. Focusing solely on operational carbon emissions (OCE) will not get Canada to its goal of net-zero emissions in the housing sector. Initiatives to reduce OCE in buildings by improving energy efficiency that have been successful in the past may soon face a plateau, where the reductions in carbon emissions are slowing down, especially for electrified homes in regions with relatively clean electrical grids.

Three existing studies on MCE indicate that the emissions associated with building materials are quite substantial. Based on these studies, a typical low-rise residential building in North America has an average MCE footprint of approximately 250 kg CO_2e per square meter of floor area. (International Energy Agency, 2018; Simonen et al., 2017; Magwood, 2019). If this average is accurate and it is applied to the total additional annual average of 56.33 million m^2 (Natural Resources Canada, 2020) of new low rise (Part 9 of the NBC) built in Canada each year, the MCE of Canadian homes would be 14.1 Mt CO_2e/year. This is equivalent to the annual emissions from 3.1 million Canadian vehicles (Natural Resources Canada, 2014) or 3.6 coal-fired power plants (Israël & Flanagan, 2016) (figure 2). The housing sector does not account for or address these emissions.

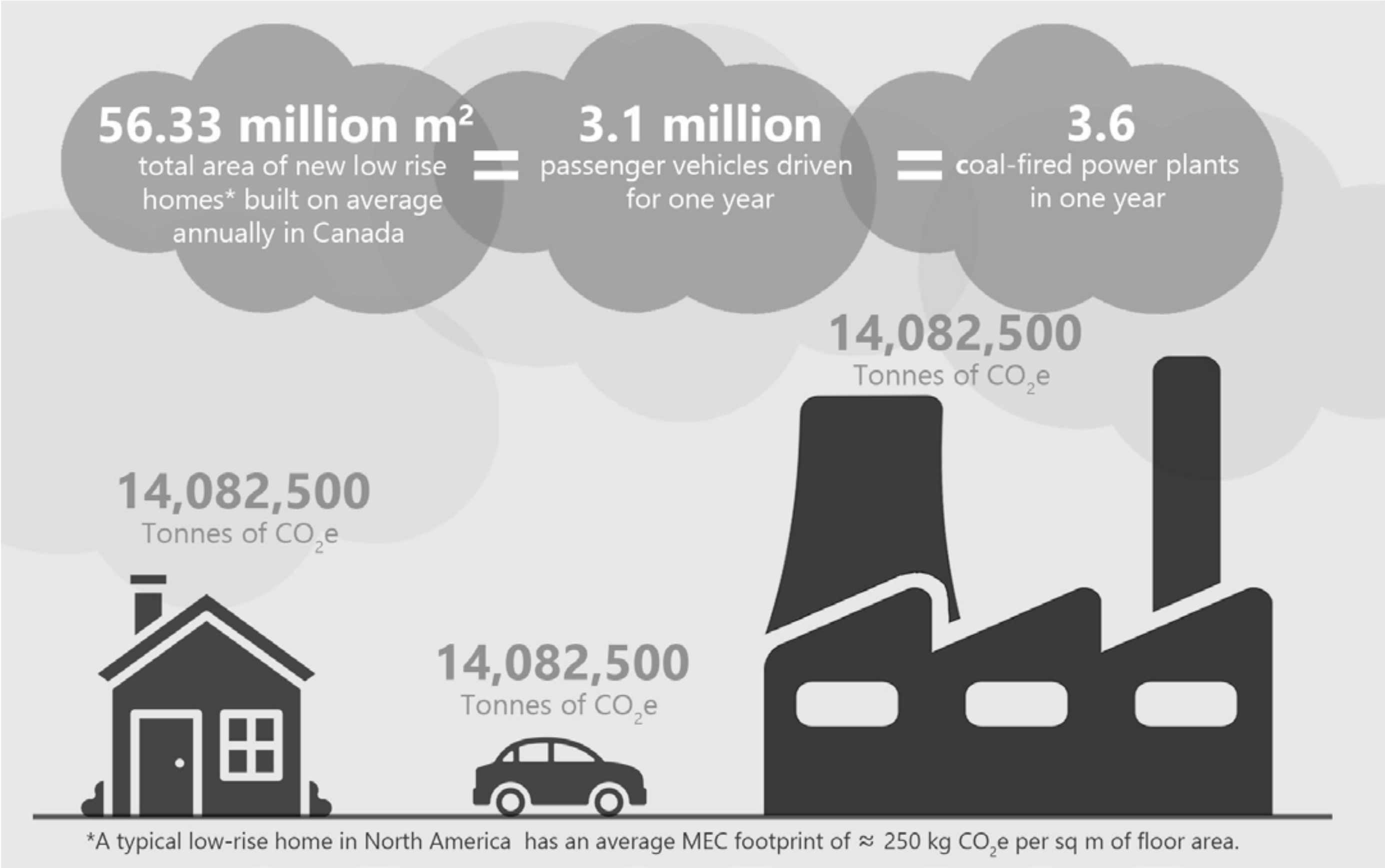


Figure 2 Carbon emission equivalents to MCE for new homes built each year on average in Canada

Acknowledging this large amount of carbon emissions is only the first step, reducing these emissions must be integrated into climate policies and actions moving forward.

For Canadian homes to truly reach net-zero GHG emissions across the crucial decades from now until 2050, both MCE and OCE must be clearly understood and addressed together. This study is intended to consider the scale of MCE in new homes and examine the overall and relative impact on reductions of considering both MCE and OCE in the sector. Globally, the critical importance of MCE is rapidly being recognized, and the limitations of solely addressing OCE is being acknowledged. The International Energy Agency supports the conclusion that reaching net-zero emissions in the construction sector must include both operational and material emissions:

> Zero-carbon-ready building energy codes should also target net-zero emissions from material use in buildings. Material efficiency strategies can cut cement and steel demand in the buildings sector by more than a third relative to baseline trends, and embodied emissions can be further reduced by more robust uptake of bio-sourced and innovative construction materials (Global ABC Roadmap for Buildings and Construction 2020-2050).

Achieving net-zero emissions in the Canadian housing sector is possible, but as this study makes clear it will require seriously addressing MCE by embracing low-carbon and carbon-storing materials and designs, while recalibrating efforts on the operational side by concentrating on total GHG metrics rather than energy use metrics. Together, these efforts could predictably lead to a zero-emission housing sector in Canada.

2. Methodology

Figure 3 The five cities, climatic zones and their HDD studied in this report

Vancouver **HDD 2825**
Pacific Maritime
Cool summers July 17.7°C (63.9°F)
Moderately cold winters January 2.5°C (36.5°F)
Precipitation 1283 mm (50.5 inches)

Prince Albert **HDD 6100**
Humid Continental
Cool summers July 18.4°C (65.1°F)
Cold winters January -15.8°C (3.5°F)
Precipitation 502 mm (19.8 inches)

Toronto **HDD 3520**
Subarctic
Hot humid summers July 21.5°C (70.7°F)
Cold winters January -5.3°C (22.5°F)
Precipitation 785 mm (30.9 inches)

Quebec City **HDD 5080**
Subarctic
Cool summers July 19.9°C (67.8°F)
Cold winters February -11.1°C (12.0°F)
Precipitation 1101 mm (43.3 inches)

Halifax **HDD 4000**
Atlantic Maritime
Cool summers August 18.0°C (64.4°F)
Moderately cold winters February -5.0°C (23.0°F)
Precipitation 1410 mm (55.5 inches)

This study examines three single-dwelling housing archetypes used by Natural Resources Canada (NRCan): a bungalow, a two-storey home, and the row house-end unit. Each archetype was studied in five Canadian cities to represent a mix of Canadian climate zones: Vancouver, BC; Prince Albert, Saskatchewan; Toronto, Ontario; Québec City, Québec; and Halifax, Nova Scotia (figure 3). Energy models for each building type in each city were created using NRCan's HOT2000 energy modelling software to estimate operational carbon emissions at Tiers 3, 4 and 5 of the 2020 National Building Code of Canada. Four different sets of material selection scenarios were created in the NRCan Material Carbon Emissions estimator tool, from the highest emissions to the lowest. For comparative purposes, the energy source was electric in all cases. A separate set of scenarios examined natural gas as the heating source for Prince Albert and Toronto only. In total, the study examines 196 sample building scenarios.

2.1 Housing Archetypes

Architectural plans were provided by NRCan for the three archetype homes (figure 4). Each archetype was assumed to be representative of homes built in each of the five cities, with no variations in overall architecture considered in order to keep the models closely comparable. Floor areas and all key building dimensions remained constant as the level of energy efficiency was adjusted for different tiers of energy efficiency. Where increases in insulation thickness were required to meet higher tiers of performance, it was determined that increasing wall thickness only added an insignificant 2% to cladding areas and therefore exterior wall surface areas were kept constant.

Figure 4 The three sample archetypes included in the scope of this project

2.2 NRCan Material Carbon Emissions Estimator

NRCan has collaborated with the Endeavour Center to develop the Material Carbon Emissions Estimator tool specifically for residential construction in Canada. The calculator provides GHG reporting of emissions from building materials suitable for low-rise residential construction in Canada for which sufficient data was available. The building material data essential for GHG calculations is sourced from Environmental Product Declarations (EPDs). EPDs are generated by professional organizations according to ISO standards as a means of reporting on seven categories of environmental impacts, including Global Warming Potential (GWP). GWP values, expressed in units of carbon dioxide mass equivalent (kg CO_2e, in which all GHGs are converted to the impact of CO_2), represent the embodied carbon emissions of each product or material.

The MCE[2] tool converts a building's various dimensions into estimations of material quantities. Based on material selections, it attributes GWP values to building materials in order to estimate the MCEs for all major building assemblies, including structure, enclosures and main finishing materials. Total emissions are estimated for each building type in the study. The tool considers the "cradle to gate" emissions phases (stages A1-A3 in an EPD), which account for the vast majority of life cycle emissions from building materials (WorldGBC, 2019). This project uses the NRCan MCE[2] Estimator version 4.1 updated as of April 16th, 2021. See Appendix-A for more details about the functions and limitations of this tool version.

The net total embodied carbon emissions resulting from each building model is expressed in metric tonnes of carbon dioxide equivalent emissions (t CO_2e) and the net material carbon intensity (MCI) is expressed in kilograms per meter squared of heated floor area (kg CO_2e/m^2). The former is useful in comparing buildings of the same archetype, while the latter is better suited to comparing between different building archetypes.

The MCE results from the estimator tool can be used to inform decision-making for new construction or renovation projects with the goal of reducing overall project emissions through optimal material selection and design iteration. The MCE results are an estimate, similar to the calibre of results from the HOT2000 energy modelling software, since the MCE tool prioritizes accuracy, accessibility, and efficiency rather than precision on matters of low significance or certainty. The developers of the MCE tool have taken care to provide a consistent comparison of materials by considering standard product sizes, Canadian building codes, and industry practices.

The MCE estimator is capable of importing energy modeling data from HOT2000 files, including building dimensions, fuel use and electricity consumption. The operational energy is converted to operational carbon emissions based on provincial electricity carbon intensity factors and combined with the estimated MCEs of the building. The resulting total carbon footprint for the building project can be used to make more informed holistic climate impact decisions.

2.3 Net zero MCE and biogenic carbon storage

Building materials are responsible for embodied carbon emissions as a result of raw material extraction, transportation, and manufacturing in the "cradle-to-gate" phase of their life cycle, which accounts for 70-80% of their full life cycle emissions (Moncaster & Symons, 2013). The choice of building material can either improve or worsen the embodied carbon that is released or stored in construction. For buildings to achieve net-zero MCE at the moment of construction completion, the cradle-to-gate carbon emissions from all building materials must be equivalent to the carbon stored in the building's biogenic material content, specifically the materials composed of biomass that sequestered carbon during biological processes. Without using carbon-storing materials, all homes will have some degree of MCE footprint, making it impossible to reach net-zero emissions.

Most building materials produced from renewable organic materials, also known as biogenic building materials, act as net carbon sinks rather than sources. The vast majority of biogenic building materials are made from plant matter found in agricultural or waste stream residues. During photosynthesis, plants capture atmospheric carbon dioxide, release the oxygen and use the carbon atoms to form plant matter (i.e. biomass) and fix carbon in the soil. Typically, plants are around 50% carbon by mass. The carbon remains captive in the biomass unless it is burned, consumed, or decayed. Storing and protecting this biomass in building materials presents an opportunity to lock vast amounts of carbon into buildings, preventing this stored carbon from returning to the atmosphere for the lifetime of the house, converting the building into a carbon sink (Breton et al., 2018). The NRCan MCE[2] Estimator tool includes numerous conventional and alternative biomass materials, accounting for both their carbon storage and emissions. The potential carbon storage value for virgin timber products is not included in the tool, as the value of long-cycle timber harvesting is a subject of much debate and there is no consistent methodology available to apply (Pierobona et al., 2019)

2.4 Material selection in archetypes

NRCan has identified the bungalow, the two-story house, and the row house-end unit as archetypes to represent Part 9 housing in Canada. Sample architectural plans for these archetypes were provided by NRCan for this project and used to determine building dimensions and material quantities.

Four sets of material selections were applied to each sample building to represent a spread of potential MCE outcomes:

- **2.4.1. High carbon material selection (HCM):** These materials were selected to represent the highest MCE options available in the tool. These materials are readily available and commonly used in residential construction. Though this selection represents a worst-case scenario, it also represents a scenario not uncommon in the home building industry. HCM is characterized in this report in red.

- **2.4.2. Mid-range carbon material selection (MCM):** These materials were selected to represent the most commonly used mid-range MCE materials available in the tool. This set of materials is readily available and represents a fairly typical residential building constructed in today's market that intentionally avoids the worst materials from a MCE perspective. MCM is characterized in this report in blue.

- **2.4.3. Best available carbon material selection (BAM):** These materials were selected to represent a building that could be constructed today using widely available mainstream products with the lowest MCE. All materials allow for prescriptive code-compliant construction and are installed using common construction practices. From a MCE perspective, this is the best material selection set for homes that could readily be built in large-scale quantities today. BAM is characterized in this report in yellow.

2.4.4 Best possible carbon material selection (BPM): These materials were selected to achieve the best possible MCE results from existing materials. Some of these materials are not yet available in the mainstream market but have been used in code-compliant homes across Canada and the world. A home constructed from this combination of low-carbon and carbon-storing materials has negative MCE emissions, meaning it stores more carbon than it emits. This represents a potential for the housing sector to become a national carbon sink, given adequate investment in developing these climate-smart materials for the market. BPM is characterized in this report in green.

The same four material selections were used for all building archetypes and locations, as the selected materials are available nationally (though distribution and costs may vary regionally). See Appendix B for the list of materials selected for each MCE level.

2.5 Energy Efficiency Tiers

Each energy performance tier of the NBC is distinguished by an overall energy performance improvement target and an envelope performance improvement target realizing reductions in GHG emissions. Tier 1 in the NBC 2020 aligns closely with the requirements of section 9.36 of the NBC 2015. Tiers 2 to 5 have increasingly stringent energy efficiency specifications. Part 9 buildings have 4 tiers of prescriptive and 5 tiers of performance compliance paths. In the prescriptive compliance path, a home's energy performance is expected to be 10%, 20% and 40% better than the baseline reference, for Tiers 2, 3 and 4, respectively. The Tier 5 performance path requires a 70% improvement over the reference building defined in the National Building Code 2020 (Lockhart, 2020). These improvements in energy performance are achieved through higher levels of insulation, airtightness and energy-efficient systems. S ee Appendix-C for specifications for each building type and city.

The HOT2000 files and electrical grid carbon intensities provided by NRCan are assumed to provide reasonably accurate representations of operational carbon emissions (OCE) based on performance tiers. Given that certain energy conservation measures are not considered in the calculation of Material Carbon Emissions (e.g. mechanical systems & airtightness), modeling assumptions had to be made in order to minimize discreet jumps in performance without a corollary impact on MCE. The modeled buildings used electric baseboard heaters with electric air source heat pumps to meet heating needs and electric storage-type service water heaters for domestic hot water. A set of results are generated for the two-storey house in Toronto and Prince Albert where natural gas is the heating source fuel in order to examine the impact of fossil fuel use.

2.6 Cost Estimates

Material costs were examined for the two material categories with the greatest impact on overall MCE results, insulation and exterior cladding. Cost estimates were based on material quantities in the MCE^2 tool and using national retail websites to provide average Canadian pricing during May, 2021. Where multiple options exist for a product, the average cost of all available options is used. The cost estimates do not account for standard material purchasing practices for bulk order discounts, offcut margins or on-site waste, nor are costs for transportation to the construction site included. No attempt was made to include labour costs as these vary widely across Canada, based on region and season.

3. Results

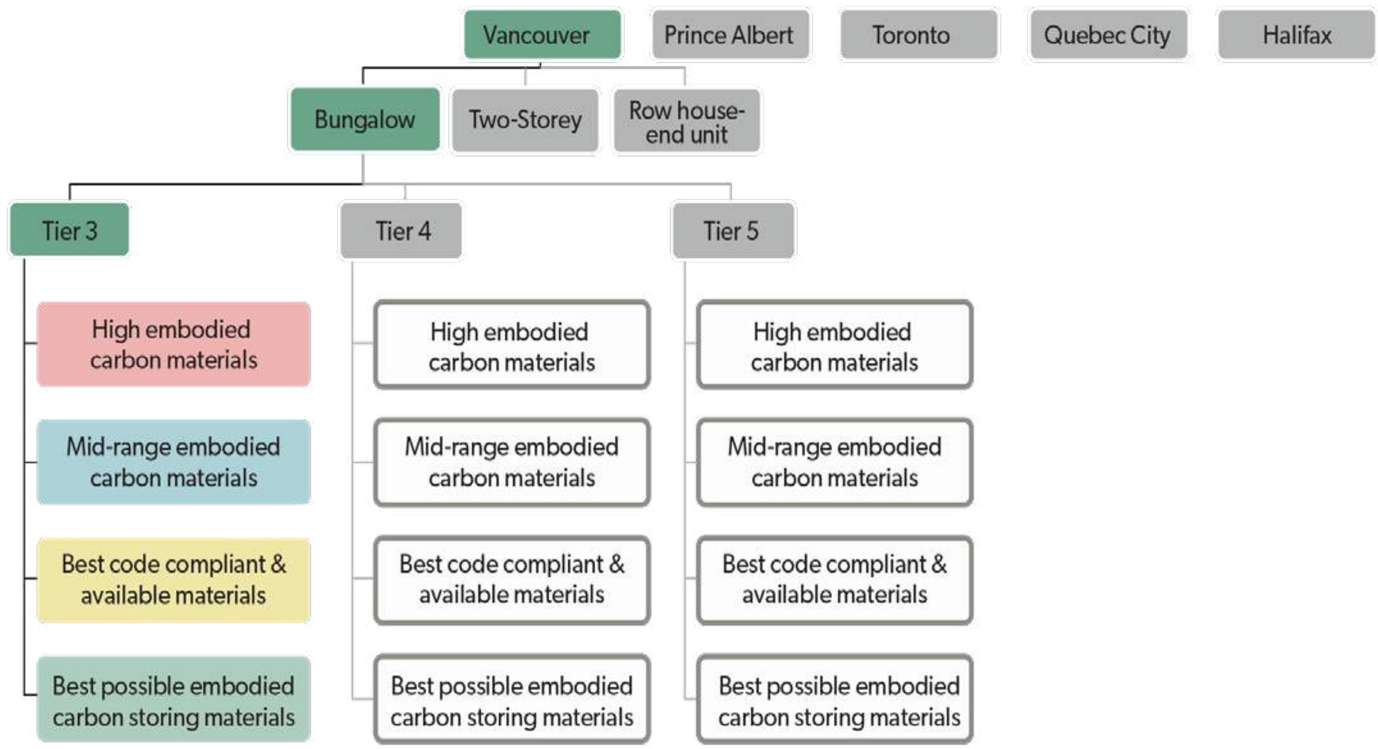


Figure 5 Diagram of the sample building variables included in the scope of this project

Results for each variable in the study are presented separately: housing archetype, location, energy performance tier, MCE material selection type and cost (figure 5). In addition, some results track across two or more variables. The key results are presented in the body of the report, and the full set of results can be found in Appendix-D.

3.1 Material Carbon Emissions (MCE) and Material Carbon Intensity (MCI)

Results for MCI varied widely, from a high of 758 kg CO_2e/m^2 for the two-storey archetype in Prince Albert at Tier 5 when built with high MCE materials to a low of -88 kg CO_2/m^2 for the two-storey archetype in Prince Albert and Québec at Tier 5 when built with the best available materials. The very wide range of results indicates that material selection can impact the total MCE of a new home by as much as 198 t CO_2e without changing the design or performance of the home. The results with the highest and lowest overall MCE and material carbon intensity (MCI) for each housing archetype are summarized in figure 6.

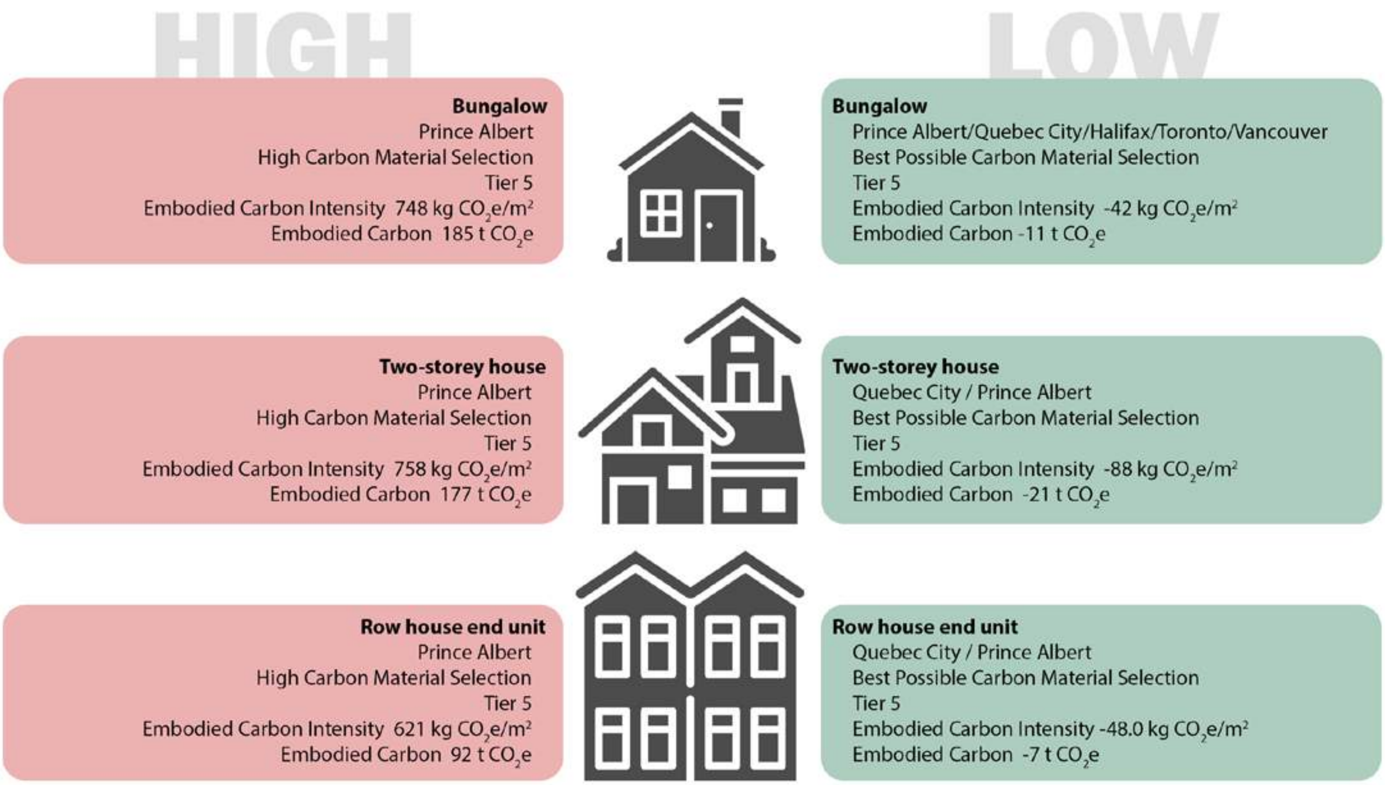


Figure 6 Visual summary of highest and lowest material carbon intensity and carbon emissions for the three archetypes

		Tier 3		Tier 4		Tier 5	
		Avg MCE t CO_2e	Avg MCI kg CO_2e/m^2	Avg MCE t CO_2e	Avg MCI kg CO_2e/m^2	Avg MCE t CO_2e	Avg MCI kg CO_2e/m^2
Bungalow	High Carbon Materials (HCM)	133	538	142	574	158	639
Two-storey		120	514	133	572	149	637
Row house		72	486	75	505	80	541
Bungalow	Mid-range Carbon Materials (MCM)	40	162	41	165	42	169
Two-storey		29	125	31	132	32	139
Row house		24	162	24	165	26	173
Bungalow	Best Available Materials (BAM)	4	16	3	11	1	6
Two-storey		-2	-7	-4	-15	-6	-26
Row house		-1	-4	-1	-6	-2	-14
Bungalow	Best Possible Materials (BPM)	-8	-31	-9	-37	-11	-42
Two-storey		-17	-74	-18	-79	-20	-84
Row house		-7	-46	-7	-47	-7	-47

Table 1 Summary of the MCE results averaged between all five regions

Results for MCE were relatively similar between the five different cities. Table 1 summarizes the MCE[2] results averaged between all five regions. The MCE results decrease significantly with each move between material selection tiers. Moving to higher tiers of energy efficiency always increases MCE and MCI for the conventional materials represented in the HCM and MCM models (figure 7).

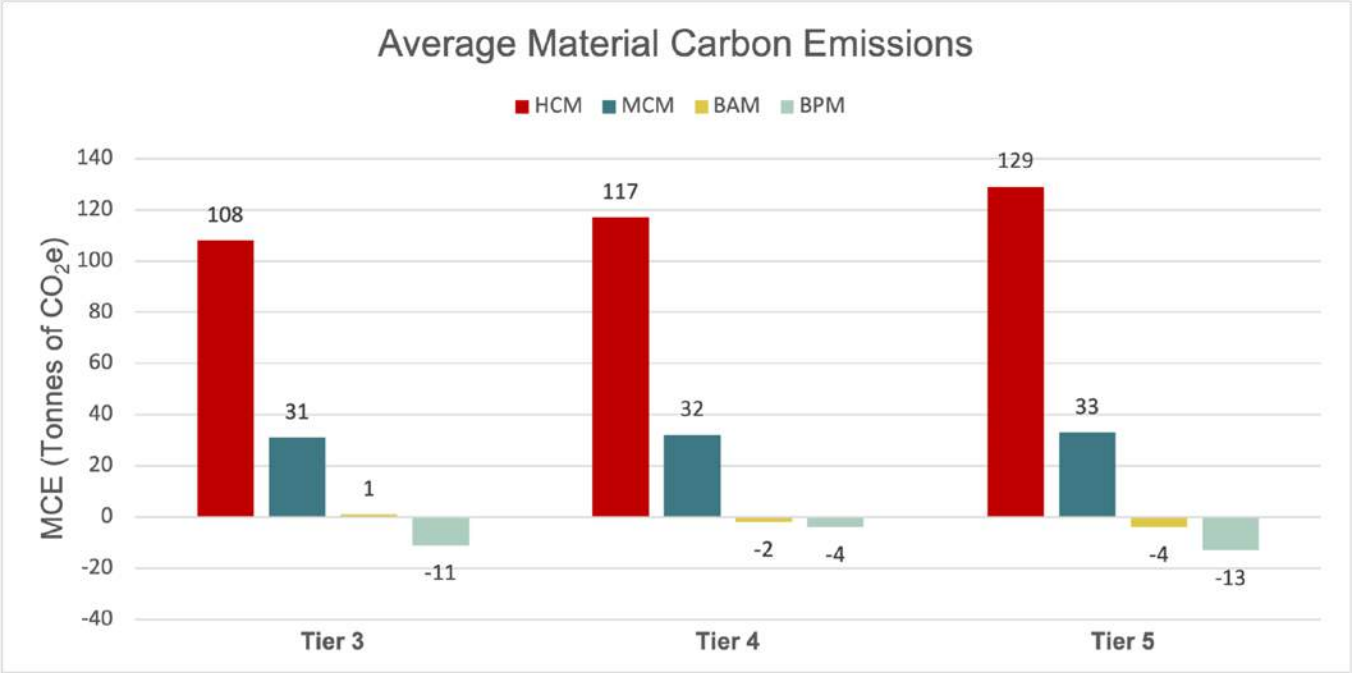


Figure 7 Average MCE per material selection scenarios for each NBC energy efficiency Tier

A decrease in MCE was evident in the BCM and BAM models due in most part to the increase in carbon storing insulations. As seen in table 1 and figure 6, the difference between the three NBC tiers is less impactful on MCE than the difference between the carbon intensity of material choices.

Averaging the results for all regions and archetypes provides a snapshot of potential MCE outcomes across the country. Though the mix of housing archetypes and designs in Canada is more complex than modeled in this study, the averages provide an indication of the range of outcomes and the trends that arise from improving energy efficiency and reducing MCE.

The highest average MCI is for a tier 5 HCM bungalow at 639 kg CO_2e/m^2 and the lowest is for a Tier 5 BAM two storey at -84 kg CO_2e/m^2. The highest average MCE is for a tier 5 HMC bungalow at 158 t CO_2e and the lowest is for a Tier 5 BAM two storey at -20 kg CO_2e/m^2.

The average results (table 1) show up to a 300% increase in MCE from tier 3 to tier 5. In most cases the delta is higher for tier 4-5 than tier 3-4, for instance the row house-end unit MCE is unchanged between tier 3 and 4 for MCM, BCM and BAM while there is a 5%, 7% and 57% increase between tier 4 and 5 for MCM, HCM and BCM respectively.

The row house-end unit has the least significant increase in MCE and MCI moving up the efficiency tiers. The Bungalow rates high overall in average MCI as the highest or second highest in every MCE category. On average HCM carbon emissions increase by 9 tonnes of CO_2e between tier 3 and 4. The same move between tier 4 and 5 increases carbon emissions by double at 12 tonnes of CO_2e (table 2).

1 Year Operational Carbon Emissions - All Electric Homes									
	Bungalow			**Two-storey house**			**Row house- end unit**		
	Tier 3	Tier 4	Tier 5	Tier 3	Tier 4	Tier 5	Tier 3	Tier 4	Tier 5
Prince Albert	**19.30**	**16.11**	**12.22**	**22.58**	**18.36**	**12.93**	**15.20**	**13.24**	**9.91**
Halifax	**13.09**	**12.43**	**8.86**	**16.02**	**14.36**	**9.92**	**14.31**	**10.60**	**7.73**
Vancouver	**0.17**	**0.16**	**0.12**	**0.18**	**0.17**	**0.13**	**0.15**	**0.14**	**0.11**
Québec City	**0.03**	**0.03**	**0.02**	**0.04**	**0.03**	**0.02**	**0.03**	**0.03**	**0.02**
Toronto	**0.59**	**0.54**	**0.40**	**0.71**	**0.62**	**0.44**	**0.50**	**0.47**	**0.47**
1 Year Operational Carbon Emissions - Natural Gas Heating and Hot Water									
Prince Albert				**10.3**	**9.0**				
Toronto				**3.5**	**2.7**				

Table 2 Operational Carbon emissions of the 3 archetypes in five cities. The red font represents carbon-intensive electrical grids. The green font represents low carbon electrical grids. Natural Gas is represented in orange font.

3.2 Operational Carbon Emissions (OCE)

A majority of all the homes modeled were all-electric, using baseboard heaters for space heating with electric heat pumps and electric storage-type service water heaters. The OCE for the modeled homes therefore varies depending on the carbon intensity of the local electrical grid. The OCE results were very similar for the three cities—Vancouver, Toronto and Québec—which have relatively low-carbon electrical grids, resulting in emissions at every tier of energy efficiency well below 1 tonne of CO_2e per home per year.

For the two cities with more emissions-intensive electrical grids, Prince Albert and Halifax, the annual emissions are much higher. Even the most energy-efficient home in these two cities, the row house-end unit in Halifax at Tier 5, with 7.73 tonnes of OCE per year, emits over 10 times as much as the least efficient home with a cleaner grid, the two-storey in Toronto at Tier 3 at 0.71 tonnes. At the most extreme, the two-story house in Prince Albert at Tier 3, with 22.58 tonnes of OCE per year, emits over 500 times more than the Tier 3 home in Québec City at 0.04 tonnes.

In the scenarios where the two-storey house uses natural gas for heating and hot water, the results also indicate the importance of electrical grid carbon intensity. In Prince Albert, with OCE of 10.3 and 9.0 tonnes for tiers 3 and 4, respectively, the natural gas scenario is an over 50 percent improvement from using an all-electric strategy. However, in Toronto the use of natural gas results in OCE that is five times higher.

The stark difference between these results indicates the importance of addressing energy source emissions as a critical step in reducing OCE from Canadian homes.

4. Cost

The considerable impact of MCE on Canada's emissions will need to be viewed with affordability in mind. Costing of construction for new homes is a complex undertaking, with hundreds of different material types and brands being selected to meet a range of criteria including material cost, labour cost, labour availability, durability, appearance and customer preference. For the purposes of this study, we compared the material costs of the two most impactful categories—insulation and cladding—and costed the range of materials in both categories in the MCE[2] tool. Material costs are based on 10 m^2 of coverage, and insulation materials were normalized to thermal performance of R10. Prices were sourced from the websites of major Canadian material retailers in June, 2021, and the prices of multiple options and sources were averaged to provide mid-range costs. For each material type presented, there are options that are both more and less expensive on the market. The results are valuable for comparison but not intended to reflect the actual cost for a particular building.

The result shows no direct correlation between the cost and MCE of materials. In some cases, such as cellulose or straw bale cavity insulation, low costs are combined with very low MCE, while the wood fiberboard insulation has the best MCE in its category but also the highest cost. Brick cladding has both the highest MCE and cost, while lime stucco has the lowest cost and a mid-range MCE.

Cost and MCE Comparison of Wall Cavity Insulation Options				
Wall Cavity Insulation	**Type**	**R/inch**	**$kgCO_2e$ for 10 m^2 @ R10**	**Cost for 10 m^2 @ R10**
	Straw bale	3.3	-128	$49.11
	Hempcrete	2.1	-76	$213.15
	Hemp fiber batt	3.7	-31	$96.33
	Wood fiber batt	3.8	-19	$210.33
	Cellulose batt	3.6	-14	$70.79
	Cellulose dense packed	3.7	-13	$40.83
	Fiberglass batt	3.6	12	$55.47
	Mineral wool batt	3.8	23	$75.84
	Wool batt	3.6	23	$133.93
	ccSPF with HFO blowing agent	6.6	73	$11.73
	ccSPF with HFC blowing agent	6.6	232	$10.66

Table 3 Cost per unit of wall cavity insulation

Cost and MCE Comparison of Continuous Board Insulation Options				
Board insulation	**Type**	**R/inch**	**kgCO$_2$e for 10 m^2 @ R10**	**Cost for 10 m^2 @ R10**
	Wood fiber (European imports)	3.6	-36	$567.44
	EPS foam with graphite	4.7	49	$150.12
	Polyiso foam	6.5	50	$244.32
	Mineral wool	4.3	51	$467.87
	EPS foam	4	66	$145.75
	XPS foam	5	987	$279.55

Table 4 Cost per unit of wall continuous insulation

Cost and MCE Comparison of Exterior Cladding Options			
Cladding	**Material**	**kgCO$_2$e for 10 m^2**	**Cost for 10 m^2**
	Wood - SPF (unfinished)	12	$489.52
	Wood - WRC (unfinished)	17	$525.81
	Synthetic stucco	35	$77.50
	Vinyl - avg of all products	54	$370.50
	Lime stucco	96	$12.34
	Steel panel - corrugated & painted	150	$133.01
	Fiber-cement - avg of all products	170	$616.42
	Brick	472	$753.48

Table 5 Cost per unit of exterior cladding

5. Analysis of Results

This project was commissioned to explore the impact on material carbon emissions (MCE) of increasing the energy efficiency of residential buildings via the upper tiers of the 2020 NBC. Analysis of the results revealed a correlation between MCE and increasing energy performance from Tier 3 to Tier 5 of the code. However, as discussed in 5.4 below, this impact is not linear, and the magnitude of the impact varies greatly depending on the climate zone of the home and the local electrical grid carbon intensity.

Beyond revealing important factors linking energy performance tiers and MCE, the study illuminates the significance of MCE as the largest source of emissions for new homes and the area in which the most meaningful climate impacts can be achieved most rapidly because each tonne of MCE reduction occurs entirely at the very start of a home's life cycle rather than incrementally over the lifespan of the home. Each tonne of emissions reduced today is more valuable to reducing climate impact than a tonne reduced at some later date due to improved energy efficiency.

Analysis of the results reveals several important findings that should prove to be valuable information for the Canadian government as it works towards net zero emissions from the housing sector by 2050.

The results clearly indicate that achieving net-zero emissions in the housing sector is fundamentally impossible without addressing MCE.

5.1 Material carbon emissions (MCE) are a major source of GHGs from the home building sector

The material carbon emissions from new homes can be surprisingly high. Across all housing archetypes in all regions, the mean MCI for High Carbon Material (HCM) models was 556 kg CO_2e/m^2, over half a tonne per square meter of living space. Additionally, the average MCI result for Mid-range Carbon Material (MCM) buildings was 146 kg CO_2e/m^2, a significant improvement but not a result compatible with Canada's emissions targets.

The HCM and MCM results were used to approximate the net annual MCE from new home construction in Canada at 8.2 – 31.3 Mt CO_2e/year. Averaging HCM and MCM would result in 19.8 Mt CO_2e/year. Based only on three archetypes and two kinds of material selections, these estimates should not be interpreted as an accurate reflection of MCE from new Canadian homes, but indicate the serious implications of MCE in reaching Canada's emission targets for the housing sector.

MCE Tier	MCI Average (kg CO_2e/m^2)	Average m^2 of archetypes	Emissions from 56.33 million m^2 of new homes built in Canada each year (million tonnes)
High Carbon Materials (HCM)	556	210	31.3
Mid-range Carbon Materials (MCM)	146	210	8.2
Average of HCM & MCM	351	210	19.8

Table 6 Material carbon emissions from average new home construction each year as per high carbon materials and mid-range carbon material selection

5.2 It is possible to build homes with near-zero MCE today and intentionally create homes that provide net carbon storage in the near future

This study points out the significant emissions impacts of MCE, but it also points to a solution by demonstrating the feasibility of creating new homes with a net-zero MCE impact. The Best Available Materials (BAM) category uses materials selected to be widely available and fully code compliant, and the average MCI across all the BAM home models was 4.3 kg CO_2e/m^2 of net carbon storage, rather than emissions.

These are very encouraging results. It is rare to find a viable pathway to reduce a major GHG source to zero using existing materials, designs and code scenarios. However, these results clearly show that it is possible to build new homes that are code-compliant, energy-efficient and built using widely available products, while also having net zero material carbon emissions. The Canadian housing sector is very well positioned to feasibly reduce megatons of emissions with available materials and to do so well ahead of the 2050 deadline for net-zero emissions.

The sector also has the potential to go beyond net-zero emission goals. The Best Possible Materials (BPM) models in this study achieved an average of 54.2 kg CO_2/m^2 of net carbon storage, which would equate to negative emissions of 3.05 Mt CO_2 per year across the sector. This is roughly equivalent to soaking up the annual emissions from one of Canada's remaining coal-fired power plants (Israël & Flanagan, 2016), or removing the emissions from 663,985 automobiles (Natural Resources Canada, 2014).

The BPM models include some materials that are not very common in typical Canadian homebuilding. However, all of the BPM materials have been used in code-approved homes in the country and many have proven their durability and performance for over 25 years in the Canadian context. These are material options that are entirely feasible to be used at a wider scale to achieve sector-wide net negative emissions by 2050 with appropriate incentives, R&D investments, and regulation. This finding concurs with the federal government's 2020 "A Healthy Environment and a Healthy Economy" report:

> *To grow Canada's green building manufacturing sector and supply chains, the Government of Canada will:*
>
> - *Work with the building materials sector and other stakeholders to develop a robust, low-emissions building materials supply chain to ensure Canadian, locally-sourced products are available, including low-carbon cement, energy-efficient windows and insulation (Environment and Climate Change Canada, 2020).*

MCE Tier	MCI Average (kg CO_2e/m^2)	Average m² of archetypes	Negative emissions from 56.33 million m² of new homes built in Canada each year (Mt of net CO_2e storage)
Best Available Materials (BAM)	-4.3	210	0.24
Best Possible Materials (BPM)	-54.2	210	3.05

Table 7 Gross material carbon emissions from average new home construction each year as per best available materials and best possible material selection.

A concerted effort to develop the supply chains and scale up the technological advancements of carbon-storing building materials—insulation materials in particular—would accelerate the elimination of all MCEs from the homebuilding sector in a timeframe well within Canada's 2050 net-zero goals.

5.3 Cost impacts of achieving zero MCE

Comparing costs for residential construction is a complicated undertaking, and no attempt was made to comprehensively assess the complete construction costs for any of the model buildings in this study. This study examined the retail prices for the two material categories with the highest impact on MCE results. Prices for insulation (10 square meters normalized to an R-value of 10 to ensure that the cost for thermal performance is equivalent) and exterior cladding (10 square meters) were obtained from retail websites in Canada and averaged across product ranges.

Prince Albert – 2 Storey house – Tier 5					
Wall area - 274.12 m²	**Material**	**R-Value**	**$kgCO_2e$ for 2 storey house**	**Total Material Cost**	**Total Cost to MCE**
HCM					
Cavity Insulation	CcSPF with HFC blowing agent	40	6,360	$ 1,170	$ 29,490 / 20,285 $kgCO_2e$
Continuous insulation	XPS foam	10	987	$ 7,665	
Cladding	Brick	-	12,938	$ 20,655	
MCM					
Cavity Insulation	Mineral wool batt	40	2,522	$ 8,315	$ 38,040 / 8,070 $kgCO_2e$
Continuous insulation	Mineral wool board - average	10	1,398	$12,825	
Cladding	Fiber cement siding - average	-	4,150	$16,900	
BAM					
Cavity Insulation	Cellulose - average	40	-1,425	$ 7,760	$ 36,735 / -2,083 $kgCO_2e$
Continuous insulation	Wood fiber board - average	10	-987	$15,555	
Cladding	Wood – SPF (unfinished)	-	329	$13,420	
BPM					
Cavity Insulation	Wood frame with straw bale infill	40	-14,035	$ 5,385	$ 18,805 / -13,706 $kgCO_2e$
Continuous insulation	N/A	0			
Cladding	Wood - SPF (unfinished)	-	329	$13,420	

Table 6 Costing comparison of high impact wall building elements for a two-storey in Prince Albert at tier 5

There was no direct correlation between material costs and MCE. The two storey archetype at Tier 5 in Prince Albert had both the highest and lowest MCE in this study. Combining material costs for cavity insulation, continuous insulation and exterior cladding—the material categories with the highest MCE impact in this study—for the two storey archetype provides illustration of the lack of direct cost correlation. As all of these wall systems use similar amounts of framing lumber and other structural components, this cost comparison gives a sense of the scale of material cost differences. However, without labour costs figured in, this comparison is informative but not at all definitive.

In this comparison, the models with the highest and lowest carbon footprint had lower material costs than the mid-range and best available materials models. At best, this comparison demonstrates that achieving net zero MCE and even net negative MCE may not come with a high price tag, as some of the materials that achieve the most encouraging MCE values can be combined into assemblies with reasonable costs.

The range of costs and the dissociation between cost and MCE indicates that builders would be able to make material choices that would balance cost concerns and favourable MCE results. Where the highest costs and MCE overlap, these choices could be avoided while the lowest costs and MCE could be substituted. Given the range of options and prices, a builder may be able to greatly reduce a home's MCE without increasing overall costs. A full costing exercise for these archetype homes would be a useful and informative addition to this study.

It is worth noting that some of the BAM and BPM materials are currently manufactured on a very small scale and would likely benefit from cost reductions as a result of greater uptake in the marketplace.

This is an area that is deserving of further study, adding labour and delivery costs to present a clearer picture of the relationship between cost and MCE.

5.4 MCE typically increases with each step up the energy code tiers

Each step up the energy code tiers tends to increase a home's insulation thickness. This either increases the building's MCE for carbon emitting insulations or decreases overall MCE for carbon storing insulations.

Increase in average MCI by Tier			
Material Tier	**Tier 3 to 4 increase in kg CO_2e/m^2**	**Tier 4 to 5 increase in kg CO_2e/m^2**	**Tier 3 to 5 increase in kg CO_2e/m^2**
High carbon material selection (HCM)	37.7 ↑	55.2 ↑	92.9 ↑
Mid-range carbon material selection (MCM)	3.9 ↑	5.8 ↑	9.7 ↑
Best available carbon material selection (BAM)	-5.1 ↓	-7.8 ↓	-12.9 ↓
Best possible carbon material selection (BPM)	-3.9 ↓	-3.4 ↓	-7.3 ↓

Table 8 Average increase in MCI moving one tier up across all archetypes and regions

The results of incorporating more insulation in a home has a linear effect on the total MCE. The use of insulation materials that have net GHG emissions, including all petrochemical- and mineral-based products, will drive the MCE of the building higher as more of the material is added to achieve improved operational performance. The use of insulation materials that have net carbon storage will drive the MCE of the building lower as operational efficiency improves, and was the key factor leading to the climate-positive results for the BAM and BPM models.

Table 8 lists the average MCI changes caused by NBC energy performance Tier shifts across all archetypes and regions.

The HCM and MCM models exhibit the expected increase in MCI due to the addition of more insulation material. The 60 percent increase from Tier 3 to Tier 5 for the HCM model presents a cautionary warning in the pursuit of energy efficiency strategies, as increases in net carbon emitting insulation products cause increases in MCE.

It is important to recognize that the opposite effect on MCE is seen in the BAM and BPM models. For these homes, an increase in the amount of insulation results in a reduction in MCE because the insulation materials offer net carbon storage. These results present a win-win scenario in which improvements in operational emissions are reinforced by improvements in material emissions, showing that energy efficiency and low MCE can be complementary pursuits.

5.5 OCE reductions are outweighed by MCE between tiers moving up the NBC tiered energy code

The express purpose of the NBC Tiered Energy Code is to limit the excessive use of energy in Part 9 Canadian buildings, most of which are homes, thereby reducing carbon emissions. The HOT2000 models provided for this study show that when heating and DHW in homes is electric there is a measurable reduction in emissions at each progression along the steps, from Tier 3 to Tier 5.

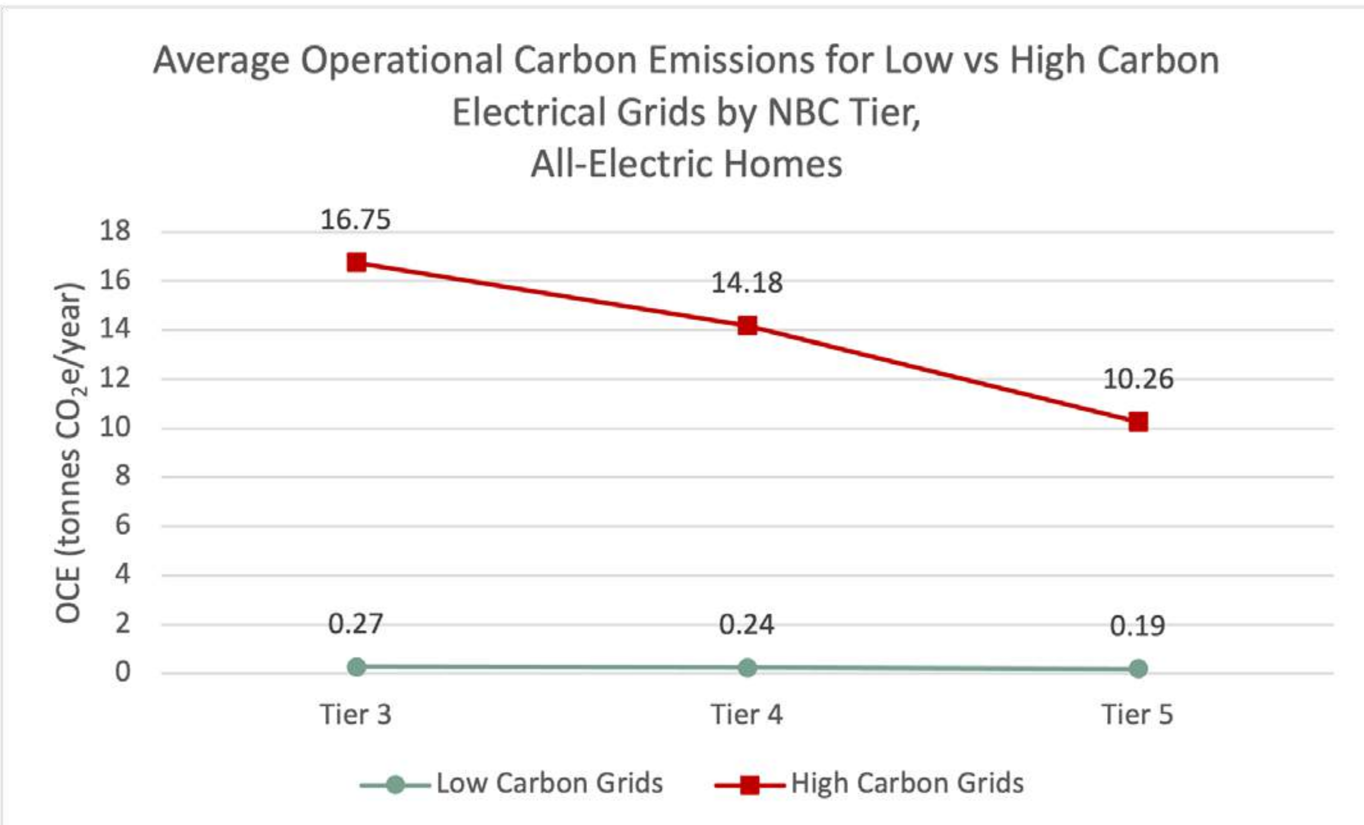


Figure 8 Comparison of average operational carbon emissions from carbon-intensive "dirty" electrical grids and "clean" low carbon electrical grids

However, the OCE results vary dramatically depending on the location of the homes. Three of the cities in the study have relatively clean electricity grids, while two have emission-intensive grids. Despite achieving the appropriate level of energy efficiency required by each NBC tier, homes in areas with emission-intensive grids have much greater emissions.

The average operational carbon emission reduction going from Tier 3 to Tier 5 per home across all typologies in the three clean grid cities was 0.08

tonnes of CO_2e per year, while the reduction in dirty grid cities was 6.5 tonnes, 80 times more impactful. It is important to note that the average total operational emissions in clean grid cities (0.19-0.27 t CO_2e/year) are a fraction of the reductions in OCE gained from Tier improvements in locations with dirty grids (6.40 t CO_2e/year.) This indicates that while reductions in OCE can be made by pushing homes to higher efficiency tiers, when heating with electricity, grid carbon intensity is a greater driver of carbon than energy efficiency measures. Greater overall carbon reductions would be achieved by reducing the emission intensity of the energy source in those regions of the country that still operate with carbon-intensive energy.

In cities with relatively clean electrical grids, improvements in MCE dwarf the improvements in OCE. Making any one-tier improvement in MCE represents decades or centuries of OCE improvements (figure 9).

In cities with emission-intensive grids, the difference is much less dramatic but still significant. Going up from one tier to the next at HCM to MCM materials represents 8 years of OCE savings (figure 9). This may represent enough time for the significant efforts underway to reduce the emissions of electricity grids across the country to catch up and match the results shown from the cleaner cities, essentially "buying time" to bring renewable energy sources online without an overall emissions penalty.

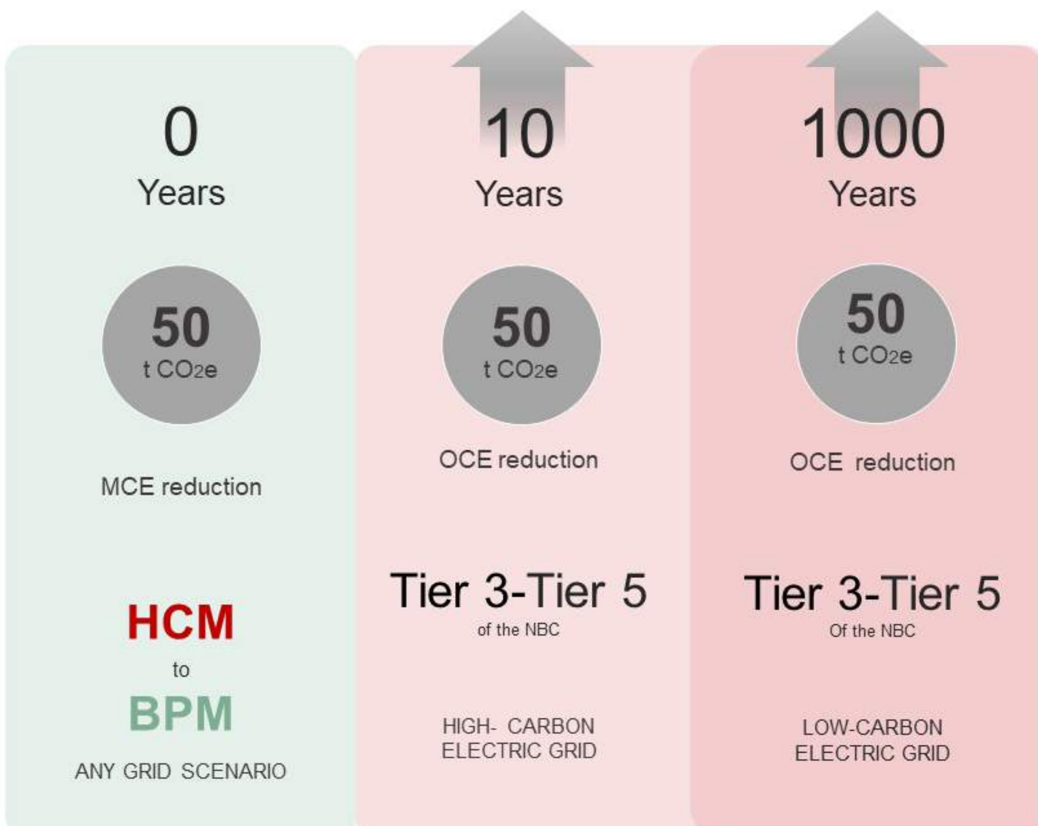


Figure 9 Operational carbon emissions reduction recovered in terms of Material Carbon Emissions over time

5.6 Material categories with highest impacts

Within each material category in the MCE[2] tool there is a wide range of MCE outcomes, but due to the volume of material used in certain assemblies there are three material categories with the greatest impact on overall MCE for homes:

1. Insulation

2. Cladding

3. Concrete

Even as emissions are reduced by using lower-emitting versions of these top three material categories, they remain the three most important categories to address.

Using Toronto's 2 storey house at Tier 4 as an example, the HCM model has 124,787 kg of total emissions. Total MCE from insulation for external walls, foundation walls, slabs, and roofing is 85,364 kg CO_2e or 68% of total emissions. Exterior cladding is 12,952 kg CO_2e or 10%, and concrete in the foundation walls and slabs is 5,785 kg CO_2e or 5% of the total emissions (figure 10).

Insulation for the MCM model for external walls, foundation walls, slabs, and roofing is 9,516 kg CO_2e or 32% of total emissions. Exterior cladding is 4,668 kg CO_2e or 16%, and concrete in the foundation and slabs is 3,976 kg CO_2e or 13% of the total emissions (figure 11).

The BAM and BPM (figure 12-13) models use carbon-storing insulation materials, thereby removing the emissions from insulations, the single most impactful category. By using low-emissions cladding materials and eliminating concrete from the foundation walls and/or slab, the BAM and BPM models also reduce these emissions substantially. By eliminating concrete from the foundation walls and/or slab the BAM and BPM models also reduce foundation emissions by up to 92[%]. Windows become the leading source of emissions for these homes.

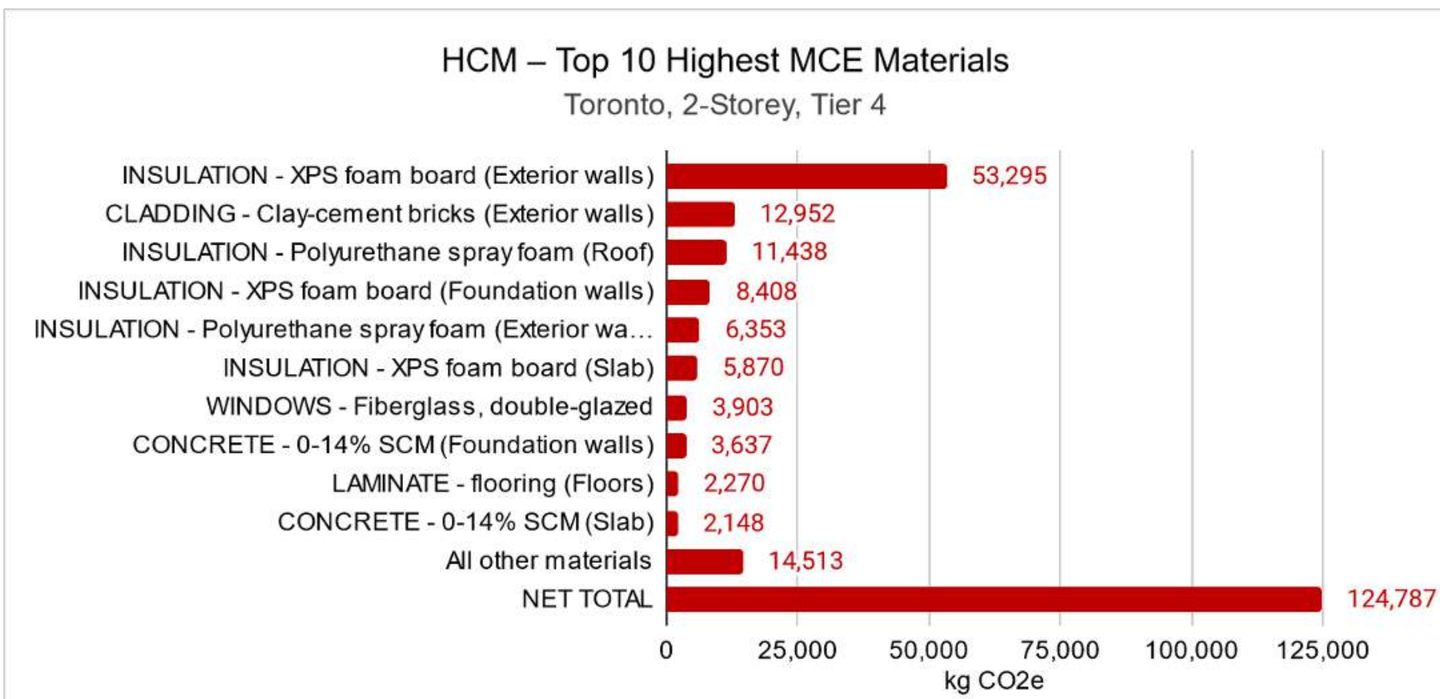


Figure 10 Top 10 highest-ranking carbon-intensive building materials in Tier 4, Two Storey house in Toronto as per the HCM selection

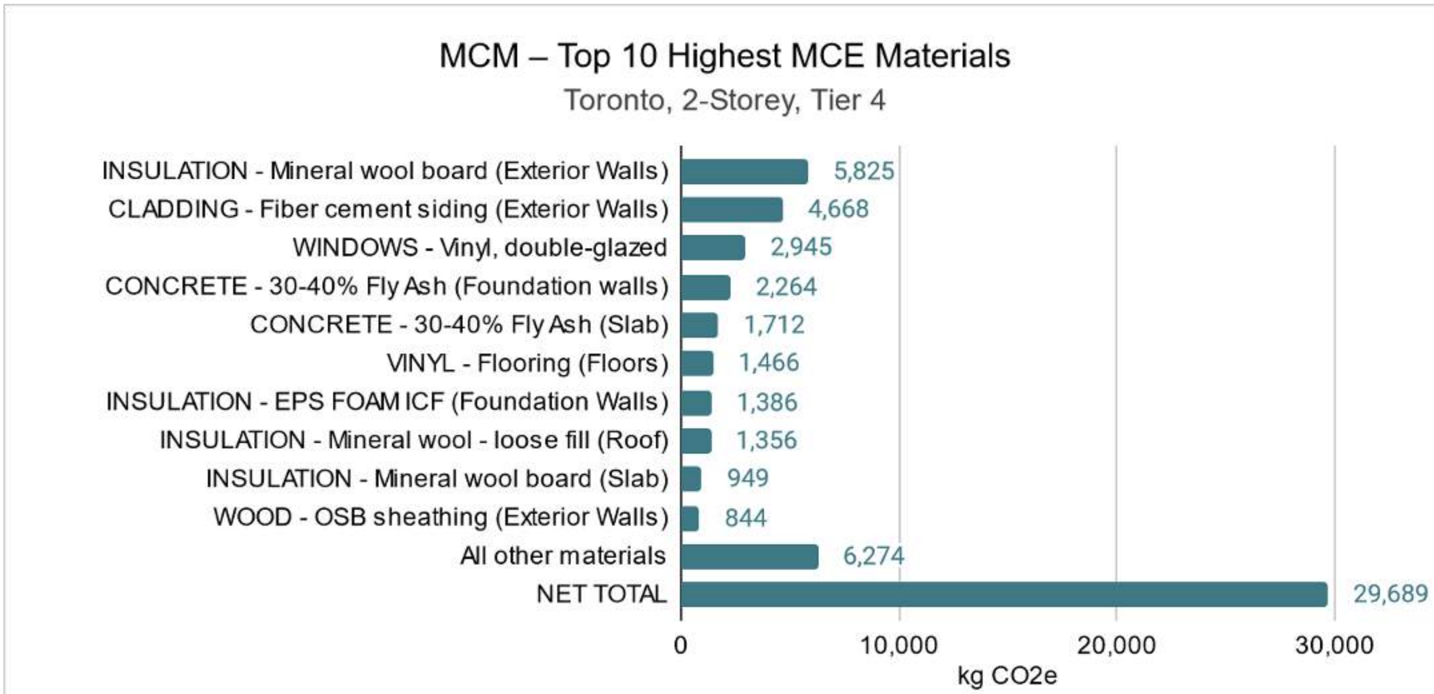


Figure 11 Top 10 highest-ranking carbon-intensive building materials in Tier 4, Two Storey house in Toronto as per the MCM selection

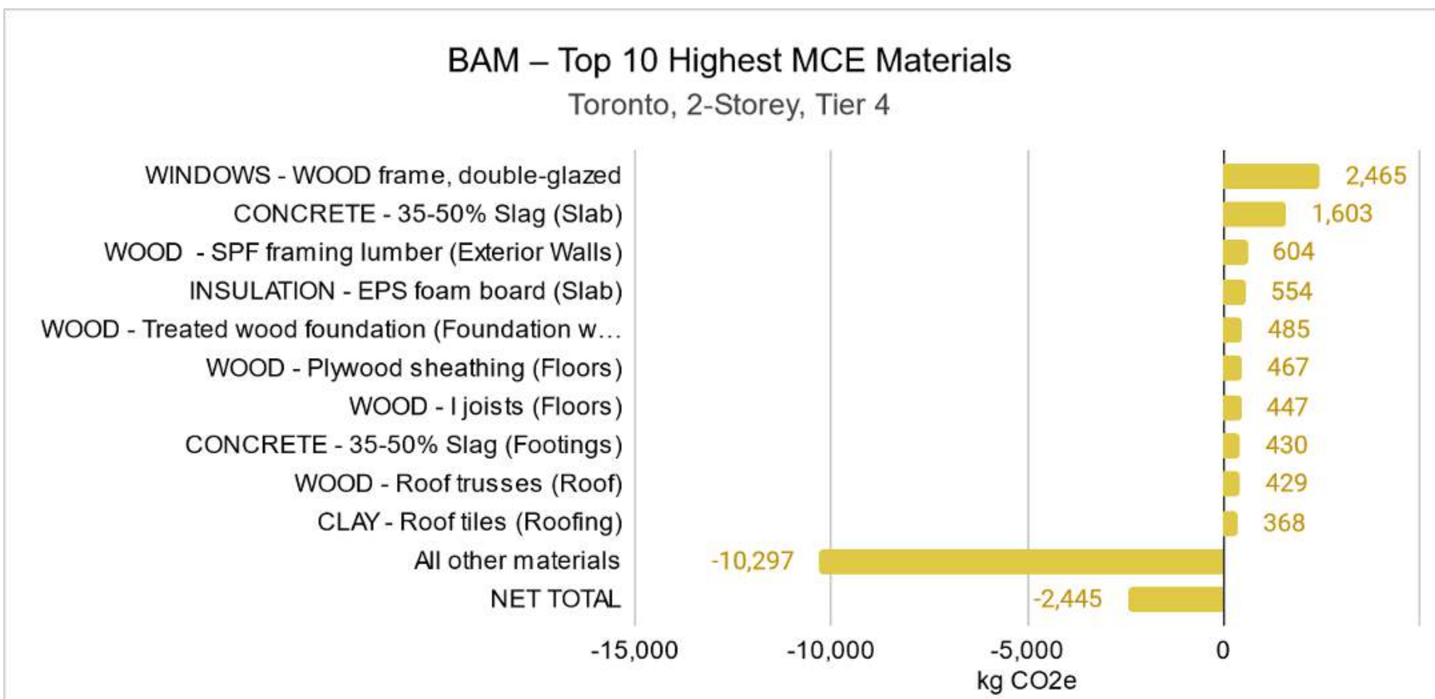


Figure 12 Top 10 highest-ranking carbon-intensive building materials in Tier 4, Two Storey house in Toronto as per the BAM selection

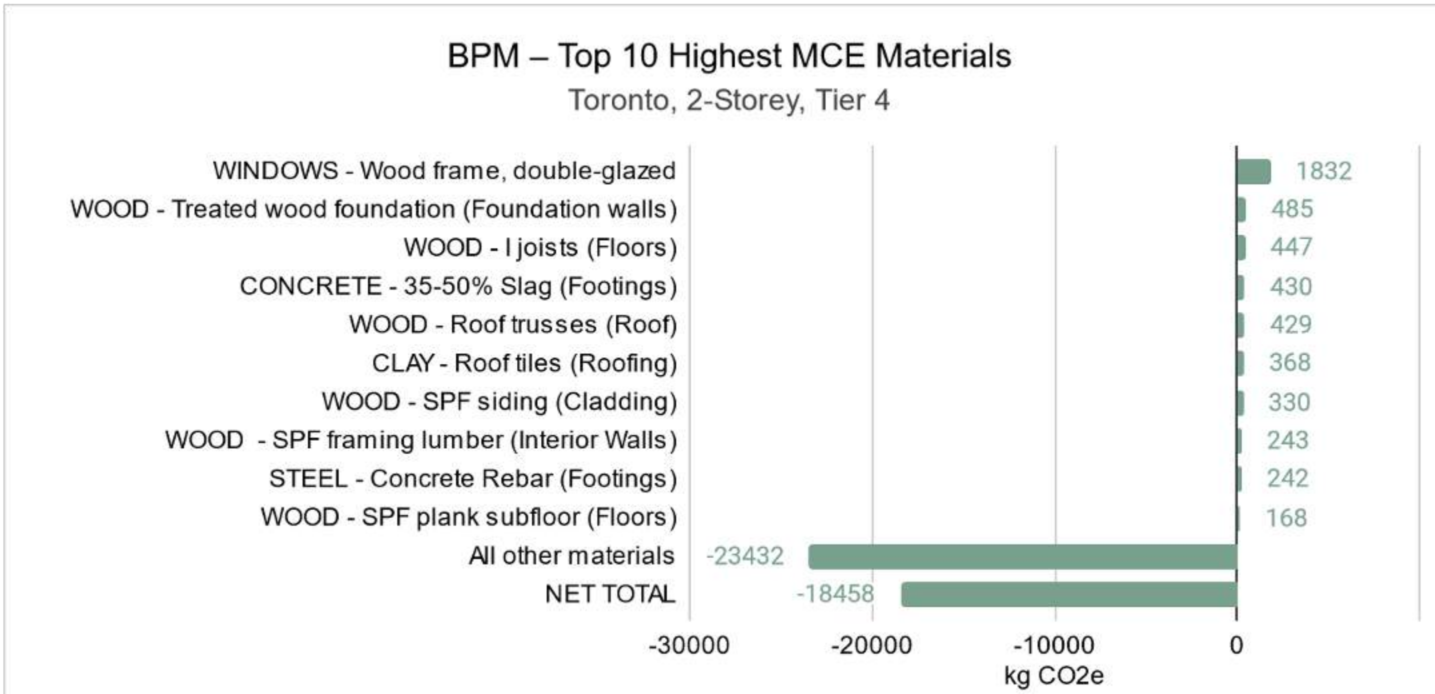


Figure 13 Top 10 highest-ranking carbon-intensive building materials in Tier 4, Two Storey house in Toronto as per the BPM selection

5.7 Not intended to be prescriptive

This study applied four different material selection sets to building models in order to illuminate the potential MCE impacts of various approaches to material selection, either positive or negative. It is important to recognize that these four selections are not intended to be prescriptive in the selection of materials. The many building assemblies that make up a home can be composed from a wide variety of materials to create a full spectrum of whole building MCE results. A home's total MCE results could land anywhere between the worst-case and best-case scenarios presented in this study, or even better or worse, depending on design and materials available at the time.

We encourage readers to focus on achieving a desired whole building MCE target. There will be a temptation to use the results of this study to pick specific materials to target as "bad" or "good." However, this study does not contend that any material(s) should be excluded from use in a home or be mandated for use in a home.

Using MCE data, designers and builders can continue to make material selections based on the wide range of criteria they already use, including cost, availability, labour, durability and aesthetics; and incorporate MCE targets as one more valuable criterion in the often complex task of material selection. The results of this study indicated that it is possible to include a material with higher emissions in combination with other low-emission materials and, ideally, some carbon-storing materials to arrive at a whole-building MCE that is reasonable and acceptable within future regulatory schemes.

This study demonstrates that we can greatly reduce, or eliminate material carbon emissions for the enclosures of Canadian homes. However, there is no single path to this goal that can be applied to the entire sector, but rather many unique pathways that can be shaped by designers and builders that choose to add this important metric to their decision-making matrix.

6. Challenges and Opportunities

This report suggests there is an exciting opportunity for Canada to reach net-zero carbon in the homebuilding sector well in advance of 2050. Homebuilders can immediately make material substitutions that would reduce emissions significantly and approach or achieve net-zero MCE using materials that are available, affordable, code-compliant and compatible with the NBC energy performance tiers. This is a more straightforward pathway than many other sectors of the economy face in moving to net zero emissions by 2050. It would be difficult to overstate the opportunity at play. The federal government's Greening Government Strategy (Treasury Board of Canada, 2021) indicates positive movement in this direction is already underway for government-owned and leased real property:

> *The government will reduce the environmental impact of structural construction materials by:*
>
> - *Disclosing the amount of embodied carbon in the structural materials of major construction projects by 2022, based on material carbon intensity or a life-cycle analysis*
> - *Reducing the embodied carbon of the structural materials of major construction projects by 30%, starting in 2025, using recycled and lower-carbon materials, material efficiency and performance-based design standards*

Some leading municipal governments in Canada are already moving in this direction. In 2019, the Township of Douro-Dummer in Ontario became the first jurisdiction in North America to offer an incentive program that recognizes both material emissions and operational emissions. The Sustainable Development Program (Township of Douro-Dummer, 2020) offers a financial rebate to homebuilders who meet a MCI threshold of 75 kg CO_2e/m^2 and zero-carbon OCE. The municipality expects that "the efforts of this program are estimated to reduce our GHG emissions by up to 50 tonnes of CO_2 per building, which would represent a 2500 tonne reduction in CO_2e over two years for 50 buildings." Similar programs are currently being developed in Nelson and Castlegar, and are actively being discussed in Vancouver and Toronto.

Despite this support from different levels of government, the path to net-zero carbon buildings is not without significant challenges. Based on the results and analysis in this study, the following challenges have been identified.

6.1 Development of methodology standards for MCE estimation tools

This study uses a beta version of the NRCan MCE^2 spreadsheet. Tools such as this will need to be widely available and understood in the industry to address MCE in a reliable, consistent way. Results from such tools need to be aligned so that users receive comparable information regardless of the tool they use. Canada can set standards for MCE tools to ensure that there is a clear and consistent methodology in place for measuring MCE.

6.2 Encouraging the creation of EPDs for all construction materials

The most reliable data for measuring MCE comes from Environmental Product Declarations (EPDs). The NRCan MCE^2 tool collects all of the currently available and valid EPDs for home building materials in Canada, but this covers only a fraction of the materials and products available to builders. Support for small and innovative material manufacturers to obtain EPDs for their products would accelerate the uptake of new, carbon-storing materials.

In particular, an emphasis should be placed on encouraging EPDs for mechanical, electrical and plumbing materials, as they represent a potentially significant source of overall emissions from new homes that is not captured in this study due to lack of data.

6.3 Development of methodology for assessing carbon storage in materials

This study makes it clear that carbon storage in building materials can have a drastic impact on net emissions from the homebuilding sector. While it is straightforward to estimate the physical quantity of carbon stored in a building material (as done by NRCan's MCE[2] tool), there is no widely accepted protocol for assessing the climate value of removing this carbon from the atmosphere in a long-lived building. The overwhelming majority of homes in northern climates have a lifespan exceeding 30 years, with studies of home demolition showing that 50 percent of homes stand for 75 years or more (O'Connor, 2004) . Clear protocols for assessing the time value of carbon stored in buildings for such lengths of time are required to accurately assess the impact of using such materials. We recommend that a form of tonne-year accounting—such as the Moura-Costa method (Costa et al., 1999) (figure 14)—be applied to biogenic carbon storage and that this methodology be considered in four distinct categories: wood/timber, agricultural residues, purpose-grown crops and waste/recycling-stream fibres.

This type of tonne-year accounting indicates that storing one tonne of CO_2e from a biogenic source for approximately 46 years has the equivalent impact of averting one tonne of CO_2e at year 0. Whole building life cycle analyses typically identify 60 years as the functional lifespan of a building (Rodriguez & Simonen, 2017), and the majority of the enclosure materials examined in this study would be expected to have a lifespan of at least 46 years, providing the full value of each tonne of storage, even if all the carbon is released to the atmosphere after this period. Using a tonne-year methodology, a suitable proportion

of carbon storage value could be assessed for biogenic materials with an expected lifespan of less than 46 years.

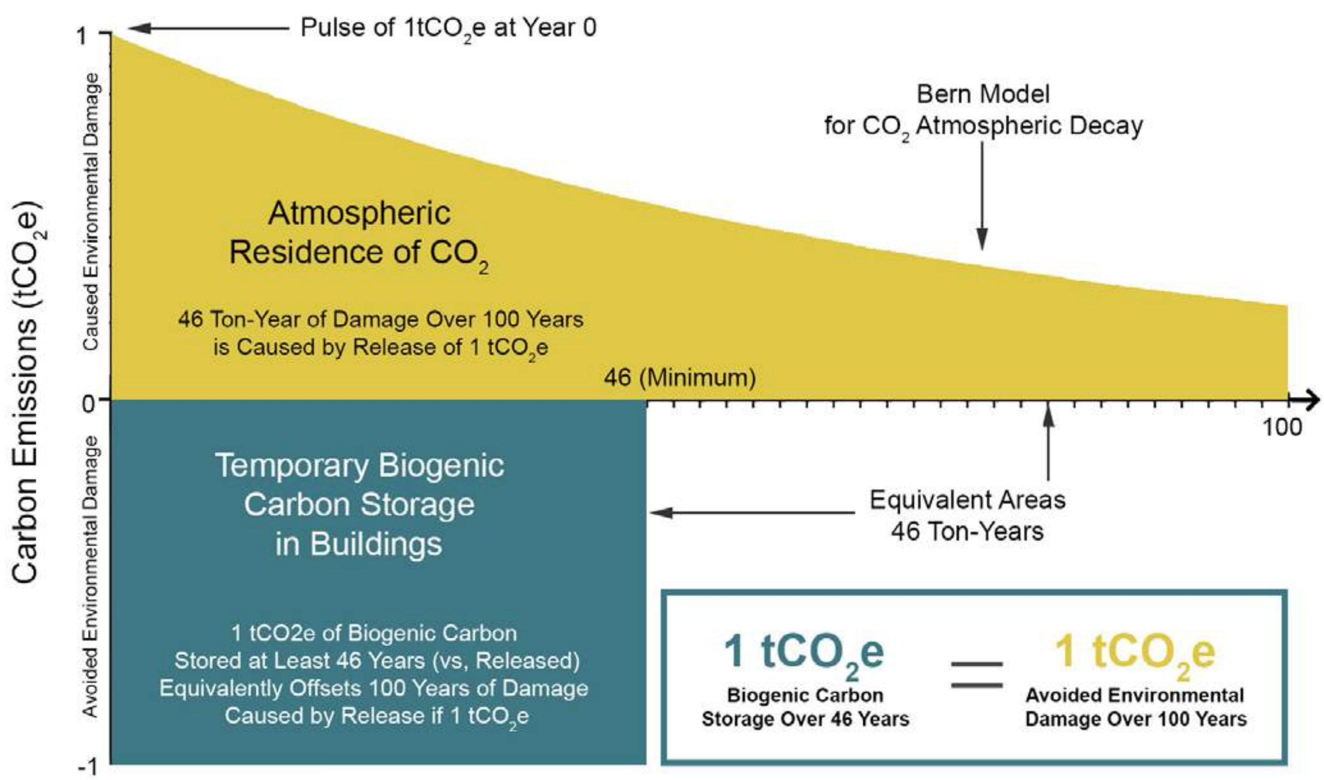


Figure 14 Moura Costa method for establishing the carbon offset equivalence of temporary biogenic carbon storage. Adapted from "Establishing a Carbon Offset Equivalence for Temporary Biogenic Carbon Storage in Buildings (Srubar, n.d.)

Table 9 demonstrates the potential attribution of carbon storage value for biogenic materials using the Moura-Costa method, with 46 years determined to be the full value to the climate of one stored tonne of CO_2. Using such a methodology would allow for more robust and accurate attribution of storage value in MCE estimation tools.

6.4 Planning for end-of-life scenarios for biogenic carbon

While the full value of temporary biogenic carbon storage can be realized over the first 4-5 decades of storage time (well within the expected lifespan of most building enclosure materials), the return to the atmosphere of carbon stored in Canadian homes at the end of their useful lifespan should be mitigated to the greatest extent possible.

Planning should begin today for reliable means of preventing carbon stored in buildings in the upcoming decades from being released back to the atmosphere at the end of a building's useful life. Reuse (including modular "design for disassembly" approaches), recycling, biochar production and soil amendment are all pathways that would ensure that carbon stored in Canadian homes remains out of the atmosphere in the future, extending the benefit to the climate for additional decades.

6.5 Encouraging more innovation in low-carbon and carbon-storing materials

The number of commercially available materials in these categories is currently small, with cellulose insulation (made from recycled newsprint) the most widely produced. Canada has abundant stocks of raw materials for carbon-storing building materials and can become a leader in developing new materials. In Canadian forests, "of the >66 Mt C/yr in the residual or waste biomass carbon stream, about 60 Mt C/yr may be considered an 'available' feedstock for a bio-based economy" (A Canadian Biomass Inventory, Industry Canada, 2003). Canadian grain farms covered 62.5 million acres in 2020 (Government of Canada, 2020), producing approximately 109 Mt of straw (Evans, 2019). 3.6 Mt of waste paper is diverted from landfill each year in Canada (Environment and Climate Change Canada, 2016). These three biomass stocks alone account for 29 tonnes of storage in the Tier 5, two storey, BPM home in Prince Albert and 35 tonnes of storage in the BAM version, giving some indication of the potential for the Canadian market to put available biomass to use in reducing the MCE of Canadian homes.

As noted in section 5.2 of this report, the federal government's Healthy Environment and a Healthy Economy report indicates the importance of developing a "robust, low-emissions building materials supply chain to ensure Canadian, locally-sourced products are available." A carbon-storing supply chain for Canadian homebuilding could have profound impacts on communities and economies beyond the climate impacts that are the focus of this study. Increasing the use and value of residue materials can improve incomes for foresters, farmers and recycling programs.

Tonne-year calculations for biogenic carbon storage value		
Carbon stored	**Duration**	**Equivalent (present emission) offset**
100 tonnes	1 year x 2.17%	2.17 tonnes
100 tonnes	20 years x 2.17%	43.4 tonnes
100 tonnes	46 years x 2.17%	100 tonnes
100 tonnes	80 years x 2.17 %	174 tonnes

Table 9 Carbon storage value of biogenic materials as per the Moura-Costa method

Increased manufacturing of building materials from these stocks would provide employment opportunities, particularly in rural communities close to the raw material supplies. Export opportunities exist, particularly to the American market, should Canada take the lead on carbon-storing material production. There are ample opportunities to support innovation, inclusion and reconciliation through the development of carbon-storing supply chains.

6.6 Support training for building designers, energy auditors and developers/builders in MCE calculation

To move the homebuilding sector to net-zero carbon, stakeholders at all levels will need to understand the concept of material carbon emissions and know how to calculate them and use these calculations to meet climate goals while also meeting the needs of their clients and business models. Practitioners will also need to learn what the best MCE materials and reduction strategies are, as well as how to properly implement them. The speed at which training specific to the needs of each stakeholder can be developed and delivered will determine the rate at which homes in Canada can reach net-zero emissions.

6.7 Support training for builders in the use of carbon-storing materials and assemblies

Current trades training programs lack appropriate curriculum content on energy-efficient construction and air tightness and do not address low-carbon or carbon-storing materials or assemblies. To get zero carbon homes built, both existing workers and new tradespeople will need training in the application of carbon-smart materials.

We recommend studying the training needs and delivery options that could be pursued to achieve zero carbon homes, including existing trades training as well as skills upgrading for existing tradespeople.

6.8 Applying lessons learned about MCE from this study to home retrofits

The construction of new homes represents a significant source of GHGs, but the retrofit of existing homes will also become a major source of MCE as existing homes strive to be more energy-efficient or require routine updates. The Canada Greener Homes Grant will invest $2.6 billion over 7 years to help up to 700,000 Canadian homeowners across the country improve the energy efficiency of their homes and reduce their energy bills. The 2021 Federal Budget proposed $4.4 billion over 5 years, starting in 2021-2022 to help up to 200,000 homeowners complete deep home retrofits through interest-free loans of up to $40,000 (Canada Mortgage and Housing Corporation (CMHC), 2021). A large percentage of this grant money will be spent on insulation materials, which this study has shown to be the most impactful, and often most detrimental, to MCE. Without incorporating MCE into these retrofit programs, the Canadian government may be incentivizing an overall increase in GHGs, rather than a net reduction.

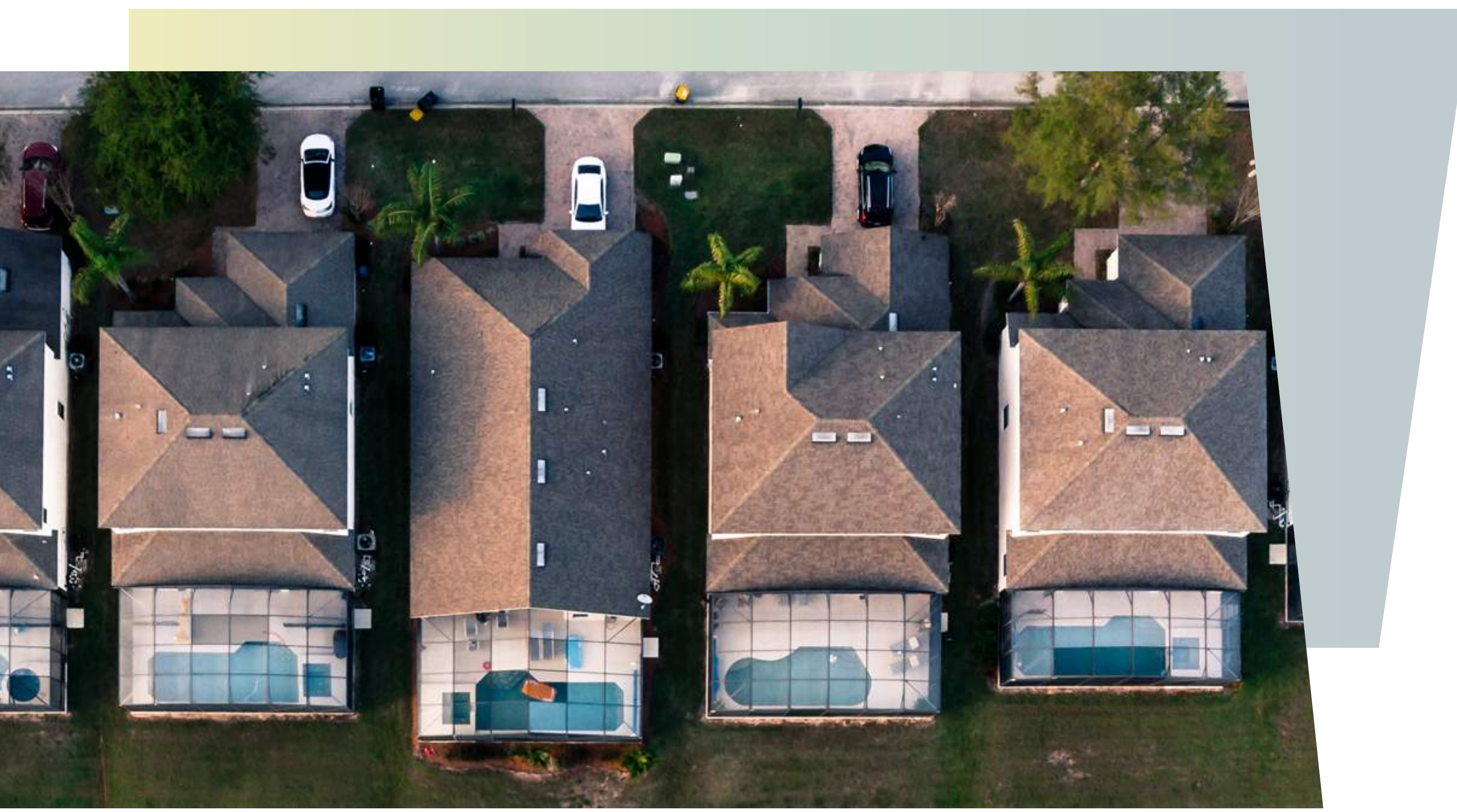
6.9 Accounting for changing fuel source emissions

As this study indicates, homes with a high-emission fuel source (emission-intensive electrical grids or fossil fuels) will never be able to meet net-zero emission targets. Assessments of a home's GHG impact are made using current fuel emission levels, but commitments by all levels of government to decrease emissions from energy sources will alter the forecasts depending on the timing and impact of such reductions. A carbon emissions target based on current energy source emission levels could encourage a strategy that will be inappropriate as energy source emissions decrease.

6.10 MCE emissions are not directly managed by the federal government

This study demonstrates the large scale of MCE from home building materials. Regulations could greatly reduce the net MCE from new homes by encouraging builders to use low-carbon and carbon-storing materials, and to incentivize manufacturers to produce such materials. However, it is important to note that the sources of material GHG emissions are not currently attributed to the home building sector but rather to the manufacturing facilities in whatever jurisdiction they occur. In many cases, these manufacturing facilities may be outside the province where construction takes place and may be outside Canada altogether.

Incentives to move the home building sector to net-zero MCE would need to recognize that such programs do not directly reduce manufacturing emissions for any particular building material. Rather, such incentives or regulations would steer the design, construction, and manufacturing sectors to reduce MCE through a combination of material substitutions and improvements in the manufacturing sector required to maintain market share in a zero-carbon industry. The impact of such efforts can be measured on a building-by-building or sector basis, but these reductions would not contribute directly to a national or provincial GHG inventory. This should not lessen the focus on MCE as an important emission reduction strategy; GHGs do not respect borders and, regardless of where they are counted, must be reduced to zero. A focus on MCE, as demonstrated in this report, can help to eliminate millions of tonnes of GHG emissions from the homebuilding sector.



7. Recommendations

Carbon Use Intensity (CUI); a new standardised metric for measuring emissions from Part 9 homes

As Canada works to meet its commitments to reach net-zero emissions by 2050, the results of this study make it clear that achieving this goal in the home building sector requires addressing three interrelated sources of GHGs:

- **Material Carbon Emissions.** This study estimates the impact of MCE within the Canadian homebuilding sector, and the results show that it is significant. Net-zero emissions will not be achievable without bringing MCE to net zero alongside operational emissions.

- **Energy Efficiency.** Home energy use has been well identified as a critical source of GHG emissions. The National Building Code of Canada has designed a pathway to reduce energy consumption, mainly by improving the energy efficiency of enclosure assemblies and mechanical systems.

- **Fuel Source Emissions.** This study illuminates the disproportionately large impact that fuel source emissions have on the operational emissions from homes. Achieving energy efficiency at the upper Tiers of the 2020 NBC can still result in high emission rates if the fuel source is emissions-intensive. In this study, the emissions-intensive energy source was electricity, but the two examples of natural gas use similarly point to continued significant emissions regardless of the level of energy efficiency achieved in a home.

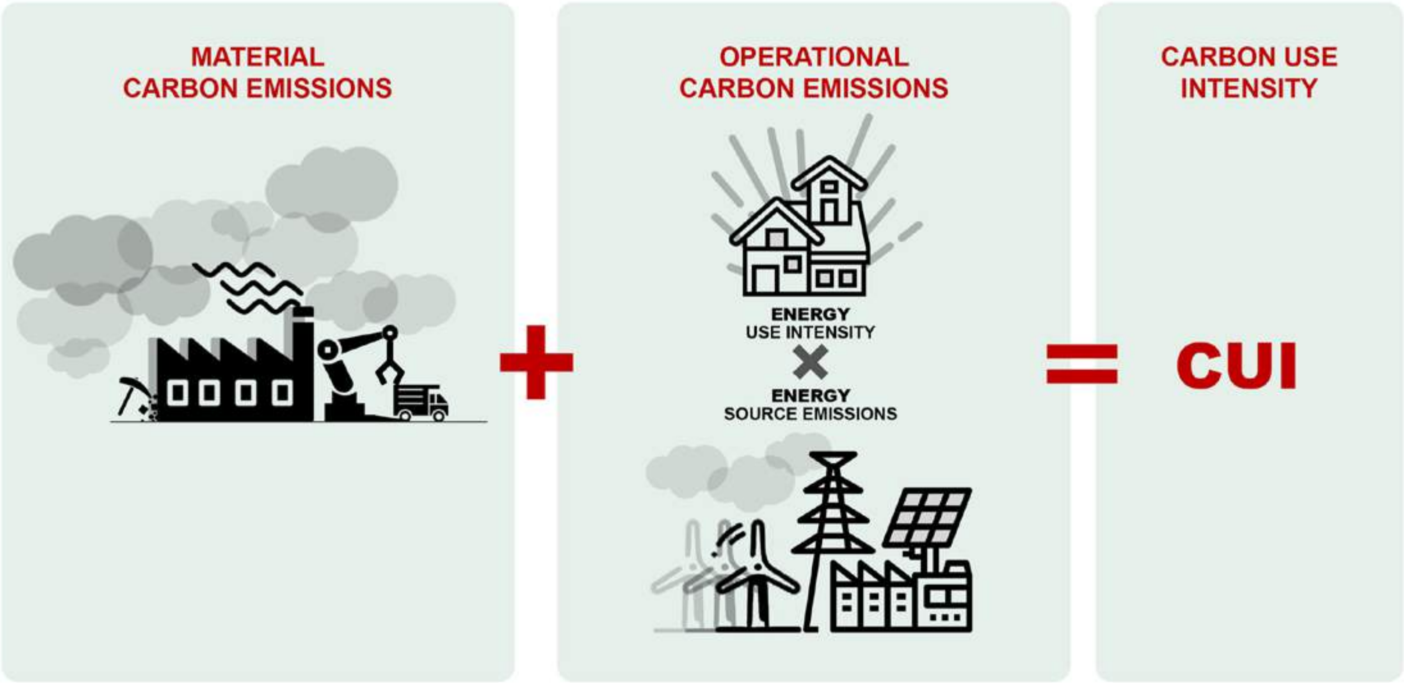


Figure 15 Carbon Use Intensity (CUI) a combined metric of upfront MCE plus OCE

The key recommendation from this study is to consider adopting a unified metric for measuring and regulating emissions in the homebuilding sector that combines all three emissions factors into a single metric: Carbon Use Intensity (CUI). The current regulatory framework addresses only energy efficiency and ignores MCE and fuel source emissions. Canada will not be able to assist home builders to truly achieve net-zero carbon while energy efficiency remains the only metric. CUI would be the total of material carbon emissions plus operational carbon emissions, determined by multiplying the anticipated energy use of the home by the emissions intensity of the energy fuel source (figure 15).

The Carbon Use Intensity metric would enable more accurate accounting for GHGs from the homebuilding sector, and would also allow for regionally appropriate ways to reach CUI targets. In those jurisdictions with available clean electricity, the focus for improving CUI would be more weighted to material emissions, while in jurisdictions with emissions-intensive energy sources, CUI reductions could be achieved by addressing material and operational emissions in conjunction. Anywhere in the country, designers and builders could respond to any national, provincial or regional CUI regulations while pursuing a CUI strategy that meets the needs of their clients and the climate with as much flexibility as possible.

A CUI metric would require a time boundary to capture the total material emissions and anticipated operational emissions over a given number of years or decades, such as the 30 year time horizon used in this study (CUI_{30}). A CUI_{30} would begin now and encompass the first three decades of the lifespan of the house.

This study provides some examples of how a CUI metric could drive different types of solutions in different regions of the country. In all examples, the worst CUI results arise from using high carbon materials at tier 3 of the energy code and the best results arise from using the best possible materials at the highest tier of the energy code.

Figure 17 helps to illustrate the impact of different approaches to managing CUI. In the three cities with a relatively low emission grid, there is relatively little downward movement of the lines across the graph, showing that moving the homes along the energy efficiency tiers is not the most effective emission reduction strategy, especially compared to the vertical height difference between the four material models. In the regions with higher grid emissions, it requires a combination of improved efficiency and the best possible materials to even begin approaching low overall carbon emissions.

In Prince Albert, the city with the highest GHGs from grid electricity in this study, the benefits of moving up tiers in the energy code are the clearest. However, making lower-carbon material choices can outweigh the impacts of moving up the energy code tiers. A Best Available Materials (BAM) model at Tier 3 has a better CUI than a High Carbon Materials (HCM) model at Tier 4, and the same applies between Tiers 4 and 5. This implies that a builder in Prince Albert could strategically choose whether to improve material selections or energy efficiency and "tune" a home design to meet a CUI target.

As the energy source emissions are reduced, the flexibility in approach to meeting a CUI target becomes wider. In Halifax, a BAM model at Tier 3 has a similar CUI to a HCM model at Tier 5. Even an MCM model exceeds or nearly matches a HCM model at the next highest tier.

With energy source emissions reduced as low as those in the Toronto area, material selections begin to outweigh the CUI impact of energy code tiers significantly. A MCM model at Tier 3 has three times less CUI than a HCM model at Tier 5.

At Toronto levels of energy source emissions, it becomes possible to achieve a CUI of near-zero at Tier 5 with BAM material selections and to exceed a CUI of zero with BPM materials at Tier 5.

With energy source emissions as low as those in Québec, it becomes possible to achieve a CUI of zero at Tier 3 using BAM materials. Every move down one level in material carbon emissions at Tier 3 outperforms the CUI of higher levels of material carbon emissions at any energy code tier.

These results suggest that a strategic approach could consider the measures most appropriate to the region and the type of intervention, as well as those best suited to intervene. Fuel carbon intensity cannot easily be addressed by builders or homeowners. OCE is dependent on provincial codes and costs. MCE is dependent on material availability and costs. The competencies of the builder to improve efficiency and/or work with new materials is also an important factor.

The adoption of a CUI metric for measuring the climate impact of new housing can result in regionally appropriate solutions to meeting national emissions targets. This would also avoid regulations that force movement on either the energy or material tiers that do not meaningfully contribute to meeting Canada's climate goals.

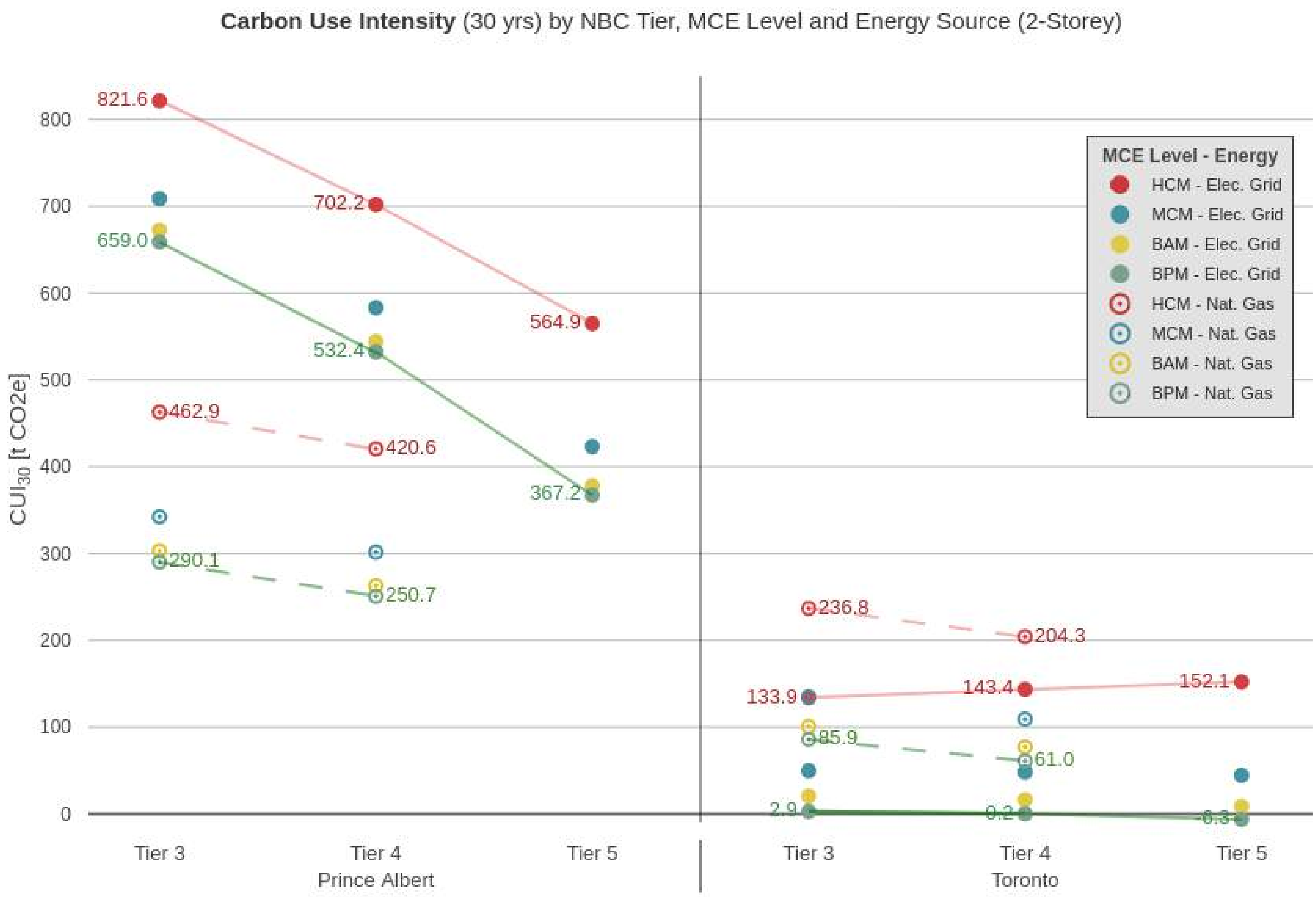


Figure 16 Two- storey home carbon use intensity, 30 year horizon (CUI 30) by NBC Tier, MCE Level and Energy Source (electricity and natural-gas)

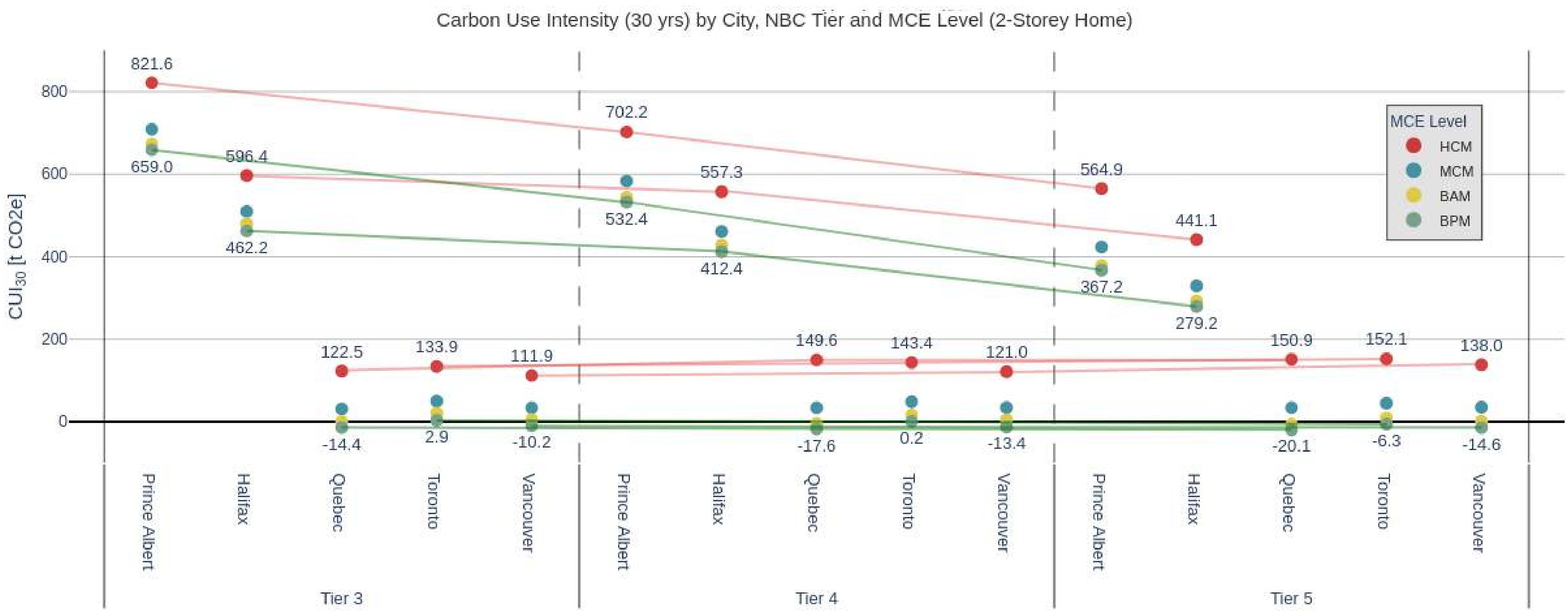


Figure 17 Two-storey home carbon use intensity, 30 year horizon (CUI30) by city, at four MCE material selection models of the NBC tier 3, 4 and 5

The establishment of a CUI metric for new homes is similar to the development of new fuel-efficiency standards for electric vehicles. While litres of fuel per 100 kilometres sufficed for many decades as an appropriate means of measuring fuel efficiency, the new paradigm of zero-emission vehicles required a systemic adjustment. The EnerGuide system was adapted by developing the Le/100km system for hybrid and electric vehicles (Canada E. i., 2019). Such a shift is required for the homebuilding sector to properly address combined material and operational emissions.

The establishment of a CUI metric would require addressing the challenges outlined in section 6, in particular the methodology, tools and training required to align the sector with a new metric. CUI would need to be written into building codes and incentive programs.

CUI would provide a metric that could also benefit Canada's home retrofit strategy, as it would ensure that upgrades to home performance do not result in higher net emissions rather than the intended lower emissions.

The effort to shift to a CUI metric could, despite the challenges, put the sector on the proper footing to meet the country's 2050 climate goals in a way that is more holilstic and offers more flexibility to the unique conditions that exist in every region where homes are built.

Finally, figure 17 shows the potential for the proposed approach, through multiple scenarios in which the CUI30 for a home could be close to net zero emissions, demonstrating a feasible pathway to real net zero emission homes in line with Canada's overall net zero strategy.

References

Adams, M., Burrows, V., & Richardson, S. (2019). Bringing embodied carbon upfront. In worldgbc.org. World Green Building Council. https://www.worldgbc.org/sites/default/files/WorldGBC_Bringing_Embodied_Carbon_Upfront.pdf

Agency, I. E., & Programme, U. N. E. (2018). 2018 Global Status Report: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector. In wedocs.unep.org. International Energy Agency ; United Nations Environment Programme. https://wedocs.unep.org/20.500.11822/27140

Breton, C., Blanchet, P., Amor, B., Beauregard, R., & Chang, W.-S. (2018). Assessing the Climate Change Impacts of Biogenic Carbon in Buildings: A Critical Review of Two Main Dynamic Approaches. Sustainability, 10(6), 2020. https://doi.org/10.3390/su10062020

Canada Mortgage and Housing Corporation (CMHC). (2021, May 26). Canada greener homes. CMHC SCHL. https://www.cmhc-schl.gc.ca/en/professionals/project-funding-and-mortgage-financing/funding-programs/all-funding-programs/canada-greener-homes

Canada, E. and C. C. (2021, July 12). Government of Canada confirms ambitious new greenhouse gas emissions reduction target. www.canada.ca. https://www.canada.ca/en/environment-climate-change/news/2021/07/government-of-canada-confirms-ambitious-new-greenhouse-gas-emissions-reduction-target.html

Canada, N. R. (2018a, March 6). energy-code-your-province-territory. Www.nrcan.gc.ca. https://www.nrcan.gc.ca/energy-efficiency/energy-efficiency-buildings/energy-efficiency-new-buildings/canadas-national-energy-code/energy-code-your-province-territory/20677

Canada, N. R. (2018b, April 30). energuide-vehicles. www.nrcan.gc.ca. https://www.nrcan.gc.ca/energy-efficiency/energuide-canada/energuide-vehicles/21010

Costa, P., Salmi, J., Simula, M., & Wilson, C. (1999). FINANCIAL MECHANISMS FOR SUSTAINABLE FORESTRY. http://blogs.ubc.ca/apfnet04/files/2015/08/SUFES_05_Module-III_Financing-Mechanism-for-sustainable-Forestry.pdf

Environment and Climate Change Canada. (2016). Solid waste diversion and disposal - Canada.ca. Canada.ca. https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/solid-waste-diversion-disposal.html

Environment and Climate Change Canada. (2020, December 11). A Healthy Environment and a Healthy Economy. ; Government of Canada. https://www.canada.ca/en/environment-climate-change/news/2020/12/a-healthy-environment-and-a-healthy-economy.html

Evans, I. (2019, February 12). Selling nutrients: the last straw. Grainews. https://www.grainews.ca/columns/selling-nutrients-the-last-straw/

Global alliance for buildings and construction, IEA, & UNEP 2020. (2020). GRoadmap for Buildings and Construction 2020-2050. IEA. https://iea.blob.core.windows.net/assets/6cca78af-2327-4e97-868c-294d48cb66b3/GlobalABC_Roadmap_for_Buildings_and_Construction_2020-2050.pdf

Government of Canada, S. C. (2020, August 31). Estimated areas, yield, production, average farm price and total farm value of principal field crops, in metric and imperial units. www150.Statcan.gc.ca. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210035901

Israël, B., & Flanagan, E. (2016). Out with the coal, in with the new National benefits of an accelerated phase-out of coal-fired power. In Pembina Institute. https://www.pembina.org/reports/out-with-the-coal-in-with-the-new.pdf

Lockhart, K. (2020, February 4). An innovation approach to building codes. What You Need to Know about the New Building Codes; Efficiency Canada. https://www.efficiencycanada.org/what-you-need-to-know-about-the-new-building-codes/

Magwood, C. (2019). OPPORTUNITIES FOR CARBON DIOXIDE REMOVAL AND STORAGE IN BUILDING MATERIALS. TRENT UNIVERSITY.

Moncaster, A. M., & Symons, K. E. (2013). A method and tool for “cradle to grave” embodied carbon and energy impacts of UK buildings in compliance with the new TC350 standards. Energy and Buildings, 66, 514–523. https://doi.org/10.1016/j.enbuild.2013.07.046

Natural Resources Canada. (2014). AutoSmart-Learn the facts: Fuel consumption and CO 2. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/oee/pdf/transportation/fuel-efficient-technologies/autosmart_factsheet_6_e.pdf

Natural Resources Canada. (2020). Residential end-use model. In Residential Housing Stock and Floor Space. Natural Resources Canada. https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=HB&sector=res&juris=00&rn=11&page=3

O'connor, J. (2004). Presented at Woodframe Housing Durability and Disaster Issues conference. https://www.woodworks.org/wp-content/uploads/2012/02/fpi-survey-actual-service-lives.pdf

Pierobon, F., Huang, M., Simonen, K., & Ganguly, I. (2019). Environmental benefits of using hybrid CLT structure in midrise non-residential construction: An LCA based comparative case study in the U.S. Pacific Northwest. Journal of Building Engineering, 26(), 100862. https://doi.org/10.1016/j.jobe.2019.100862

Rock, M et al. (2020) Embodied GHG emissions of buildings - The hidden challenge for effective climate change mitigation. Applied Energy 258, 114107

Rodriguez, B., & Simonen, K. (2017). Comparison of methodologies for Whole Building Life Cycle Assessment: A Review EXECUTIVE SUMMARY. University of Washington College of Built Environments Department of Architecture. https://www.carbonleadershipforum.org/wp-content/uploads/2018/01/LCA-Method-Comparison_04.06.2017.pdf

Simonen, K., Droguett, B., Strain, L., & McDade, E. (2020). Embodied carbon benchmark study. In *Carbon Leadership Forum*. Carbon Leadership Forum. https://carbonleadershipforum.org/embodied-carbon-benchmark-study-1/

Srubar, W. (n.d.). *Aureus Earth - Building the World's Carbon Solution* (S. Barnes, A. Orens, & M. Grieshaber, Eds.). AureusEarth - Building the World's Carbon Solution. Retrieved July 20, 2021, from https://www.aureusearth.com/

US EPA,OAR,OAP,CPPD. (2019, February 19). *Greenhouse Gas Equivalencies Calculator | US EPA*. US EPA. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Wetzel, B. (2019, March 27). *Breakthrough | Strategic Transportation Solution Provider*. Www.breakthroughfuel.com. https://www.breakthroughfuel.com/blog/carbon-tax-canada-transportation-cost

Appendix-A

NRCan Material Emissions Calculator functions and limitations

Natural Resources Canada | Ressources naturelles Canada | CanmetENERGY | LEEP LOCAL ENERGY EFFICIENCY PARTNERSHIPS

Notes on the use of this calculator:

1 - The results from this calculator are an <u>estimate</u> of the material carbon emissions (MCEs) of your finished construction project. These results can be considered in a similar vein as the results of a basic energy model for a home. Just as a simple energy model is a relatively good predictor of the comparative effectiveness of different efficiency strategies, such a model won't necessarily tell you exactly how much energy the building will eventually use. This calculator should be used to gauge the relative MCEs of different construction approaches to a home or renovation project.

2 - This calculator is not intended to be used as a program or compliance tool. The calculator is intended to provide the homebuilding and renovating industry with knowledge tools to support decisions regarding to the relative MCEs of different construction approaches.

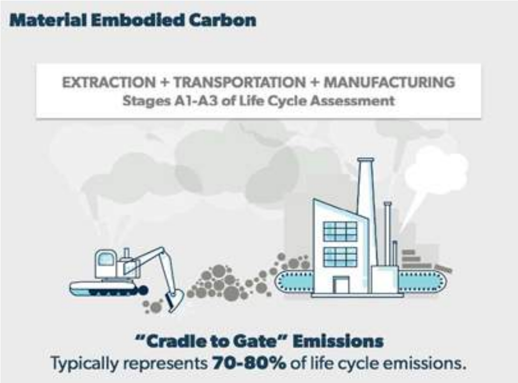
3 - This calculator provides a range of possible material and construction technologies, but does not include every material available. Every effort has been made to include the most relevant information on common materials and systems at the time of publication. Product manufacturers and suppliers whose product data is not included can provide NRCan with relevant EPD and product documentation, and these will be reviewed and included in annual updates (timing TBD).

Overview and Context:

This calculator is designed to compare the greenhouse gas emissions (GHGs) of different building materials for residential construction. The comparative results can help users to make material selections to reduce the carbon footprint of the homes and renovations they are planning.

In conjunction with the annual operational carbon data from HOT2000, users will be able to estimate the upfront MCEs of their projects and plot the total carbon footprint of their home and renovation projects.

This calculator allows users to compare materials on a component-by-component basis, as well by whole assemblies. The majority of a building's mass is represented in the calculator. NRCan has included a wide range of enclosure assemblies and materials, as well as the main cladding, sheathing and finishing materials for residential construction.



This calculator focuses on material carbon emissions (MCEs - often referred to as "embodied carbon") because the high volume of emissions arising directly from the harvesting and production of building materials, represents a key opportunity to drive major emission reductions. Low-rise residential buildings average 150-400 kg of GHGs per square metre of floor area (25-75 tonnes for a 2,000 square foot home). Multiplied across all of the low-rise residential buildings constructed each year in Canada, this produces emissions that are equivalent to approximately 2 coal fired power plants.

Canada recognizes this considerable source of GHGs. This calculator is designed to support the homebuilding and renovation industries in making informed material choices to reduce up-front carbon emission.

By making informed material choices, a building with the same size, function and energy performance can dramatically reduce its MCEs. In fact, it is possible with materials available today to get the MCEs of buildings close to – and even below – zero.

This calculator is intended to open up a dialogue, and allows industry to take a leading role in moving the residential building industry from a driver of climate change, to a leader in carbon drawdown.

Data for calculations:

The data for this calculator comes from published Environmental Product Declarations (EPDs). These documents provide the results of a "life cycle assessment" (LCA) that has been performed and reported according to product category rules (PCRs). EPDs are performed or verified by a third party. EPDs cannot compare materials intended for different uses (ie. dimensional lumber to floor tiles). Even within the same product category, it can be difficult to compare EPD figures because the values expressed for each material may not be directly comparable (ie. kilograms of brick can't be compared to square metres of wood siding). This calculator normalizes all of the values expressed in the source EPDs to ensure that appropriate types of materials are being compared in appropriate quantities (ie. square metres of brick and square metres of wood siding).

NRCan has worked to ensure that all material comparisons are equivalent, using standard product sizes, code norms and best practice to make this an "apples to apples" comparison.

Data source: LCA Study
Data source: ICE Database (UK)
Data source: EPD includes phases A1-A3 and B1 (VOC off-gassing)
Data source: recently expired EPD
Data source: Not from EPD, LCA or database.

Limitations of This Calculator

It is important to note that this calculator has a number of limitations of which you should be aware. Please read this section carefully so that you are fully informed.

There are several factors to keep in mind regarding this calculators' accuracy:
1. All the data is based on publicly available Environmental Product Declarations (EPDs). The calculations used to create an EPD can be compared to calculating the fuel mileage for a car or truck. A series of assumptions and generic data are used to predict the carbon footprint of a material. The rules for making EPDs ensure that these assumptions are similar for all products in a particular category, but this does not necessarily guarantee that the actual figure is a perfect representation of the actual emissions from manufacturing the material.
A range of uncertainty from 5-25% is typical in EPDs.

2. Calculations may not reflect your practices.

In order to make the calculator simple to use and to minimize the number of inputs, numerous assumptions have been made in the calculations for material quantities. To the best of our ability we have chosen factors that are well-established industry norms, but these norms may not reflect the actual design or execution of your building.

While the quantities of materials we estimate in the calculator are unlikely to be a perfect match to your actual material use, the quantities are consistent between all the options we present. This means that the comparison of emissions between materials is accurate. For example, you may use more or less framing material than we have estimated for your project but the relative difference between the framing options as depicted by the calculator will be accurate.

3. No waste factor for materials is included.

Every construction project generates offcuts and waste. None of our calculations assume any waste factors due to the wide variation in on-site practices.

If you would like your total emissions to reflect waste factors, you can add an appropriate percentage to each material category using the percentage function in Column F.

4. We have not included data for all of the components in a building.
There are many materials that will go into your building that are not included here:
Mechanical, electrical and plumbing (MEP) systems and components
Damp-proofing, air/vapour barriers and membranes
Flashing, sealants, adhesives
Fasteners
Appliances and fixtures
Millwork, cabinetry and stairs
Paints, stains and surface finishes

There is currently limited data available in some of these categories and/or the quantities of materials and emissions would be quite similar (ie. toilets and washing machines don't have much variation for comparison according to the available data).

The total of all these missing elements could be quite sizable, so it shouldn't be assumed that the results from this calculator accurately reflect the entire carbon footprint of the building. Even a carbon-banking result may actually be a net emitter if all of these materials were included in the total.
NRCan will consider updating the calculator as EPDs in these categories become available.

5. We have only included data for "cradle-to-gate" (A1-A3) emissions, not transportation to site, product use emissions/off-gassing or job site emissions.
Getting building materials from the factory to the job site can add a significant quantity of emissions to the overall project. Typically, transportation to the construction site adds 5-10% to the total material emissions. We encourage you to understand your supply chains and to attempt to do your own transportation emission calculations. The emissions from a construction site are likewise difficult to estimate, but average between 5-10% of the total materials emissions, and will depend on emissions factors associated with the energy source on the job site (electricity grid versus diesel generator)
It should be noted that job site emissions (A5) have been included in MCE calculations for those materials that have a necessary, sizable and very predictable volume of emissions created on site. Examples include emissions from site-mixed foam insulation and from concrete poured into insulated concrete forms. These types of emissions are included in A5 in many EPDs but are more related to the static emission profile of the product than to construction site specific activity.

6. No end of life emissions calculated
There are emission impacts at the end of life for a building component or a whole building. We have excluded end of life estimates for a few reasons:
We have based our calculations on a time window of 30 years. While we acknowledge that there will be emissions released when these materials reach the end of their service life, we are focusing on immediate emissions.
All the materials included in this calculator have a lifespan of at least 30 years (with the exception of asphalt shingle roofing, for which we doubled the emissions figure to cover replacement). End of life for buildings and materials is hard to predict.
The actual service life of a material or whole building is rarely the cause for replacement or demolition; instead factors like property value, aesthetics and planning issues tend to bring about the demise of materials and buildings, not the expected service life.

7. No costing information.
No attempt has been made to include material costs as a comparative factor in this calculator. Builders should use their own costing information to understand the impact of alternative materials in their own projects.

Appendix-B

Embodied Carbon Emission material selections – four models

High carbon material selection (HCM)

SECTION	CATEGORY	MATERIAL
Footings & Slabs	CRUSHED STONE BASE	Aggregate / / / Avg construction aggregate (gravel & sand)
Footings & Slabs	FOOTINGS & PADS	Concrete - 0-25 MPa, 0-14% FA/SL, GU / CRMCA / Can. Avg. /
Footings & Slabs	REBAR	Rebar / Concrete Reinforcing Steel Institute / / 10M
Footings & Slabs	SLAB FLOOR(S)	Concrete - 0-25 MPa, 0-14% FA/SL, GU / CRMCA / Can. Avg. /
Footings & Slabs	SUB-SLAB INSULATION	XPS foam board / Owens Corning / Foamular 250 / R 5/inch
Footings & Slabs	BASEMENT FLOORING	Linoleum flooring - AVERAGE 2.5 mm
Footings & Slabs	BASEMENT FLOORING	Laminate flooring / Novalis / LVT /
Foundation Walls	CONCRETE FOUNDATION WALLS	Concrete - 0-25 MPa, 0-14% FA/SL, GU / CRMCA / Can. Avg. /
Foundation Walls	FOUNDATION WALL CONTINUOUS INSULATION	XPS foam board / Owens Corning / Foamular 250 / R 5/inch
Foundation Walls	INTERIOR FOUNDATION WALL FRAMING - STEEL	Steel Framing - AVERAGE
Foundation Walls	FOUNDATION WALL INSULATION	Aerogel blanket / Aspen Aerogels / / R9.6/inch, White/Grey blanket
Foundation Walls	INTERIOR FOUNDATION WALL CLADDING	Drywall 1/2" - AVERAGE
Structural Elements	HEAVY STEEL COMPONENTS	Steel beam / W250x25 (W10x17) / American Institute of Steel Construction
Structural Elements	HEAVY STEEL COMPONENTS	Steel post / Generic / / 3.5 x 0.216" (89 x 5.5 mm), Sched 40 STD
Ext. Walls	WOOD FRAME WALLS	Wood framing & siding - SPF / American Wood Council & Canadian Wood Council / /
Ext. Walls	STRUCTURAL SHEATHING	OSB sheathing / American Wood Council & Canadian Wood Council / / 1/2"
Ext. Walls	CAVITY INSULATION	Spray polyurethane foam - Closed Cell (HFC) / SPFA / / R 6.6/inch
Ext. Walls	CONTINUOUS INSULATION (EXT. or INT.)	XPS foam board / Owens Corning / Foamular 250 / R 5/inch
Cladding	EXTERIOR CLADDING	Brick, Clay, Generic Modular / Brick Industry Association / US-Canada Industry Average / 3-5/8" x 2-3/4" x 7-5/8" incl. 3/8" mortar
Cladding	INTERIOR CLADDING for EXTERIOR WALLS	Drywall 1/2" Typical - Interior Cladding for Exterior Walls - AVERAGE
Windows	DOUBLE PANE WINDOWS - GENERIC	Window - double pane / Fiberglass frame / / USA & CAN
Int. Walls	INTERIOR WALL FRAMING	Steel Framing - Interior Walls - AVERAGE
Int. Walls	INTERIOR WALL CLADDING	MgO board 1/2" / North American MgO / MagTech Ultra / 1/2"
Floors	WOOD FLOOR FRAMING	Wood framing & siding - SPF / American Wood Council & Canadian Wood Council / /
Floors	SUBFLOORING	OSB sheathing / American Wood Council & Canadian Wood Council / / 5/8"
Floors	FINISHED FLOORING	Ceramic tile flooring - AVERAGE
Floors	FINISHED FLOORING	Laminate flooring / Novalis / LVT /
Floors	FINISHED FLOORING	Carpet / / / Average from 150 samples in the EC3 database
Ceilings	CLADDING	MgO board 1/2" / North American MgO / MagTech Ultra / 1/2"
Roof	WOOD FRAME ROOF	Wood roof truss - prefabricated / Quebec Wood Export Bureau / Common (Double Howe) Gabrel Roof / 2x6 Chords, 2x4 Webs, 4:12 Pitch, 40 ft span, 20" overhang
Roof	ROOF DECKING	OSB sheathing / American Wood Council & Canadian Wood Council / / 5/8"
Roof	ROOFING	Aluminum I Panels - Roofing - AVERAGE
Roof	ROOF INSULATION	Spray polyurethane foam - Closed Cell (HFC) / SPFA / / R 6.6/inch
Garage	GARAGE CRUSHED STONE BASE	Aggregate / / / Avg construction aggregate (gravel & sand)
Garage	GARAGE SLAB FLOOR	Concrete - 0-25 MPa, 0-14% FA/SL, GU / CRMCA / Can. Avg. /
Garage	GARAGE REBAR	Rebar / Concrete Reinforcing Steel Institute / / 10M
Garage	GARAGE WOOD FRAME WALLS	Wood framing & siding - SPF / American Wood Council & Canadian Wood Council / /
Garage	GARAGE WALL SHEATHING	OSB sheathing / American Wood Council & Canadian Wood Council / / 1/2"
Garage	GARAGE ATTACHMENT WALL INSULATION	Spray polyurethane foam - Closed Cell (HFC) / SPFA / / R 6.6/inch
Garage	GARAGE EXTERIOR CLADDING	Brick, Clay, Generic Modular / Brick Industry Association / US-Canada Industry Average / 3-5/8" x 2-3/4" x 7-5/8" incl. 3/8" mortar
Garage	GARAGE CEILING CLADDING	MgO board 1/2" / North American MgO / MagTech Ultra / 1/2"
Garage	GARAGE WOOD ROOF FRAMING	Wood roof truss - prefabricated / Quebec Wood Export Bureau / Common (Double Howe) Gabrel Roof / 2x6 Chords, 2x4 Webs, 4:12 Pitch, 40 ft span, 20" overhang
Garage	GARAGE ROOF DECKING	OSB sheathing / American Wood Council & Canadian Wood Council / / 5/8"
Garage	GARAGE ROOFING	Aluminum I Panels - Roofing - AVERAGE

Moderate Carbon Material (MCM) Selection

SECTION	CATEGORY	MATERIAL
Footings & Slabs	CRUSHED STONE BASE	Aggregate / / / Avg construction aggregate (gravel & sand)
Footings & Slabs	FOOTINGS & PADS	Concrete - 0-25 MPa, 30-40% Fly Ash, GU / CRMCA / Can. Avg. /
Footings & Slabs	REBAR	Rebar / Concrete Reinforcing Steel Institute / / 10M
Footings & Slabs	SLAB FLOOR(S)	Concrete - 0-25 MPa, 30-40% Fly Ash, GU / CRMCA / Can. Avg. /
Footings & Slabs	SUB-SLAB INSULATION	Mineral wool board - heavy density / NAIMA / R 4.2/inch
Footings & Slabs	BASEMENT FLOORING	Vinyl flooring - AVERAGE
Foundation Walls	FOUNDATION WALL ICF - EPS FOAM	EPS FOAM ICF R-23, 2 Sheets of 2.75" @ R4/in., 15M rebar (6" CONCRETE CORE must be added separately)
Foundation Walls	FOUNDATION WALL ICF - EPS FOAM	Concrete - 0-25 MPa, 30-40% Fly Ash, GU / CRMCA / Can. Avg. /
Foundation Walls	INTERIOR FOUNDATION WALL CLADDING	Drywall 1/2" - AVERAGE
Structural Elements	HEAVY STEEL COMPONENTS	Steel beam / W250x25 (W10x17) / American Institute of Steel Construction
Structural Elements	HEAVY STEEL COMPONENTS	Steel post / Generic / / 3.5 x 0.216" (89 x 5.5 mm), Sched 40 STD
Ext. Walls	WOOD FRAME WALLS	Wood framing & siding - SPF / American Wood Council & Canadian Wood Council / /
Ext. Walls	STRUCTURAL SHEATHING	OSB sheathing / American Wood Council & Canadian Wood Council / / 1/2"
Ext. Walls	CAVITY INSULATION	Mineral wool batt / Rockwool / Safe'n'Sound, ComfortBatt / R 3.8/inch
Ext. Walls	CONTINUOUS INSULATION (EXT. or INT.)	Mineral wool board - AVERAGE
Cladding	EXTERIOR CLADDING	Fiber Cement siding - AVERAGE
Cladding	INTERIOR CLADDING for EXTERIOR WALLS	Drywall 1/2" Typical - Interior Cladding for Exterior Walls - AVERAGE
Windows	DOUBLE PANE WINDOWS - GENERIC	Window - double pane / Vinyl frame / / USA & CAN
Int. Walls	INTERIOR WALL FRAMING	Wood framing & siding - SPF / American Wood Council & Canadian Wood Council / /
Int. Walls	INTERIOR WALL CLADDING	Drywall 1/2" Typical - Interior Walls - AVERAGE
Floors	WOOD FLOOR FRAMING	Wood I joist / American Wood Council & Canadian Wood Council / / TJI 230/360
Floors	SUBFLOORING	OSB sheathing / American Wood Council & Canadian Wood Council / / 5/8"
Floors	FINISHED FLOORING	Vinyl flooring - AVERAGE
Ceilings	CLADDING	Drywall 1/2" - Ceilings - AVERAGE
Roof	WOOD FRAME ROOF	Wood roof truss - prefabricated / Quebec Wood Export Bureau / Common (Double Howe) Gabrel Roof / 2x6 Chords, 2x4 Webs, 4:12 Pitch, 40 ft span, 20" overhang
Roof	ROOF DECKING	OSB sheathing / American Wood Council & Canadian Wood Council / / 5/8"
Roof	ROOFING	Asphalt Shingles - Roofing - AVERAGE
Roof	ROOF INSULATION	Mineral wool loose fill / NAIMA / R 3/inch
Garage	GARAGE WOOD FRAME WALLS	Wood framing & siding - SPF / American Wood Council & Canadian Wood Council / /
Garage	GARAGE WALL SHEATHING	OSB sheathing / American Wood Council & Canadian Wood Council / / 1/2"
Garage	GARAGE EXTERIOR CLADDING	Fiber Cement siding - AVERAGE
Garage	GARAGE CEILING CLADDING	Drywall 1/2" - Ceilings - AVERAGE
Garage	GARAGE WOOD ROOF FRAMING	Wood roof truss - prefabricated / Quebec Wood Export Bureau / Common (Double Howe) Gabrel Roof / 2x6 Chords, 2x4 Webs, 4:12 Pitch, 40 ft span, 20" overhang
Garage	GARAGE ROOF DECKING	OSB sheathing / American Wood Council & Canadian Wood Council / / 5/8"
Garage	GARAGE ROOFING	Asphalt Shingles - Roofing - AVERAGE

Best available carbon material selection (BAM)

SECTION	CATEGORY	MATERIAL
Footings & Slabs	CRUSHED STONE BASE	Aggregate / Vulcan Mtls Co. / / Avg construction aggregate (gravel & sand)
Footings & Slabs	FOOTINGS & PADS	Concrete - 0-25 MPa, 35-50% Slag, GU / CRMCA / Can. Avg. /
Footings & Slabs	REBAR	Rebar / Concrete Reinforcing Steel Institute / / 10M
Footings & Slabs	SLAB FLOOR(S)	Concrete - 0-25 MPa, 35-50% Slag, GU / CRMCA / Can. Avg. /
Footings & Slabs	SUB-SLAB INSULATION	EPS foam board / EPS Industry Alliance / / R 4.6/inch, Type IX, 25 psi (Type 3, 140 kPa)
Footings & Slabs	BASEMENT FLOORING	Linoleum flooring - AVERAGE 2.5 mm
Footings & Slabs	BASEMENT FLOORING	Cork flooring / European Resilient Flooring Manufacturers' Institute / Includes: Altro, Amorim, Amtico, Artigo, Aspecta, BeauFlor, Dickson, Mflor, Forbo, Gerflor, IVC, Nora, Polyflor, Tarkett, Kahrs, Windmoller / Cork floor tiles
Foundation Walls	TREATED WOOD FOUNDATION	TREATED WOOD FOUNDATION - 2x8 framing @ 16" OC, 3/4" plywood sheathing
Foundation Walls	FOUNDATION WALL CONTINUOUS INSULATION	Wood fiber board - AVERAGE
Foundation Walls	FOUNDATION WALL INSULATION	Cellulose - Foundation Wall Insulation - AVERAGE
Foundation Walls	INTERIOR FOUNDATION WALL CLADDING	Drywall 1/2" - AVERAGE
Foundation Walls	INTERIOR FOUNDATION WALL CLADDING	Wood framing & siding - SPF / American Wood Council & Canadian Wood Council / /
Ext. Walls	WOOD FRAME WALLS	Wood framing & siding - SPF / American Wood Council & Canadian Wood Council / /
Ext. Walls	CAVITY INSULATION	Cellulose - AVERAGE
Ext. Walls	CONTINUOUS INSULATION (EXT. or INT.)	Wood fiber board - AVERAGE
Cladding	EXTERIOR CLADDING	Wood framing & siding - SPF / American Wood Council & Canadian Wood Council / /
Cladding	STRAPPING for RAIN SCREEN	Wood framing & siding - SPF / American Wood Council & Canadian Wood Council / /
Cladding	INTERIOR CLADDING for EXTERIOR WALLS	Drywall 1/2" Typical - Interior Cladding for Exterior Walls - AVERAGE
Cladding	INTERIOR CLADDING for EXTERIOR WALLS	Wood framing & siding - SPF / American Wood Council & Canadian Wood Council / /
Windows	DOUBLE PANE WINDOWS - GENERIC	Window - double pane / Wood frame / / USA & CAN
Int. Walls	INTERIOR WALL FRAMING	Wood framing & siding - SPF / American Wood Council & Canadian Wood Council / /
Int. Walls	INTERIOR WALL CLADDING	Drywall 1/2" Typical - Interior Walls - AVERAGE
Int. Walls	INTERIOR WALL CLADDING	Wood framing & siding - SPF / American Wood Council & Canadian Wood Council / /
Floors	WOOD FLOOR FRAMING	Wood I joist / American Wood Council & Canadian Wood Council / / TJI 230/360
Floors	SUBFLOORING	Plywood / American Wood Council & Canadian Wood Council / / 1/2"
Floors	FINISHED FLOORING	Linoleum flooring - AVERAGE
Floors	FINISHED FLOORING	Cork flooring / European Resilient Flooring Manufacturers' Institute / Includes: Altro, Amorim, Amtico, Artigo, Aspecta, BeauFlor, Dickson, Mflor, Forbo, Gerflor, IVC, Nora, Polyflor, Tarkett, Kahrs, Windmoller / Cork floor tiles
Ceilings	CLADDING	Drywall 1/2" - Ceilings - AVERAGE
Ceilings	CLADDING	Wood framing & siding - SPF / American Wood Council & Canadian Wood Council / /
Roof	WOOD FRAME ROOF	Wood roof truss - prefabricated / Quebec Wood Export Bureau / Common (Double Howe) Gabrel Roof / 2x6 Chords, 2x4 Webs, 4:12 Pitch, 40 ft span, 20" overhang
Roof	ROOF STRAPPING	Wood framing & siding - SPF / American Wood Council & Canadian Wood Council / /
Roof	ROOFING	Clay roof tiles / HISPALYT / /
Roof	ROOF INSULATION	Cellulose - Roof Insulation - AVERAGE
Garage	GARAGE WOOD FRAME WALLS	Wood framing & siding - SPF / American Wood Council & Canadian Wood Council / /
Garage	GARAGE EXTERIOR CLADDING	Wood framing & siding - SPF / American Wood Council & Canadian Wood Council / /
Garage	GARAGE STRAPPING for RAIN SCREEN	Wood framing & siding - SPF / American Wood Council & Canadian Wood Council / /
Garage	GARAGE CEILING CLADDING	Drywall 1/2" - Ceilings - AVERAGE
Garage	GARAGE WOOD ROOF FRAMING	Wood roof truss - prefabricated / Quebec Wood Export Bureau / Common (Double Howe) Gabrel Roof / 2x6 Chords, 2x4 Webs, 4:12 Pitch, 40 ft span, 20" overhang
Garage	GARAGE ROOF STRAPPING	Wood framing & siding - SPF / American Wood Council & Canadian Wood Council / /
Garage	GARAGE ROOFING	Clay roof tiles / HISPALYT / /

Best Possible Material (BPM) Selection

SECTION	CATEGORY	MATERIAL
Footings & Slabs	FOOTINGS & PADS	Concrete - 0-25 MPa, 35-50% Slag, GU / CRMCA / Can. Avg. /
Footings & Slabs	REBAR	Rebar / Concrete Reinforcing Steel Institute / / 10M
Footings & Slabs	SUB-SLAB INSULATION	Foam glass aggregate - AVERAGE
Footings & Slabs	BASEMENT FLOORING	Linoleum flooring / Gerflor / DLW Linoleum / 4.0 mm sheet style linoleum
Footings & Slabs	BASEMENT FLOORING	Cork flooring / European Resilient Flooring Manufacturers' Institute / Includes: Altro, Amorim, Amtico, Artigo, Aspecta, BeauFlor, Dickson, Mflor, Forbo, Gerflor, IVC, Nora, Polyflor, Tarkett, Kahrs, Windmoller / Cork floor tiles
Foundation Walls	TREATED WOOD FOUNDATION	TREATED WOOD FOUNDATION - 2x8 framing @ 16" OC, 3/4" plywood sheathing
Foundation Walls	FOUNDATION WALL INSULATION	Hempcrete - Foundation Wall Insulation - AVERAGE
Foundation Walls	INTERIOR FOUNDATION WALL CLADDING	Clay plaster / Site mixed / / 15 mm
Ext. Wall Systems	PREFABRICATED PANELS	WOOD FRAME with STRAW BALE INFILL - 14" R-46, Double 2x4 @ 30" o/c
Cladding	EXTERIOR CLADDING	Wood framing & siding - SPF / American Wood Council & Canadian Wood Council / /
Cladding	STRAPPING for RAIN SCREEN	Wood framing & siding - SPF / American Wood Council & Canadian Wood Council / /
Cladding	INTERIOR CLADDING for EXTERIOR WALLS	Wood wool boards / Armstrong / Tectum / 2" (50.8 mm)
Cladding	INTERIOR CLADDING for EXTERIOR WALLS	Clay plaster / Site mixed / / 15 mm
Windows	DOUBLE PANE WINDOWS - GENERIC	Window - double pane / Wood frame, aluminum cladding / / EU
Int. Walls	INTERIOR WALL FRAMING	Wood framing & siding - SPF / American Wood Council & Canadian Wood Council / /
Int. Walls	INTERIOR WALL CLADDING	Wood wool boards / Armstrong / Tectum / 2" (50.8 mm)
Int. Walls	INTERIOR WALL CLADDING	Clay plaster / Site mixed / / 15 mm
Floors	WOOD FLOOR FRAMING	Wood I joist / American Wood Council & Canadian Wood Council / / TJI 230/360
Floors	SUBFLOORING	Wood framing & siding - SPF / American Wood Council & Canadian Wood Council / /
Floors	FINISHED FLOORING	Linoleum flooring / Gerflor / DLW Linoleum / 4.0 mm sheet style linoleum
Floors	FINISHED FLOORING	Cork flooring / European Resilient Flooring Manufacturers' Institute / Includes: Altro, Amorim, Amtico, Artigo, Aspecta, BeauFlor, Dickson, Mflor, Forbo, Gerflor, IVC, Nora, Polyflor, Tarkett, Kahrs, Windmoller / Cork floor tiles
Ceilings	CLADDING	Wood wool boards / Armstrong / Tectum / 2" (50.8 mm)
Roof	WOOD FRAME ROOF	Wood roof truss - prefabricated / Quebec Wood Export Bureau / Common (Double Howe) Gabrel Roof / 2x6 Chords, 2x4 Webs, 4:12 Pitch, 40 ft span, 20" overhang
Roof	ROOF STRAPPING	Wood framing & siding - SPF / American Wood Council & Canadian Wood Council / /
Roof	ROOFING	Clay roof tiles / HISPALYT / /
Roof	ROOF INSULATION	Straw Bale / / Wheat & rye straw / R 3.3/inch
Garage	GARAGE WOOD FRAME WALLS	Wood framing & siding - SPF / American Wood Council & Canadian Wood Council / /
Garage	GARAGE WALL SHEATHING	OSB sheathing / American Wood Council & Canadian Wood Council / / 1/2"
Garage	GARAGE EXTERIOR CLADDING	Clay plaster / Site mixed / / 15 mm
Garage	GARAGE STRAPPING for RAIN SCREEN	Wood framing & siding - SPF / American Wood Council & Canadian Wood Council / /
Garage	GARAGE CEILING CLADDING	Wood wool boards / Armstrong / Tectum / 2" (50.8 mm)
Garage	GARAGE WOOD ROOF FRAMING	Wood roof truss - prefabricated / Quebec Wood Export Bureau / Common (Double Howe) Gabrel Roof / 2x6 Chords, 2x4 Webs, 4:12 Pitch, 40 ft span, 20" overhang
Garage	GARAGE ROOF STRAPPING	Wood framing & siding - SPF / American Wood Council & Canadian Wood Council / /
Garage	GARAGE ROOFING	Clay roof tiles / HISPALYT / /

Appendix-C

NRCan Archetype Building Code Tier Specifications

CBAT Archetype

Small Bungalow - Electric Baseboards w/ Electric DHW

HDD	2825	3520	4000	5080	6100
	Vancouver	**Toronto**	**Halifax**	**QC**	**Prince Albert**
Tier 1	HRV 65% SRE ACH 2.5 Main Wall: 2.78 Foundation Wall: 2.98 Ceiling: 4.96 DHW Tank SL : 77w - 12000w Windows U: 1.8 / SHGC 0.26	HRV 65% SRE ACH 2.5 Main Wall: 2.78 Foundation Wall: 2.98 Ceiling: 8.56 DHW Tank SL : 77w - 12000w Windows U: 1.8 / SHGC 0.26	HRV 65% SRE ACH 2.5 Main Wall: 2.78 Foundation Wall: 2.98 Ceiling: 8.56 DHW Tank SL : 77w - 12000w Windows U: 1.8 / SHGC 0.26	HRV 65% SRE ACH 2.5 Main Wall: 2.97 Foundation Wall: 2.98 Ceiling: 8.56 DHW Tank SL : 77w - 12000w Windows U: 1.8 / SHGC 0.26	HRV 65% SRE ACH 2.5 Main Wall: 4.40 Foundation Wall: 2.98 Ceiling: 8.56 DHW Tank SL : 77w - 12000w Windows U: 1.8 / SHGC 0.26
Tier 3	HRV 65% SRE ACH 2.5 Main Wall: 2.97 Foundation Wall: 2.98 Ceiling: 4.96 DHW Tank SL : 77w - 12000w Windows U: 1.8 / SHGC 0.26 ASHP HSPF: 7.1	HRV 65% SRE ACH 2.5 Main Wall: 2.97 Foundation Wall: 2.98 Ceiling: 8.56 DHW Tank SL : 77w - 12000w Windows U: 1.8 / SHGC 0.26 ASHP HSPF: 7.1	HRV 65% SRE ACH 2.5 Main Wall: 3.85 Foundation Wall: 2.98 Ceiling: 8.56 DHW Tank SL : 77w - 12000w Windows U: 1.8 / SHGC 0.26 ASHP HSPF: 7.1	HRV 65% SRE ACH 2.5 Main Wall: 3.85 Foundation Wall: 2.98 Ceiling: 8.56 DHW Tank SL : 77w - 12000w Windows U: 1.8 / SHGC 0.26 ASHP HSPF: 7.1	HRV 65% SRE ACH 2.5 Main Wall: 5.45 Foundation Wall: 3.97 Ceiling: 8.56 DHW Tank SL : 77w - 12000w Windows U: 1.8 / SHGC 0.26 ASHP HSPF: 7.1
Tier 4	HRV 78% SRE ACH 2.5 Main Wall: 3.08 Foundation Wall: 2.98 Ceiling: 8.56 Windows: 1.44U / SHGC 0.26 ASHP HSPF: 7.1 DHW Tank SL : 77w - 12000w	HRV 78% SRE ACH 2.5 Main Wall: 3.85 Foundation Wall: 2.98 Ceiling: 8.56 Windows: 1.44U / SHGC 0.26 ASHP HSPF: 7.1 DHW Tank SL : 77w - 12000w	HRV 78% SRE ACH 2.5 Main Wall: 4.73 Foundation Wall: 2.98 Ceiling: 8.56 Windows: 1.44U / SHGC 0.26 ASHP HSPF: 7.1 DHW Tank SL : 77w - 12000w	HRV 78% SRE ACH 2.5 Main Wall: 4.73 Foundation Wall: 2.98 Ceiling: 10.83 Windows: 1.44U / SHGC 0.26 ASHP HSPF: 7.1 DHW Tank SL : 77w - 12000w	HRV 78% SRE ACH 2.5 Main Wall: 5.45 Foundation Wall: 3.97 Ceiling: 10.83 Windows: 1.22U / SHGC 0.26 ASHP HSPF: 10.6 ES DHW Tank SL : 77w - 12000w
Tier 5	HRV 78% SRE ACH 0.6 Main Wall: 3.85 Foundation Wall: 2.98 Ceiling: 10.83 Windows: 0.85U / SHGC 0.26 DHW HP COP: 2.6 ASHP HSPF: 10.6 ES	HRV 78% SRE ACH 0.6 Main Wall: 4.73 Foundation Wall: 2.98 Ceiling: 10.83 Windows: 0.85U / SHGC 0.26 DHW HP COP: 2.6 ASHP HSPF: 10.6 ES	HRV 78% SRE ACH 0.6 Main Wall: 5.45 Foundation Wall: 3.97 Ceiling: 10.83 Windows: 0.85U / SHGC 0.26 DHW HP COP: 2.6 ASHP HSPF: 10.6 ES	HRV 78% SRE ACH 0.6 Main Wall: 5.45 Foundation Wall: 3.97 Ceiling: 10.83 Windows: 0.85U / SHGC 0.26 DHW HP COP: 2.6 ASHP HSPF: 10.6 ES	HRV 78% SRE ACH 0.6 Main Wall: 7.00 Foundation Wall: 3.97 Ceiling: 10.83 Windows: 0.85U / SHGC 0.26 DHW HP COP: 2.6 ASHP HSPF: 10.6 ES

Table 3 NBC Energy Performance Tiers

		Applicable Energy Performance Tier				
Volume V_T	Target Metrics	1	2	3	4	5
> 300 m³ and where volume is not determined	Percent Heat Loss Reduction	n/a	≥ 5%	≥ 10%	≥ 20%	≥ 40%
	Percent Improvement	≥ 0%	≥ 10%	≥ 20%	≥ 40%	≥ 70%
≤ 300 m³	Percent Heat Loss Reduction	n/a	≥ 0%	≥ 5%	≥ 15%	≥ 25%
	Percent Improvement	≥ 0%	≥ 0%	≥ 10%	≥ 30%	≥ 60%

CBAT Archetype

2 Storey Atlantic - Electric Baseboards w/ Electric DHW

HDD	2825	3520	4000	5080	6100
	Vancouver	**Toronto**	**Halifax**	**QC**	**Prince Albert**
Tier 1	HRV 65% SRE ACH 2.5 Main Wall: 3.08 Foundation Wall: 2.98 Ceiling: 4.99 DHW Tank SL : 77w - 12000w Windows U: 1.8 / SHGC 0.25	HRV 65% SRE ACH 2.5 Main Wall: 3.85 Foundation Wall: 2.98 Ceiling: 4.99 DHW Tank SL : 77w - 12000w Windows U: 1.8 / SHGC 0.25	HRV 65% SRE ACH 2.5 Main Wall: 3.85 Foundation Wall: 2.98 Ceiling: 9.09 DHW Tank SL : 77w - 12000w Windows U: 1.8 / SHGC 0.25	HRV 65% SRE ACH 2.5 Main Wall: 3.85 Foundation Wall: 2.98 Ceiling: 9.09 DHW Tank SL : 77w - 12000w Windows U: 1.8 / SHGC 0.25	HRV 65% SRE ACH 2.5 Main Wall: 4.40 Foundation Wall: 2.98 Ceiling: 9.09 DHW Tank SL : 77w - 12000w Windows U: 1.61 / SHGC 0.25
Tier 3	HRV 65% SRE ACH 2.5 Main Wall: 2.78 Foundation Wall: 2.98 Ceiling: 4.99 DHW Tank SL : 77w - 12000w Windows U: 1.8 / SHGC 0.25 ASHP HSPF: 7.1	HRV 65% SRE ACH 2.5 Main Wall: 2.97 Foundation Wall: 2.98 Ceiling: 9.09 DHW Tank SL : 77w - 12000w Windows U: 1.8 / SHGC 0.25 ASHP HSPF: 7.1	HRV 65% SRE ACH 2.5 Main Wall: 3.08 Foundation Wall: 2.98 Ceiling: 9.09 DHW Tank SL : 77w - 12000w Windows U: 1.8 / SHGC 0.25 ASHP HSPF: 7.1	HRV 65% SRE ACH 2.5 Main Wall: 3.85 Foundation Wall: 2.98 Ceiling: 4.99 DHW Tank SL : 77w - 12000w Windows U: 1.8 / SHGC 0.25 ASHP HSPF: 7.1	HRV 65% SRE ACH 2.5 Main Wall: 4.73 Foundation Wall: 3.97 Ceiling: 9.09 DHW Tank SL : 77w - 12000w Windows U: 1.61 / SHGC 0.25 ASHP HSPF: 7.1
Tier 4	HRV 65% SRE ACH 2.5 Main Wall: 3.08 Foundation Wall: 2.98 Ceiling: 9.09 Windows: 1.44U / SHGC 0.26 ASHP HSPF: 7.1 DHW Tank SL : 77w - 12000w	HRV 65% SRE ACH 2.5 Main Wall: 3.85 Foundation Wall: 2.98 Ceiling: 9.09 Windows: 1.44U / SHGC 0.26 ASHP HSPF: 7.1 DHW Tank SL : 77w - 12000w	HRV 65% SRE ACH 2.5 Main Wall: 3.85 Foundation Wall: 2.98 Ceiling: 9.09 Windows: 1.44U / SHGC 0.26 ASHP HSPF: 7.1 DHW Tank SL : 77w - 12000w	HRV 65% SRE ACH 2.5 Main Wall: 5.45 Foundation Wall: 2.98 Ceiling: 9.09 Windows: 1.44U / SHGC 0.26 ASHP HSPF: 7.1 DHW Tank SL : 77w - 12000w	HRV 65% SRE ACH 2.5 Main Wall: 5.45 Foundation Wall: 3.97 Ceiling: 9.09 Windows: 1.22U / SHGC 0.26 ASHP HSPF: 10.6 ES DHW Tank SL : 77w - 12000w
Tier 5	HRV 78% SRE ACH 0.6 Main Wall: 4.40 Foundation Wall: 2.98 Ceiling: 9.09 Windows: 1.08U / SHGC 0.26 DHW HP COP: 2.6 ASHP HSPF: 10.6 ES	HRV 78% SRE ACH 0.6 Main Wall: 4.73 Foundation Wall: 2.98 Ceiling: 10.65 Windows: 1.08U / SHGC 0.26 DHW HP COP: 2.6 ASHP HSPF: 10.6 ES	HRV 78% SRE ACH 0.6 Main Wall: 4.73 Foundation Wall: 3.97 Ceiling: 10.65 Windows: 1.08U / SHGC 0.26 DHW HP COP: 2.6 ASHP HSPF: 10.6 ES	HRV 78% SRE ACH 0.6 Main Wall: 5.45 Foundation Wall: 3.97 Ceiling: 12.33 Windows: 0.85U / SHGC 0.26 DHW HP COP: 2.6 ASHP HSPF: 10.6 ES	HRV 78% SRE ACH 0.6 Main Wall: 7 Foundation Wall: 3.97 Ceiling: 12.33 Windows: 0.85U / SHGC 0.26 DHW HP COP: 2.6 ASHP HSPF: 10.6 ES

Table 3 NBC Energy Performance Tiers

		Applicable Energy Performance Tier				
Volume V_T	Target Metrics	1	2	3	4	5
> 300 m^3 and where volume is not determined	Percent Heat Loss Reduction	n/a	≥ 5%	≥ 10%	≥ 20%	≥ 40%
	Percent Improvement	≥ 0%	≥ 10%	≥ 20%	≥ 40%	≥ 70%
≤ 300 m^3	Percent Heat Loss Reduction	n/a	≥ 0%	≥ 5%	≥ 15%	≥ 25%
	Percent Improvement	≥ 0%	≥ 0%	≥ 10%	≥ 30%	≥ 60%

CBAT Archetype

Row house End Unit - Electric Baseboards w/ Electric DHW

HDD	2825	3520	4000	5080	6100
	Vancouver	Toronto	Halifax	QC	Prince Albert
Tier 1	HRV 65% SRE ACH 2.5 Main Wall: 3.85 Foundation Wall: 2.98 Ceiling: 4.97 DHW Tank SL : 77w - 12000w Windows U: 1.8 / SHGC 0.25	HRV 65% SRE ACH 2.5 Main Wall: 4.73 Foundation Wall: 2.98 Ceiling: 4.97 DHW Tank SL : 77w - 12000w Windows U: 1.8 / SHGC 0.25	HRV 65% SRE ACH 2.5 Main Wall: 5.45 Foundation Wall: 2.98 Ceiling: 5.48 DHW Tank SL : 77w - 12000w Windows U: 1.8 / SHGC 0.25	HRV 65% SRE ACH 2.5 Main Wall: 5.45 Foundation Wall: 2.98 Ceiling: 5.48 DHW Tank SL : 77w - 12000w Windows U: 1.8 / SHGC 0.25	HRV 65% SRE ACH 2.5 Main Wall: 5.45 Foundation Wall: 2.98 Ceiling: 5.98 DHW Tank SL : 77w - 12000w Windows U: 1.61 / SHGC 0.25
Tier 3	HRV 65% SRE ACH 2.5 Main Wall: 3.69 Foundation Wall: 2.98 Ceiling: 4.97 DHW Tank SL : 77w - 12000w Windows U: 1.22 / SHGC 0.25	HRV 65% SRE ACH 2.5 Main Wall: 3.85 Foundation Wall: 2.98 Ceiling: 4.97 DHW Tank SL : 77w - 12000w Windows U: 1.44 / SHGC 0.25	HRV 65% SRE ACH 2.5 Main Wall: 4.40 Foundation Wall: 2.98 Ceiling: 5.48 DHW Tank SL : 77w - 12000w Windows U: 1.44 / SHGC 0.25	HRV 65% SRE ACH 2.5 Main Wall: 4.40 Foundation Wall: 2.98 Ceiling: 5.48 DHW Tank SL : 77w - 12000w Windows U: 1.22 / SHGC 0.25	HRV 65% SRE ACH 2.5 Main Wall: 5.45 Foundation Wall: 2.98 Ceiling: 5.98 DHW Tank SL : 77w - 12000w Windows U: 1.22 / SHGC 0.25
Tier 4	HRV 78% SRE ACH 2.5 Main Wall: 4.40 Foundation Wall: 2.98 Ceiling: 5.48 DHW Tank SL : 77w - 12000w Windows U: 1.08 / SHGC 0.25 ASHP HSPF: 7.1	HRV 78% SRE ACH 2.5 Main Wall: 4.40 Foundation Wall: 2.98 Ceiling: 5.48 DHW Tank SL : 77w - 12000w Windows U: 1.08 / SHGC 0.25 ASHP HSPF: 7.1	HRV 78% SRE ACH 2.5 Main Wall: 4.40 Foundation Wall: 2.98 Ceiling: 5.48 DHW Tank SL : 77w - 12000w Windows U: 1.08 / SHGC 0.25 ASHP HSPF: 7.1	HRV 78% SRE ACH 2.5 Main Wall: 4.40 Foundation Wall: 2.98 Ceiling: 5.48 DHW Tank SL : 77w - 12000w Windows U: 1.08 / SHGC 0.25 ASHP HSPF: 7.1	HRV 78% SRE ACH 2.5 Main Wall: 5.45 Foundation Wall: 2.98 Ceiling: 5.98 DHW Tank SL : 77w - 12000w Windows U: 0.85 / SHGC 0.25 ASHP HSPF: 9.0
Tier 5	HRV 78% SRE ACH 0.6 Main Wall: 4.40 Foundation Wall: 2.98 Ceiling: 5.48 DHW Tank HP: 2.6 COP Windows U: 0.85 / SHGC 0.25 ASHP HSPF: 10.6 ES	HRV 78% SRE ACH 0.6 Main Wall: 4.40 Foundation Wall: 2.98 Ceiling: 5.48 DHW Tank HP: 2.6 COP Windows U: 0.85 / SHGC 0.25 ASHP HSPF: 10.6 ES	HRV 78% SRE ACH 0.6 Main Wall: 5.45 Foundation Wall: 2.98 Ceiling: 5.48 DHW Tank HP: 2.6 COP Windows U: 0.85 / SHGC 0.25 ASHP HSPF: 10.6 ES	HRV 78% SRE ACH 0.6 Main Wall: 5.45 Foundation Wall: 2.98 Ceiling: 5.98 DHW Tank HP: 2.6 COP Windows U: 0.85 / SHGC 0.25 ASHP HSPF: 10.6 ES	HRV 78% SRE ACH 0.6 Main Wall: 7.00 Foundation Wall: 2.98 Ceiling: 5.98 DHW Tank HP: 2.6 COP Windows U: 0.85 / SHGC 0.25 ASHP HSPF: 10.6 ES

Table 3 NBC Energy Performance Tiers

		Applicable Energy Performance Tier				
Volume V_T	Target Metrics	1	2	3	4	5
> 300 m^3 and where volume is not determined	Percent Heat Loss Reduction	n/a	≥ 5%	≥ 10%	≥ 20%	≥ 40%
	Percent Improvement	≥ 0%	≥ 10%	≥ 20%	≥ 40%	≥ 70%
≤ 300 m^3	Percent Heat Loss Reduction	n/a	≥ 0%	≥ 5%	≥ 15%	≥ 25%
	Percent Improvement	≥ 0%	≥ 0%	≥ 10%	≥ 30%	≥ 60%

CBAT Archetype
2 Storey Atlantic - Gas Furnace 95% AFUE w/ Gas DHW

HDD	3520	6100
	Toronto	Prince Albert
Tier 1	HRV 65% SRE ACH 2.5 Main Wall: 3.85 Foundation Wall: 2.98 Ceiling: 4.99 DHW Tank EF: 0.59 Windows U: 1.8 / SHGC 0.25	HRV 65% SRE ACH 2.5 Main Wall: 4.40 Foundation Wall: 2.98 Ceiling: 9.09 DHW Tank EF: 0.59 Windows U: 1.61 / SHGC 0.25
Tier 3	HRV 65% SRE ACH 2.0 Main Wall: 4.40 Foundation Wall: 2.98 Ceiling: 9.09 DHW Tank UEF: 0.64 Windows U: 1.61 / SHGC 0.25	HRV 65% SRE ACH 2.0 Main Wall: 5.45 Foundation Wall: 3.97 Ceiling: 10.65 DHW Tank UEF: 0.64 Windows U: 1.61 / SHGC 0.25
Tier 4	HRV 65% SRE ACH 2.5 Main Wall: 3.85 Foundation Wall: 2.98 Ceiling: 9.09 Windows: 1.44U / SHGC 0.26 ASHP HSPF: 7.1 DHW Tank SL : 77w - 12000w	HRV 65% SRE ACH 2.5 Main Wall: 5.45 Foundation Wall: 3.97 Ceiling: 9.09 Windows: 1.22U / SHGC 0.26 ASHP HSPF: 10.6 ES DHW Tank SL : 77w - 12000w
Tier 5	HRV 78% SRE	HRV 78% SRE

Table 3 NBC Energy Performance Tiers

		Applicable Energy Performance Tier				
Volume V_T	Target Metrics	1	2	3	4	5
> 300 m^3 and where volume is not determined	Percent Heat Loss Reduction	n/a	≥ 5%	≥ 10%	≥ 20%	≥ 40%
	Percent Improvement	≥ 0%	≥ 10%	≥ 20%	≥ 40%	≥ 70%
≤ 300 m^3	Percent Heat Loss Reduction	n/a	≥ 0%	≥ 5%	≥ 15%	≥ 25%
	Percent Improvement	≥ 0%	≥ 0%	≥ 10%	≥ 30%	≥ 60%

Appendix-D

Material Emissions Calculator results

City	Archetype	Embodied Carbon Pe	NBC Tier	MCE Total	MCE Intensity	CE 1 year [t CO2e	OCE [kgCO2e/m2]	Floor Area [m2]	OCE 30 [t CO2e	CUI 30	Energy Source
Prince Albert	2-storey House	4-HCM	Tier 3	144.2	617.6	22.58	96.702	233.5	677.40	821.6	Electricity
Prince Albert	2-storey House	3-MCM	Tier 3	31.4	134.5	22.58	96.702	233.5	677.40	708.8	Electricity
Prince Albert	2-storey House	2-BAM	Tier 3	-4.7	-20.1	22.58	96.702	233.5	677.40	672.7	Electricity
Prince Albert	2-storey House	1-BPM	Tier 3	-18.4	-78.8	22.58	96.702	233.5	677.40	659.0	Electricity
Halifax	2-storey House	4-HCM	Tier 3	115.8	495.9	16.02	68.608	233.5	480.60	596.4	Electricity
Halifax	2-storey House	3-MCM	Tier 3	28.9	123.8	16.02	68.608	233.5	480.60	509.5	Electricity
Halifax	2-storey House	2-BAM	Tier 3	-0.8	-3.4	16.02	68.608	233.5	480.60	479.8	Electricity
Halifax	2-storey House	1-BPM	Tier 3	-18.4	-78.8	16.02	68.608	233.5	480.60	462.2	Electricity
Quebec	2-storey House	4-HCM	Tier 3	121.3	519.5	0.04	0.171	233.5	1.20	122.5	Electricity
Quebec	2-storey House	3-MCM	Tier 3	29.5	126.3	0.04	0.171	233.5	1.20	30.7	Electricity
Quebec	2-storey House	2-BAM	Tier 3	-1.6	-6.9	0.04	0.171	233.5	1.20	-0.4	Electricity
Quebec	2-storey House	1-BPM	Tier 3	-15.6	-66.8	0.04	0.171	233.5	1.20	-14.4	Electricity
Toronto	2-storey House	4-HCM	Tier 3	112.6	482.2	0.71	3.041	233.5	21.30	133.9	Electricity
Toronto	2-storey House	3-MCM	Tier 3	28.4	121.6	0.71	3.041	233.5	21.30	49.7	Electricity
Toronto	2-storey House	2-BAM	Tier 3	-0.6	-2.6	0.71	3.041	233.5	21.30	20.7	Electricity
Toronto	2-storey House	1-BPM	Tier 3	-18.4	-78.8	0.71	3.041	233.5	21.30	2.9	Electricity
Vancouver	2-storey House	4-HCM	Tier 3	106.5	456.1	0.18	0.771	233.5	5.40	111.9	Electricity
Vancouver	2-storey House	3-MCM	Tier 3	27.9	119.5	0.18	0.771	233.5	5.40	33.3	Electricity
Vancouver	2-storey House	2-BAM	Tier 3	-0.5	-2.1	0.18	0.771	233.5	5.40	4.9	Electricity
Vancouver	2-storey House	1-BPM	Tier 3	-15.6	-66.8	0.18	0.771	233.5	5.40	-10.2	Electricity
Prince Albert	2-storey House	4-HCM	Tier 4	151.4	648.4	18.36	78.630	233.5	550.80	702.2	Electricity
Prince Albert	2-storey House	3-MCM	Tier 4	32.5	139.2	18.36	78.630	233.5	550.80	583.3	Electricity
Prince Albert	2-storey House	2-BAM	Tier 4	-6.5	-27.8	18.36	78.630	233.5	550.80	544.3	Electricity
Prince Albert	2-storey House	1-BPM	Tier 4	-18.4	-78.8	18.36	78.630	233.5	550.80	532.4	Electricity
Vancouver	2-storey House	4-HCM	Tier 4	115.9	496.4	0.17	0.728	233.5	5.10	121.0	Electricity
Vancouver	2-storey House	3-MCM	Tier 4	28.9	123.8	0.17	0.728	233.5	5.10	34.0	Electricity
Vancouver	2-storey House	2-BAM	Tier 4	-0.8	-3.4	0.17	0.728	233.5	5.10	4.3	Electricity
Vancouver	2-storey House	1-BPM	Tier 4	-18.5	-79.2	0.17	0.728	233.5	5.10	-13.4	Electricity
Halifax	2-storey House	4-HCM	Tier 4	126.5	541.8	14.36	61.499	233.5	430.80	557.3	Electricity
Halifax	2-storey House	3-MCM	Tier 4	30.1	128.9	14.36	61.499	233.5	430.80	460.9	Electricity
Halifax	2-storey House	2-BAM	Tier 4	-2.4	-10.3	14.36	61.499	233.5	430.80	428.4	Electricity
Halifax	2-storey House	1-BPM	Tier 4	-18.4	-78.8	14.36	61.499	233.5	430.80	412.4	Electricity
Quebec	2-storey House	4-HCM	Tier 4	148.7	636.8	0.03	0.128	233.5	0.90	149.6	Electricity
Quebec	2-storey House	3-MCM	Tier 4	32.5	139.2	0.03	0.128	233.5	0.90	33.4	Electricity
Quebec	2-storey House	2-BAM	Tier 4	-5.7	-24.4	0.03	0.128	233.5	0.90	-4.8	Electricity
Quebec	2-storey House	1-BPM	Tier 4	-18.5	-79.2	0.03	0.128	233.5	0.90	-17.6	Electricity
Toronto	2-storey House	4-HCM	Tier 4	124.8	534.5	0.62	2.655	233.5	18.60	143.4	Electricity
Toronto	2-storey House	3-MCM	Tier 4	29.7	127.2	0.62	2.655	233.5	18.60	48.3	Electricity
Toronto	2-storey House	2-BAM	Tier 4	-2.4	-10.3	0.62	2.655	233.5	18.60	16.2	Electricity
Toronto	2-storey House	1-BPM	Tier 4	-18.4	-78.8	0.62	2.655	233.5	18.60	0.2	Electricity
Prince Albert	2-storey House	4-HCM	Tier 5	177	758.0	12.93	55.375	233.5	387.90	564.9	Electricity
Prince Albert	2-storey House	3-MCM	Tier 5	35.3	151.2	12.93	55.375	233.5	387.90	423.2	Electricity
Prince Albert	2-storey House	2-BAM	Tier 5	-9.9	-42.4	12.93	55.375	233.5	387.90	378.0	Electricity
Prince Albert	2-storey House	1-BPM	Tier 5	-20.7	-88.7	12.93	55.375	233.5	387.90	367.2	Electricity
Vancouver	2-storey House	4-HCM	Tier 5	134.1	574.3	0.13	0.557	233.5	3.90	138.0	Electricity

Vancouver	2-storey House	3-MCM	Tier 5	30.9	132.3	0.13	0.557	233.5	3.90	34.8	Electricity
Vancouver	2-storey House	2-BAM	Tier 5	-3.6	-15.4	0.13	0.557	233.5	3.90	0.3	Electricity
Vancouver	2-storey House	1-BPM	Tier 5	-18.5	-79.2	0.13	0.557	233.5	3.90	-14.6	Electricity
Halifax	2-storey House	4-HCM	Tier 5	143.5	614.6	9.92	42.484	233.5	297.60	441.1	Electricity
Halifax	2-storey House	3-MCM	Tier 5	31.6	135.3	9.92	42.484	233.5	297.60	329.2	Electricity
Halifax	2-storey House	2-BAM	Tier 5	-4.9	-21.0	9.92	42.484	233.5	297.60	292.7	Electricity
Halifax	2-storey House	1-BPM	Tier 5	-18.4	-78.8	9.92	42.484	233.5	297.60	279.2	Electricity
Quebec	2-storey House	4-HCM	Tier 5	150.3	643.7	0.02	0.086	233.5	0.60	150.9	Electricity
Quebec	2-storey House	3-MCM	Tier 5	33	141.3	0.02	0.086	233.5	0.60	33.6	Electricity
Quebec	2-storey House	2-BAM	Tier 5	-6.8	-29.1	0.02	0.086	233.5	0.60	-6.2	Electricity
Quebec	2-storey House	1-BPM	Tier 5	-20.7	-88.7	0.02	0.086	233.5	0.60	-20.1	Electricity
Toronto	2-storey House	4-HCM	Tier 5	138.9	594.9	0.44	1.884	233.5	13.20	152.1	Electricity
Toronto	2-storey House	3-MCM	Tier 5	31.2	133.6	0.44	1.884	233.5	13.20	44.4	Electricity
Toronto	2-storey House	2-BAM	Tier 5	-4.6	-19.7	0.44	1.884	233.5	13.20	8.6	Electricity
Toronto	2-storey House	1-BPM	Tier 5	-19.5	-83.5	0.44	1.884	233.5	13.20	-6.3	Electricity
Vancouver	Bungalow	4-HCM	Tier 3	126.5	510.7	0.17	0.686	247.7	5.10	131.6	Electricity
Vancouver	Bungalow	3-MCM	Tier 3	39.3	158.7	0.17	0.686	247.7	5.10	44.4	Electricity
Vancouver	Bungalow	2-BAM	Tier 3	5.1	20.6	0.17	0.686	247.7	5.10	10.2	Electricity
Vancouver	Bungalow	1-BPM	Tier 3	-5.2	-21.0	0.17	0.686	247.7	5.10	-0.1	Electricity
Prince Albert	Bungalow	4-HCM	Tier 3	130.5	526.8	19.30	77.917	247.7	579.00	709.5	Electricity
Prince Albert	Bungalow	3-MCM	Tier 3	40.6	163.9	19.30	77.917	247.7	579.00	619.6	Electricity
Prince Albert	Bungalow	2-BAM	Tier 3	3.4	13.7	19.30	77.917	247.7	579.00	582.4	Electricity
Prince Albert	Bungalow	1-BPM	Tier 3	-8.4	-33.9	19.30	77.917	247.7	579.00	570.6	Electricity
Halifax	Bungalow	4-HCM	Tier 3	138.3	558.3	13.09	52.846	247.7	392.70	531.0	Electricity
Halifax	Bungalow	3-MCM	Tier 3	40.6	163.9	13.09	52.846	247.7	392.70	433.3	Electricity
Halifax	Bungalow	2-BAM	Tier 3	3.4	13.7	13.09	52.846	247.7	392.70	396.1	Electricity
Halifax	Bungalow	1-BPM	Tier 3	-8.4	-33.9	13.09	52.846	247.7	392.70	384.3	Electricity
Quebec	Bungalow	4-HCM	Tier 3	138.3	558.3	0.03	0.121	247.7	0.90	139.2	Electricity
Quebec	Bungalow	3-MCM	Tier 3	40.6	163.9	0.03	0.121	247.7	0.90	41.5	Electricity
Quebec	Bungalow	2-BAM	Tier 3	3.4	13.7	0.03	0.121	247.7	0.90	4.3	Electricity
Quebec	Bungalow	1-BPM	Tier 3	-8.4	-33.9	0.03	0.121	247.7	0.90	-7.5	Electricity
Toronto	Bungalow	4-HCM	Tier 3	132.5	534.9	0.59	2.382	247.7	17.70	150.2	Electricity
Toronto	Bungalow	3-MCM	Tier 3	40	161.5	0.59	2.382	247.7	17.70	57.7	Electricity
Toronto	Bungalow	2-BAM	Tier 3	4.2	17.0	0.59	2.382	247.7	17.70	21.9	Electricity
Toronto	Bungalow	1-BPM	Tier 3	-8.4	-33.9	0.59	2.382	247.7	17.70	9.3	Electricity
Vancouver	Bungalow	4-HCM	Tier 4	133.2	537.7	0.16	0.646	247.7	4.80	138.0	Electricity
Vancouver	Bungalow	3-MCM	Tier 4	40.1	161.9	0.16	0.646	247.7	4.80	44.9	Electricity
Vancouver	Bungalow	2-BAM	Tier 4	4.1	16.6	0.16	0.646	247.7	4.80	8.9	Electricity
Vancouver	Bungalow	1-BPM	Tier 4	-8.4	-33.9	0.16	0.646	247.7	4.80	-3.6	Electricity
Prince Albert	Bungalow	4-HCM	Tier 4	147.9	597.1	16.11	65.038	247.7	483.30	631.2	Electricity
Prince Albert	Bungalow	3-MCM	Tier 4	41.7	168.3	16.11	65.038	247.7	483.30	525.0	Electricity
Prince Albert	Bungalow	2-BAM	Tier 4	2	8.1	16.11	65.038	247.7	483.30	485.3	Electricity
Prince Albert	Bungalow	1-BPM	Tier 4	-10.5	-42.4	16.11	65.038	247.7	483.30	472.8	Electricity
Halifax	Bungalow	4-HCM	Tier 4	144.14	581.9	12.43	50.182	247.7	372.90	517.0	Electricity
Halifax	Bungalow	3-MCM	Tier 4	41.2	166.3	12.43	50.182	247.7	372.90	414.1	Electricity
Halifax	Bungalow	2-BAM	Tier 4	2.6	10.5	12.43	50.182	247.7	372.90	375.5	Electricity
Halifax	Bungalow	1-BPM	Tier 4	-8.4	-33.9	12.43	50.182	247.7	372.90	364.5	Electricity
Quebec	Bungalow	4-HCM	Tier 4	147.9	597.1	0.03	0.121	247.7	0.90	148.8	Electricity
Quebec	Bungalow	3-MCM	Tier 4	41.2	166.3	0.03	0.121	247.7	0.90	42.1	Electricity
Quebec	Bungalow	2-BAM	Tier 4	2.03	8.2	0.03	0.121	247.7	0.90	2.9	Electricity
Quebec	Bungalow	1-BPM	Tier 4	-10.5	-42.4	0.03	0.121	247.7	0.90	-9.6	Electricity

Toronto	Bungalow	4-HCM	Tier 4	138.3	558.3	0.54	2.180	247.7	16.20	154.5	Electricity
Toronto	Bungalow	3-MCM	Tier 4	40.6	163.9	0.54	2.180	247.7	16.20	56.8	Electricity
Toronto	Bungalow	2-BAM	Tier 4	3.4	13.7	0.54	2.180	247.7	16.20	19.6	Electricity
Toronto	Bungalow	1-BPM	Tier 4	-8.4	-33.9	0.54	2.180	247.7	16.20	7.8	Electricity
Vancouver	Bungalow	4-HCM	Tier 5	142.1	573.7	0.12	0.484	247.7	3.60	145.7	Electricity
Vancouver	Bungalow	3-MCM	Tier 5	41.1	165.9	0.12	0.484	247.7	3.60	44.7	Electricity
Vancouver	Bungalow	2-BAM	Tier 5	2.8	11.3	0.12	0.484	247.7	3.60	6.4	Electricity
Vancouver	Bungalow	1-BPM	Tier 5	-10.5	-42.4	0.12	0.484	247.7	3.60	-6.9	Electricity
Prince Albert	Bungalow	4-HCM	Tier 5	185.3	748.1	12.22	49.334	247.7	366.60	551.9	Electricity
Prince Albert	Bungalow	3-MCM	Tier 5	42.2	170.4	12.22	49.334	247.7	366.60	408.8	Electricity
Prince Albert	Bungalow	2-BAM	Tier 5	0.6	2.4	12.22	49.334	247.7	366.60	367.2	Electricity
Prince Albert	Bungalow	1-BPM	Tier 5	-10.5	-42.4	12.22	49.334	247.7	366.60	356.1	Electricity
Halifax	Bungalow	4-HCM	Tier 5	158	637.9	8.86	35.769	247.7	265.80	423.8	Electricity
Halifax	Bungalow	3-MCM	Tier 5	42.2	170.4	8.86	35.769	247.7	265.80	308.0	Electricity
Halifax	Bungalow	2-BAM	Tier 5	0.6	2.4	8.86	35.769	247.7	265.80	266.4	Electricity
Halifax	Bungalow	1-BPM	Tier 5	-10.5	-42.4	8.86	35.769	247.7	265.80	255.3	Electricity
Quebec	Bungalow	4-HCM	Tier 5	158	637.9	0.02	0.081	247.7	0.60	158.6	Electricity
Quebec	Bungalow	3-MCM	Tier 5	42.1	170.0	0.02	0.081	247.7	0.60	42.7	Electricity
Quebec	Bungalow	2-BAM	Tier 5	1.37	5.5	0.02	0.081	247.7	0.60	2.0	Electricity
Quebec	Bungalow	1-BPM	Tier 5	-10.5	-42.4	0.02	0.081	247.7	0.60	-9.9	Electricity
Toronto	Bungalow	4-HCM	Tier 5	147.9	597.1	0.40	1.615	247.7	12.00	159.9	Electricity
Toronto	Bungalow	3-MCM	Tier 5	41.6	167.9	0.40	1.615	247.7	12.00	53.6	Electricity
Toronto	Bungalow	2-BAM	Tier 5	2	8.1	0.40	1.615	247.7	12.00	14.0	Electricity
Toronto	Bungalow	1-BPM	Tier 5	-10.5	-42.4	0.40	1.615	247.7	12.00	1.5	Electricity
Vancouver	Row House	4-HCM	Tier 3	73.08	494.5	0.15	1.015	147.8	4.50	77.6	Electricity
Vancouver	Row House	3-MCM	Tier 3	24.02	162.5	0.15	1.015	147.8	4.50	28.5	Electricity
Vancouver	Row House	2-BAM	Tier 3	-0.57	-3.9	0.15	1.015	147.8	4.50	3.9	Electricity
Vancouver	Row House	1-BPM	Tier 3	-6.66	-45.1	0.15	1.015	147.8	4.50	-2.2	Electricity
Halifax	Row House	4-HCM	Tier 3	80.7	546.0	14.31	96.820	147.8	429.30	510.0	Electricity
Halifax	Row House	3-MCM	Tier 3	25.8	174.6	14.31	96.820	147.8	429.30	455.1	Electricity
Halifax	Row House	2-BAM	Tier 3	-2.2	-14.9	14.31	96.820	147.8	429.30	427.1	Electricity
Halifax	Row House	1-BPM	Tier 3	-6.9	-46.7	14.31	96.820	147.8	429.30	422.4	Electricity
Quebec	Row House	4-HCM	Tier 3	80.7	546.0	0.03	0.203	147.8	0.90	81.6	Electricity
Quebec	Row House	3-MCM	Tier 3	25.8	174.6	0.03	0.203	147.8	0.90	26.7	Electricity
Quebec	Row House	2-BAM	Tier 3	-2.2	-14.9	0.03	0.203	147.8	0.90	-1.3	Electricity
Quebec	Row House	1-BPM	Tier 3	-6.9	-46.7	0.03	0.203	147.8	0.90	-6.0	Electricity
Toronto	Row House	4-HCM	Tier 3	80.7	546.0	0.50	3.383	147.8	15.00	95.7	Electricity
Toronto	Row House	3-MCM	Tier 3	25.7	173.9	0.50	3.383	147.8	15.00	40.7	Electricity
Toronto	Row House	2-BAM	Tier 3	-2.2	-14.9	0.50	3.383	147.8	15.00	12.8	Electricity
Toronto	Row House	1-BPM	Tier 3	-6.7	-45.3	0.50	3.383	147.8	15.00	8.3	Electricity
Prince Albert	Row House	4-HCM	Tier 3	80.7	546.0	15.20	102.842	147.8	456.00	536.7	Electricity
Prince Albert	Row House	3-MCM	Tier 3	25.9	175.2	15.20	102.842	147.8	456.00	481.9	Electricity
Prince Albert	Row House	2-BAM	Tier 3	-2.3	-15.6	15.20	102.842	147.8	456.00	453.7	Electricity
Prince Albert	Row House	1-BPM	Tier 3	-7.1	-48.0	15.20	102.842	147.8	456.00	448.9	Electricity
Vancouver	Row House	4-HCM	Tier 4	73.47	497.1	0.14	0.947	147.8	4.20	77.7	Electricity
Vancouver	Row House	3-MCM	Tier 4	24.07	162.9	0.14	0.947	147.8	4.20	28.3	Electricity
Vancouver	Row House	2-BAM	Tier 4	-0.63	-4.3	0.14	0.947	147.8	4.20	3.6	Electricity
Vancouver	Row House	1-BPM	Tier 4	-6.88	-46.5	0.14	0.947	147.8	4.20	-2.7	Electricity
Prince Albert	Row House	4-HCM	Tier 4	80.7	546.0	13.24	89.581	147.8	397.20	477.9	Electricity
Prince Albert	Row House	3-MCM	Tier 4	25.9	175.2	13.24	89.581	147.8	397.20	423.1	Electricity
Prince Albert	Row House	2-BAM	Tier 4	-2.3	-15.6	13.24	89.581	147.8	397.20	394.9	Electricity

Prince Albert	Row House	1-BPM	Tier 4	-7.1	-48.0	13.24	89.581	147.8	397.20	390.1	Electricity
Halifax	Row House	4-HCM	Tier 4	73.1	494.6	10.60	71.719	147.8	318.00	391.1	Electricity
Halifax	Row House	3-MCM	Tier 4	24.1	163.1	10.60	71.719	147.8	318.00	342.1	Electricity
Halifax	Row House	2-BAM	Tier 4	-0.6	-4.1	10.60	71.719	147.8	318.00	317.4	Electricity
Halifax	Row House	1-BPM	Tier 4	-6.9	-46.7	10.60	71.719	147.8	318.00	311.1	Electricity
Quebec	Row House	4-HCM	Tier 4	73.1	494.6	0.03	0.203	147.8	0.90	74.0	Electricity
Quebec	Row House	3-MCM	Tier 4	24.1	163.1	0.03	0.203	147.8	0.90	25.0	Electricity
Quebec	Row House	2-BAM	Tier 4	-0.6	-4.1	0.03	0.203	147.8	0.90	0.3	Electricity
Quebec	Row House	1-BPM	Tier 4	-6.9	-46.7	0.03	0.203	147.8	0.90	-6.0	Electricity
Toronto	Row House	4-HCM	Tier 4	73.1	494.6	0.47	3.180	147.8	14.10	87.2	Electricity
Toronto	Row House	3-MCM	Tier 4	24.1	163.1	0.47	3.180	147.8	14.10	38.2	Electricity
Toronto	Row House	2-BAM	Tier 4	-0.6	-4.1	0.47	3.180	147.8	14.10	13.5	Electricity
Toronto	Row House	1-BPM	Tier 4	-6.9	-46.7	0.47	3.180	147.8	14.10	7.2	Electricity
Vancouver	Row House	4-HCM	Tier 5	73.47	497.1	0.11	0.744	147.8	3.30	76.8	Electricity
Vancouver	Row House	3-MCM	Tier 5	24.07	162.9	0.11	0.744	147.8	3.30	27.4	Electricity
Vancouver	Row House	2-BAM	Tier 5	-0.63	-4.3	0.11	0.744	147.8	3.30	2.7	Electricity
Vancouver	Row House	1-BPM	Tier 5	-6.88	-46.5	0.11	0.744	147.8	3.30	-3.6	Electricity
Prince Albert	Row House	4-HCM	Tier 5	91.8	621.1	9.91	67.050	147.8	297.30	389.1	Electricity
Prince Albert	Row House	3-MCM	Tier 5	28.4	192.2	9.91	67.050	147.8	297.30	325.7	Electricity
Prince Albert	Row House	2-BAM	Tier 5	-4.7	-31.8	9.91	67.050	147.8	297.30	292.6	Electricity
Prince Albert	Row House	1-BPM	Tier 5	-7.1	-48.0	9.91	67.050	147.8	297.30	290.2	Electricity
Halifax	Row House	4-HCM	Tier 5	80.7	546.0	7.73	52.300	147.8	231.90	312.6	Electricity
Halifax	Row House	3-MCM	Tier 5	25.8	174.6	7.73	52.300	147.8	231.90	257.7	Electricity
Halifax	Row House	2-BAM	Tier 5	-2.2	-14.9	7.73	52.300	147.8	231.90	229.7	Electricity
Halifax	Row House	1-BPM	Tier 5	-6.9	-46.7	7.73	52.300	147.8	231.90	225.0	Electricity
Quebec	Row House	4-HCM	Tier 5	80.7	546.0	0.02	0.135	147.8	0.60	81.3	Electricity
Quebec	Row House	3-MCM	Tier 5	25.8	174.6	0.02	0.135	147.8	0.60	26.4	Electricity
Quebec	Row House	2-BAM	Tier 5	-2.3	-15.6	0.02	0.135	147.8	0.60	-1.7	Electricity
Quebec	Row House	1-BPM	Tier 5	-7.1	-48.0	0.02	0.135	147.8	0.60	-6.5	Electricity
Toronto	Row House	4-HCM	Tier 5	73.1	494.6	0.47	3.180	147.8	14.10	87.2	Electricity
Toronto	Row House	3-MCM	Tier 5	24.1	163.1	0.47	3.180	147.8	14.10	38.2	Electricity
Toronto	Row House	2-BAM	Tier 5	-0.6	-4.1	0.47	3.180	147.8	14.10	13.5	Electricity
Toronto	Row House	1-BPM	Tier 5	-6.9	-46.7	0.47	3.180	147.8	14.10	7.2	Electricity
Toronto (NG)	2-storey House	4-HCM	Tier 3	132.39	567.0	3.48	3.041	233.5	104.4	236.8	Natural Gas
Toronto (NG)	2-storey House	3-MCM	Tier 3	30.52	130.7	3.48	3.041	233.5	104.4	134.9	Natural Gas
Toronto (NG)	2-storey House	2-BAM	Tier 3	-3.58	-15.3	3.48	3.041	233.5	104.4	100.8	Natural Gas
Toronto (NG)	2-storey House	1-BPM	Tier 3	-18.46	-79.1	3.48	3.041	233.5	104.4	85.9	Natural Gas
Toronto (NG)	2-storey House	4-HCM	Tier 4	124.79	534.4	2.65	2.655	233.5	79.5	204.3	Natural Gas
Toronto (NG)	2-storey House	3-MCM	Tier 4	29.69	127.2	2.65	2.655	233.5	79.5	109.2	Natural Gas
Toronto (NG)	2-storey House	2-BAM	Tier 4	-2.45	-10.5	2.65	2.655	233.5	79.5	77.1	Natural Gas
Toronto (NG)	2-storey House	1-BPM	Tier 4	-18.46	-79.1	2.65	2.655	233.5	79.5	61.0	Natural Gas
Prince Albert (NG)	2-storey House	4-HCM	Tier 3	153.42	657.0	10.32	96.702	233.5	309.5	462.9	Natural Gas
Prince Albert (NG)	2-storey House	3-MCM	Tier 3	32.75	140.3	10.32	96.702	233.5	309.6	342.4	Natural Gas
Prince Albert (NG)	2-storey House	2-BAM	Tier 3	-6.46	-27.7	10.32	96.702	233.5	309.6	303.1	Natural Gas
Prince Albert (NG)	2-storey House	1-BPM	Tier 3	-19.54	-83.7	10.32	96.702	233.5	309.6	290.1	Natural Gas
Prince Albert (NG)	2-storey House	4-HCM	Tier 4	151.46	648.7	8.97	78.630	233.5	269.1	420.6	Natural Gas
Prince Albert (NG)	2-storey House	3-MCM	Tier 4	32.5	139.2	8.97	78.630	233.5	269.1	301.6	Natural Gas
Prince Albert (NG)	2-storey House	2-BAM	Tier 4	-6.16	-26.4	8.97	78.630	233.5	269.1	262.9	Natural Gas
Prince Albert (NG)	2-storey House	1-BPM	Tier 4	-18.4	-78.8	8.97	78.630	233.5	269.1	250.7	Natural Gas