Emissions of Materials Benchmark Assessment

for Residential Construction

BUILDERS FOR CLIMATE ACTION

PASSIVE BUILDINGS CANADA

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Acknowledgments

Passive Buildings Canada is Canada's first national non-profit organization supporting the passive house community to build a more sustainable Canada and planet. We welcome a diversity of approaches and voices to connect, share knowledge, and promote passive house projects.

Builders for Climate Action is creating tools, research and resources to support practitioners and policy makers in making zero carbon buildings. Chris Magwood, Erik Bowden and Mélanie Trottier prepared this report on behalf of BfCA.

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Executive Summary

Rich Data Set

EMBARC generated a rich data set, representing 503 as-built homes of three key typologies: single detached, semi-detached and townhouses. Together, these housing types represent an average of 16,400 new homes built annually in the region.

Building Emissions Accounting for Materials

The BEAM (Building Emissions Accounting for Materials) estimator tool was used to assess GHG emissions and carbon storage for building materials that make up the structure, enclosure and main finishes, based on results from Environmental Product Declarations. Emissions from raw material harvesting, transportation to factory and manufacturing (A1-A3) were considered. Mechanical, electrical and plumbing materials, millwork, stairs, doors and surface finishes were not calculated.

503 homes = 20,122 tonnes of emissions

Material carbon emissions (MCE) across the study's sample of 503 as-built housing units totalled an estimated 20,122 tons, with an average of 40 t CO_2e per unit. The lowest emitting home was responsible for 9.5 t CO2e and the highest 827.1 t CO_2e.

16,400 homes = 840,000 tonnes of emissions

Extrapolating the study's average values to all new low-rise homes built each year in the GTHA, the total annual MCE may be around 840,000 t CO_2e annually. This is equivalent to the emissions from more than 183,000 automobiles.

As the MCE measured in this study may represent as little as 50 percent of the total MCE for these building typologies, due to the exclusion of MEP equipment, appliances, finishes and millwork, a possible impact of 1.75 Mt (megatonnes) of MCE is likely arising from new home construction.

Material Carbon Intensity

Material carbon intensity (MCI) was calculated by dividing total emissions by floor area, to enable comparisons between units of different sizes.

MCI was calculated using various definitions of floor area, with the weighted average results:

> **Gross floor area — 154 kg CO_2e/m^2**
> **Heated floor area — 189 kg CO_2e/m^2**
> **Habitable floor area — 225 kg CO_2e/m^2**

Depending on the floor area definition, each of the three housing typologies could be the best or the worst, indicating the importance of accurately defining the parameters for MCI.

Based on heated floor area, the lowest MCI result was 116 kg CO_2e/m^2 and the highest was 561 kg CO_2e/m^2. The 189 kg CO_2e/m^2 average MCI for heated floor area was higher than the 150 kg $CO_2e/$ m2 average from previous studies, due largely to bigger garages and more use of high emission cladding (brick) and insulation (XPS foam).

High Emission Materials

73 percent of all material carbon emissions in the study come ftrom just three material categories: concrete (33 percent for foundation walls, slabs and footings), insulation (26.1 percent for foundations, walls and roofs) and exterior cladding (13.4 percent). Efforts to reduce MCEs should be concentrated on these material categories.

We Can Make a Difference

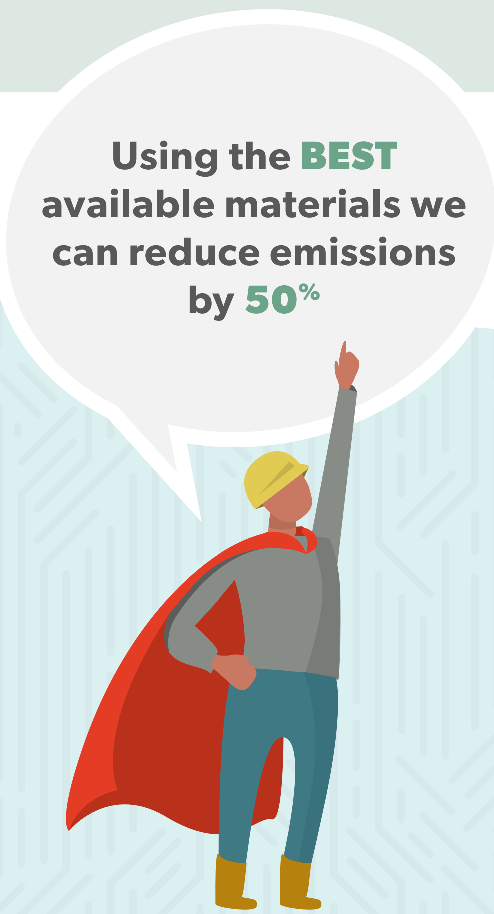
Material substitutions were explored for a home with heated floor area MCI of 116 kg CO_2e/m². Using the "best available materials" (widely available, affordable and code-compliant), this could be reduced to 56.5 kg CO_2e/m^2. If all new homes in the GTHA used the "best available materials" this would result in approximately 573,000 t CO_2e fewer emissions annually.

Using the "best possible materials" (feasible but unconventional), this could be further reduced to -54.6 kg CO_2e/m^2, indicating that homes could become sites of net carbon storage, rather than net emissions.

Using the "best possible materials" would result in the reduction of roughly 1,065,000 t CO_2e. In this hypothetical scenario, new Part 9 homes built in the GTHA would pass beyond net zero carbon to store around 225,000 tonnes of carbon from the atmosphere during a single construction year.

The New Direction

The researchers recommend that policy makers and the home building sector begin to regularly measure MCE and MCI for new homes, and implement voluntary thresholds in line with the average results from this study. Regulation of MCE may enable region-wide emission reductions of 250,000 to 1,000,000 t CO_2e annually.



Putting Material Carbon Emissions into Context

Canada, and the entire world, is faced with a rapidly declining "carbon budget" within which we must function to stave off the worst effects of climate change. The United Nations has declared the climate emergency "code red for humanity."[1] The Pan-Canadian Framework on Clean Growth and Climate Change (PCF, 2016) identified the building sector as one of the major contributors to GHG (greenhouse gas) emissions in Canada.[2] To this end, improvements in energy efficiency have been integrated into the National Building Code of Canada and the Ontario Building Code as well as municipal incentives and voluntary green building standards in order to reduce emissions from new homes.

The very short amount of time available to meet Canada's emission reduction targets of 40-45 percent below 2005 levels by 2030[3] requires us to consider all of the emission impacts from the housing sector and focus effort on those sources of emissions that have the greatest immediate impact on our remaining carbon budget. In recent years, increased attention has been drawn to the emissions arising from building materials, often referred to as "embodied carbon," (this report uses the more specific term "material carbon emissions"(MCE) to describe the cradle-to-gate phases of life cycle assessment [4]). Early research[5, 6], in this field indicated that over the next two crucial decades these emissions are likely to substantially outweigh the operational emissions attributed to newly constructed homes.

Remaining Global Emissions Budget

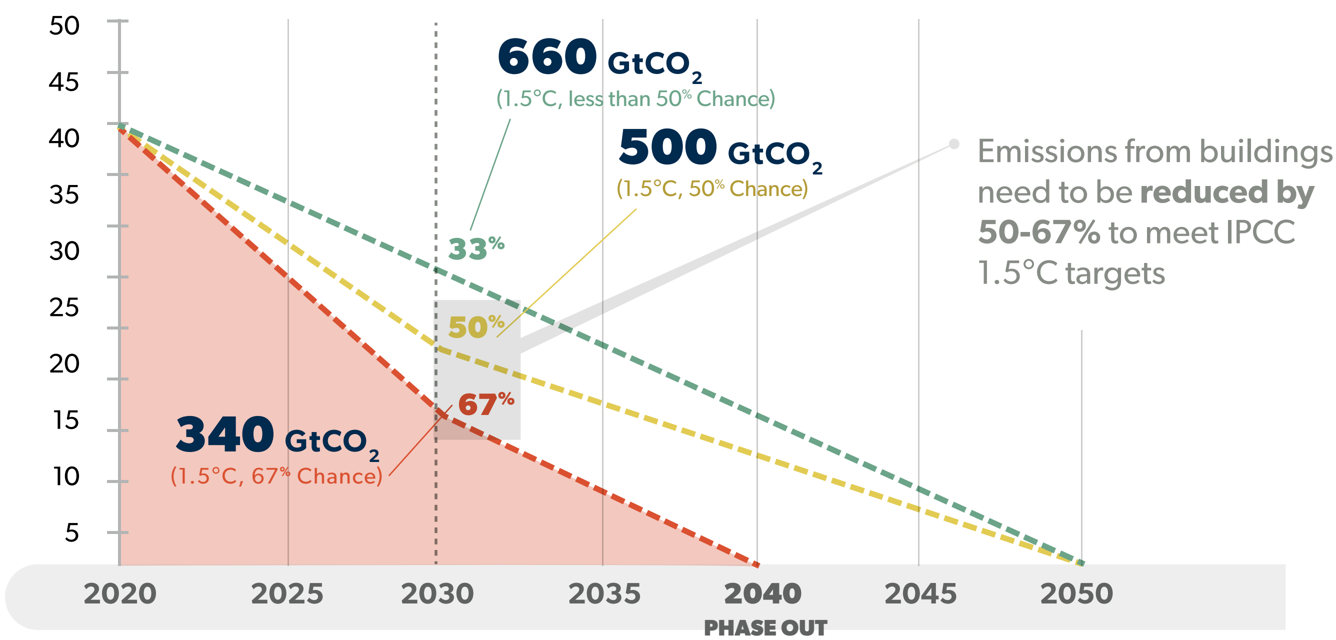


Figure 1: Emission reduction pathways to meet IPCC 1.5C targets Adapted from Architecture 2030.

Previous Studies of Material Carbon Emissions

In 2021, Natural Resources Canada (NRCan) released the report "*Achieving Real Net Zero Emission Homes*"[7] establishing that material carbon emissions (MCE) for new homes will outweigh operational carbon emissions (OCE) for electrified homes using relatively clean electrical grids such as that in the Greater Toronto and Hamilton Area (GTHA) for almost 120 years. At the highest levels of energy efficiency proposed by codes, this imbalance extends to 166 years of OCE to equal MCE. According to these results, MCE would represent a large majority of a new home's total emissions over the next few decades. Left unchecked, MCE is likely to undercut the gains made in reducing operational emissions over the past decade.

Using archetype home designs for a bungalow, two-storey and row house the NRCan report used four material palettes to reflect different MCE outcomes: high, mid-range, best available and best possible materials.

The study found that the average measured MCE for Tier 3[8] homes across five Canadian cities could vary widely based on these material selections, from a high of 513 kilograms of emissions per square meter of heated floor area (kg CO_2e/m^2) to a low of -50 kg CO_2e/m^2. The model using the most conventional mix of materials showed 150 kg CO_2e/m^2 and the model using materials with the lowest emission profile that are widely available and code compliant was 2 kg CO_2e/m^2.

In 2021, Builders for Climate Action worked with the cities of Nelson and Castlegar, BC, to examine the MCE of 34 as-built homes in the region[9]. The measured results included a high of 309 kg CO_2e/m^2 and a low of 72. The average across the 34 samples was 150 kg CO_2e/m^2. A local home that was not included in the study but measured using the same methodology matched the NRCan "best available materials" result of 2 kg CO_2e/m^2.

Both studies revealed that total MCE from new homes represents a significant, mostly overlooked and unregulated, pool of GHGs. Nationally, an average of 150 kg CO_2e/m^2 for all new housing construction would represent total GHG emissions of 8.5 million tonnes annually based on average annual construction[10].

Figure 2: Results of MCE studies

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MCE ▶ Material Carbon Emissions

Emissions of Materials Benchmark Assessment for Residential Construction (EMBARC)

The EMBARC study examines MCE in the GTHA using a large sample of as-built new Part 9 homes and the same methodology as the NRCan and Nelson/ Castlegar studies. The intent of the study is to provide an understanding of the total impact of MCE from new Part 9 homes on the region's emissions and provide decision makers – including policymakers, developers, home designers and builders, as well as homeowners – with insights on how this MCE can most effectively be reduced in future construction of the GTHA's housing stock.

> **EMBARC generated a rich data set, representing 503 as-built homes of three key typologies: single detached, semi-detached and townhouses. Together, these housing types represent an average of 16,400 new homes built annually in the region, based on data from 2017-2020 collected from municipalities by the research team.**

A detailed analysis of each set of home plans in the free software program BEAM (Building Emissions Accounting for Materials) enabled the study team to generate total MCE for each home, as well as a material-by-material breakdown.

This report offers many insights into MCE from Part 9 homes and ways in which it can be dramatically reduced. These emissions are considered "Scope 3" – generated by manufacturers across North America (and indeed around the world) – and are therefore not typically addressed by municipalities. However, decisions made by municipal policymakers and the local building sector can have significant and immediate impacts on these emissions. Addressing MCE at the regional level is an example of acting locally to make important impacts globally, and we look forward to sharing and discussing the recommendations in this report widely with stakeholders in the region to encourage action on MCEs.

On a positive note, this study does not only point out a problem, it also provides clear recommendations for how to minimize the problem. Unusual for a report on climate change, this study suggests that new homes could potentially become sites of negative emissions,[11] with atmospheric carbon stored in building materials outweighing all associated manufacturing emissions and providing a net reduction in atmospheric carbon. While it is beyond the scope of this report to consider the future supply chains necessary for a carbon-storing homebuilding sector, we want to be sure to point toward the economic potential of using the vast array of regionally available carbon-storing raw materials in new regional manufacturing of building materials and components. As there is much talk of post-pandemic "building back better" we can think of no better way to do so than by lowering CO_2 levels in the atmosphere while making energy efficient and healthy buildings out of materials that boost all sectors of our regional economy.

Methodology

The researchers chose to use the same methodology as earlier Canadian studies of MCE, following the steps illustrated in Figure 3.

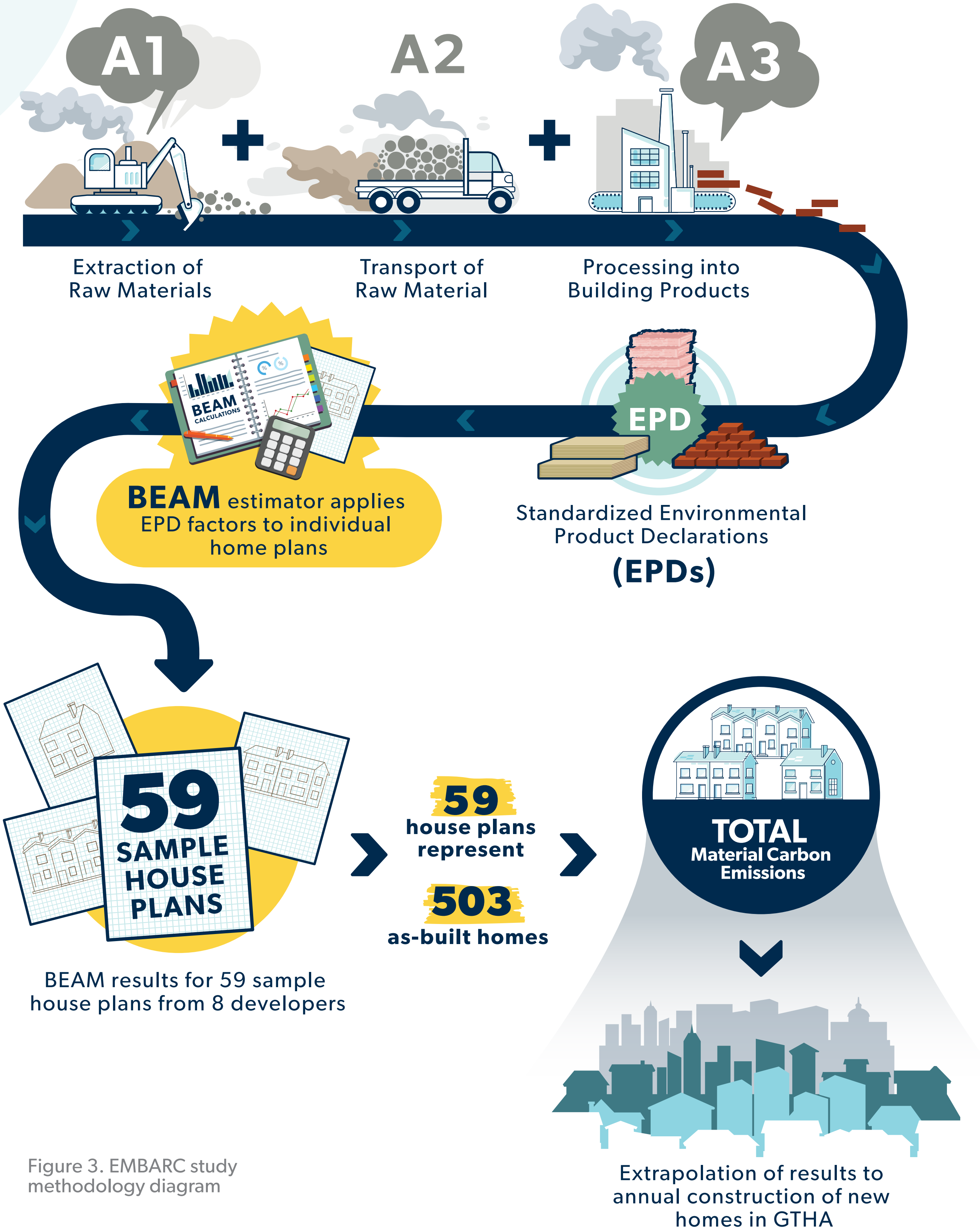


Figure 3. EMBARC study methodology diagram

2.1 New Home Starts

Each municipality in the GTHA was approached to ascertain the number of new Part 9 homes constructed between 2017-2020, composed of three typologies: single detached, semi-detached and townhouses. The annual average total is 16,428 units. The results for each typology are shown in Table 1.

Table 1. Average annual new dwelling unit completions by building type and municipal region (GTHA, 2017-2020 annual average).

Average annual new Part 9 dwelling unit completions in GTHA				
Municipal Region	**Single Detached**	**Semi-detached**	**Town-house**	**Total**
Durham	1,452	84	989	2525
Halton	1,188	169	1,036	2393
Hamilton	580	54	881	1515
Peel	2,165	419	1,137	3721
Toronto	1,122	92	570	1784
York	2,564	205	1,721	4490
GTHA	**9,071**	**1,023**	**6,334**	**16,428**
% of total units	**55%**	**6%**	**39%**	

2.2 Sample House Plans

The researchers contacted developers and builders across the GTHA with a request for Part 9 residential plans that met the criteria of the study. Eight developers/builders in the region supplied plans for the study, with the majority sharing plans for numerous homes they have constructed in the GTHA between 2017 and 2020. Most of the shared plans represent more than one constructed building. The researchers were informed of the number of times each sample plan was actually constructed during the period of the study.

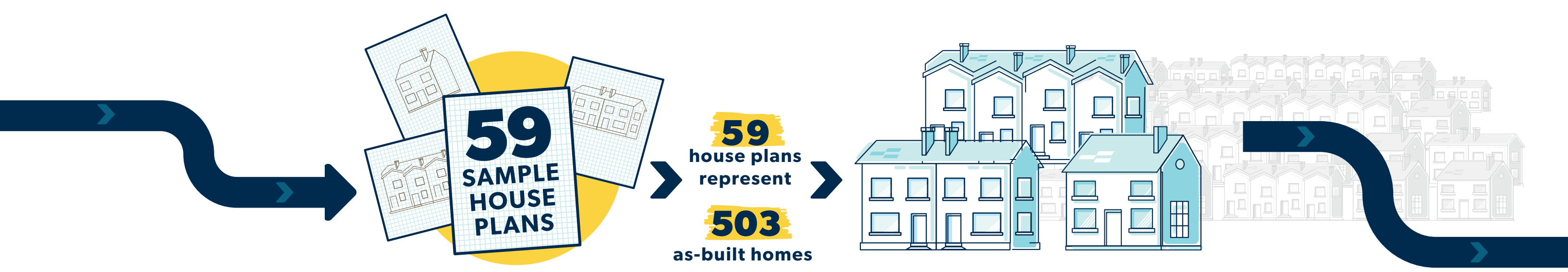
The researchers analyzed 59 different plan sets which represent 503 homes built in the GTHA region. Table 2 shows a breakdown of the plan sets by typology and built examples.

Table 2. Plan sets and number of plan sets built

Building Archetype	Plan count per archetype	Quantity of plans built
Single Detached	19	116
Semi-detached	5	38
Townhouse	35	349
Total	**59**	**503**
Single Detached	**32%**	**23%**
Semi-detached	**8%**	**8%**
Townhouse	**59%**	**69%**

The sample size is 3.1 percent of the total number of new single detached, semi-detached and townhouses typically completed annually in the GTHA. This data set of homes is the largest sample in the world of MCE-analyzed residential buildings employing a consistent methodology.

The study sample set acquired underrepresented single detached homes by 23 percent and overrepresented townhouses by 21 percent. Where applicable, the researchers adjusted for this in the calculations, as well as for the discrepancy between the sample plan floor areas and the average floor areas for the GTHA for each of the three archetypes. Floor areas for the GTHA were extracted from Milton building permits from 2017-2020, as no other municipality included floor area data in their building reporting. While Natural Resources Canada has national floor area statistics up to 2018,[12] the researchers decided this was not regionally specific enough, thus Milton's floor area values were chosen to represent all of the GTHA.[13]



TERMINOLOGY

MCE ▶ Material Carbon Emissions

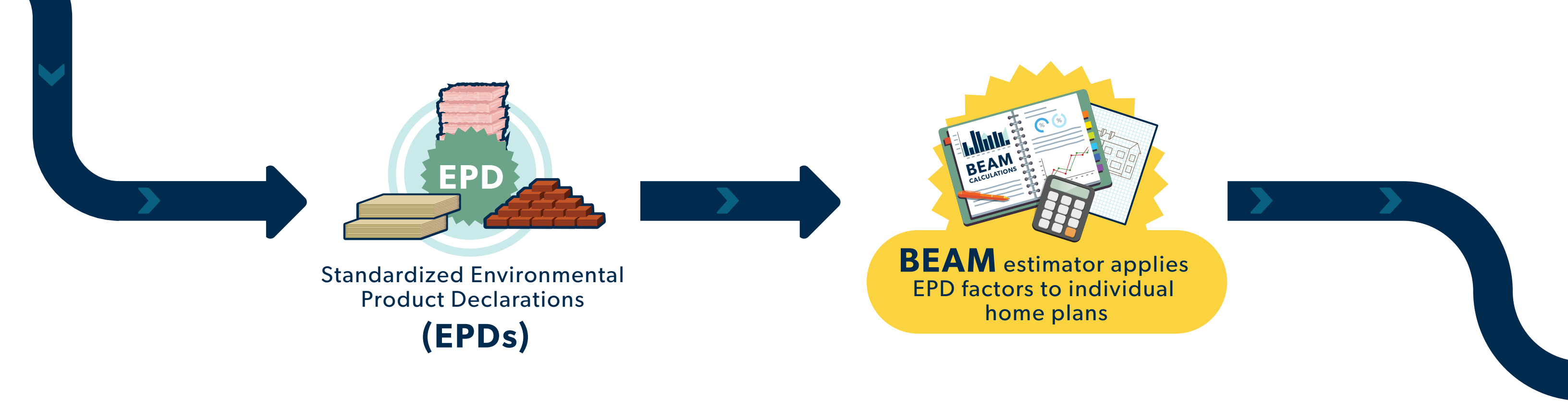
GWP ▶ Global Warming Potential

BEAM ▶ Building Emission Accounting for Materials

EPD ▶ Environmental Product Declarations

2.3 Material Carbon Emissions (MCE) Calculations

Each set of plans used in the study was entered into a beta version of a spreadsheet application called BEAM (Building Emission Accounting for Materials). BEAM was developed by Builders for Climate Action and shares an overlapping database and methodology with the Material Carbon Emissions Estimator (MCE^2) tool from Natural Resources Canada. BEAM and MCE^2 were developed specifically for Part 9 residential construction and include all materials/products used in residential applications for which there was sufficient, reliable data available at the time of the study.



2.3.1 BEAM Methodology

BEAM is based on a methodology common for embodied carbon calculations. The Global Warming Potential (GWP) factors for materials are gathered from Environmental Product Declarations (EPDs), which are third-party certified reports prepared according to ISO 14025 in addition to either EN 15804 or ISO 21930: 2017. [14] In some cases, an EPD must also conform to ISO 14071[15]. Where no EPDs exist for a product, BEAM uses an average GWP result from all applicable peer-reviewed life cycle assessments (LCAs) of the product.

The GWP factors in BEAM are a sum of life cycle stages A1 (raw material acquisition), A2 (transportation of raw materials to manufacturing facility) and A3 (manufacturing emissions). This is often referred to as a "cradle to gate" analysis and makes up the "material carbon emissions" that are the focus of this study.[16]

GWP factors are quantities of GHG emissions arising from specific life cycle stages, expressed in kilograms of carbon dioxide equivalent (kg CO_2e) per given "functional unit" of a material or product (e.g. 1 m^3, 1 kg, 1 m^2 , depending on the product). BEAM calculations begin with entering the relevant building dimensions from the plan set, which are then used as the basis for calculating material quantity estimations. Fields are provided in BEAM to further specify key dimensions and factors used to complete quantity estimations, such as R-value for insulation, framing spacing, and concrete wall and floor thickness. With all material quantity information entered, BEAM provides the GWP for every material in a given assembly. BEAM presents the user with an average GWP factor for all products in a given material category, or allows for selecting the result for a particular product within the category. For the EMBARC study, average results were selected unless there was a clear product name specified in the plans and a corresponding EPD for that product in BEAM.

2.3.2 Carbon Storage

BEAM accounts for carbon storage in products that contain biogenic materials sourced from agricultural or forestry residues and recycling streams. In such cases, the mass of biogenic material per functional unit is determined according to the product EPD or LCA and the mass of carbon within that biogenic material is calculated based on chemical composition analysis results from the Phyllis database[17]. The net GWP emissions for the product is the result of the A1-A3 carbon emissions minus the biogenic carbon storage. The net emissions for some biogenic materials therefore have a negative value when carbon storage is greater than carbon emissions. These net negative emissions materials are often termed "carbon-storing" materials.

No carbon storage attributed to virgin forest products

While there is a standard methodology in ISO 21930 for determining biogenic carbon storage credits for products, there remain important and unresolved concerns with current accounting methods related to virgin forest products like lumber. Some of these concerns include uncertainty about the amount of carbon released from soils during logging operations; the amount of carbon returning to the atmosphere from roots, slash and mill waste; the amount of carbon storage capacity lost when a growing tree is harvested; and the lag time for newly planted trees to begin absorbing significant amounts of atmospheric carbon dioxide. These factors and others are being researched and deliberated by experts from academia, the forestry industry, the building industry, environmental advocacy organizations, and LCA professions. Because these critical issues were unresolved at the time of this study, the BEAM version used for the study excluded biogenic carbon storage for products made of raw logged timbers (including framing lumber, plywood, OSB and wood trusses and I-beams).

The Positive Impact of Durable Carbon Storage: Ton Year Accounting

While there is consensus that storing carbon for a period of time has a mitigating impact on climate change, there has been considerable debate about how to account for the value of temporary carbon storage. The Moura Costa method[18] of ton-year accounting establishes the value of carbon dioxide stored in durable products such as building materials. As shown in Figure 4, a one metric ton of carbon dioxide emissions causes 46 ton-years of radiative forcing damage to the climate over a 100-year timeframe (the area in grey). Drawing one ton of carbon dioxide out of the atmosphere and storing it for a period of 46 years mitigates the climate damage from one ton of CO_2 emissions (the area in green).

The materials attributed carbon storage by BEAM have anticipated lifespans of at least 46 years and can thus be said to have at least the positive climate impact of their full carbon content. Many such materials will last longer than 46 years in a building, and may therefore increase the storage value; materials removed from the building before reaching 46 years could have their carbon storage value discounted accordingly (see Table 3).

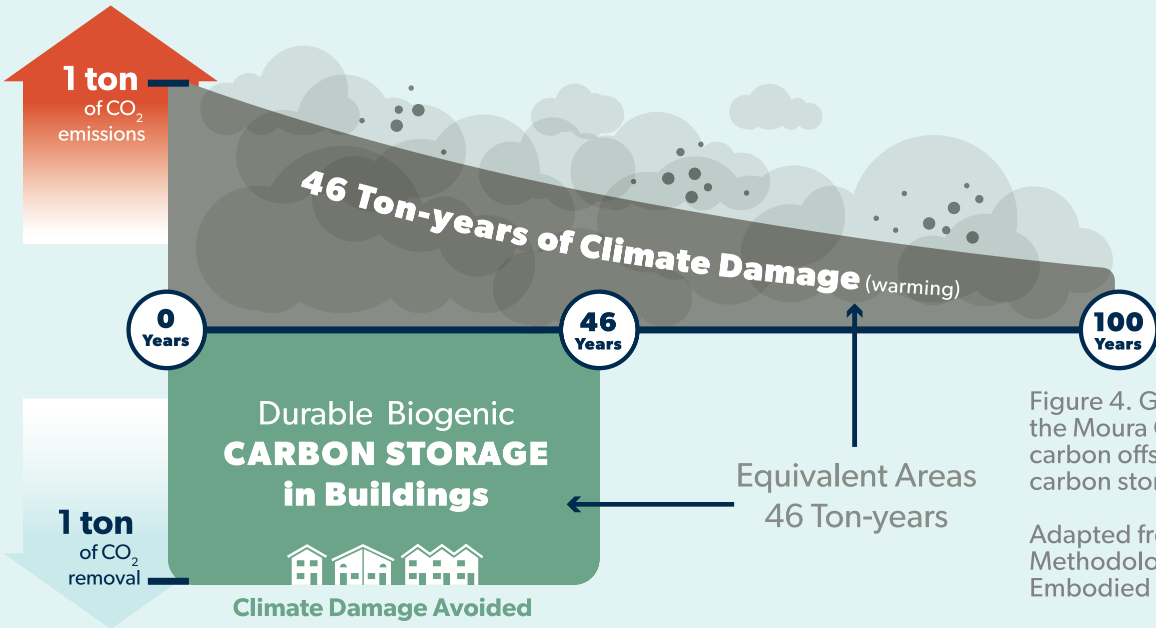


Figure 4. Graphical representation of the Moura Costa method to establish the carbon offset equivalence of biogenic carbon storage in building materials.[19]

Adapted from Srubar et al., A Methodology for Build- ing-Based Embodied Carbon Offsetting (2021)

Table 3. Examples of carbon offset value of biogenic carbon for various time horizons.

Ton Year Equivalency Factors for Biogenic Carbon		
Biogenic Carbon Stored	**Duration of Storage**	**Equivalent Offset of Present-day Emissions**
100 tons	1 year x 2.17%	2.17 tons
100 tons	20 years x 2.17%	43.4 tons
100 tons	46 years x 2.17%	**100 tons**
100 tons	80 years x 2.17%	174 tons

The factors in Table 3 assume that 100 percent of the carbon contained in the material will return to the atmosphere when removed from the building. Any material reuse, recycling or carbon capture (or a percentage of carbon materials put in landfill that do not decompose) would alter these scenarios accordingly, as any carbon that remains out of the atmosphere would continue to have a positive impact on the climate. For a world with a rapidly dwindling carbon budget and ample opportunities for biogenic carbon storage in the built environment, this methodology offers a great deal of potential to encourage this type of climate mitigation.

2.3.3 Cradle to Gate Focus on Structural, Enclosure & Interior Surface Materials

This study and the BEAM tool focus on lifecycle stages A1 to A3 emissions (defined in 2.3.1) because they represent the majority of the life cycle GHG emissions from building products, typically accounting for 70-80 percent of life cycle emissions from buildings[20]. For the first 30 years of a building's lifespan (that is, before substantial repairs or replacements of materials occur), A1-A3 emissions account for over 90 percent of material emissions. Given the timelines we are facing for dramatically reducing emissions, this methodology prioritizies the time value of addressing A1-A3 emissions.

Using the building plans, each material for each assembly in the building is selected, and the kg CO_2e results are calculated both for the assembly and for the whole building. Once all materials have been selected, BEAM provides a total for Material Carbon Emissions (MCE) for the building in both kilograms and tonnes of CO_2e, as well as the Material Carbon Intensity (MCI) which is the MCE divided by the floor area of the building in kilograms of CO_2e per square meter (kg CO_2e/m^2).

This study, and the BEAM tool, focus on the main structural, enclosure and interior surface elements of a new Part 9 home. Figure 5 shows the materials that are included in this study.

- ✔ Footings and slabs
- ✔ Foundation walls
- ✔ Structural elements (posts and beams)
- ✔ Exterior walls
- ✔ Party walls (where applicable)
- ✔ Exterior cladding
- ✔ Windows
- ✔ Interior walls
- ✔ Floors
- ✔ Ceilings
- ✔ Roof

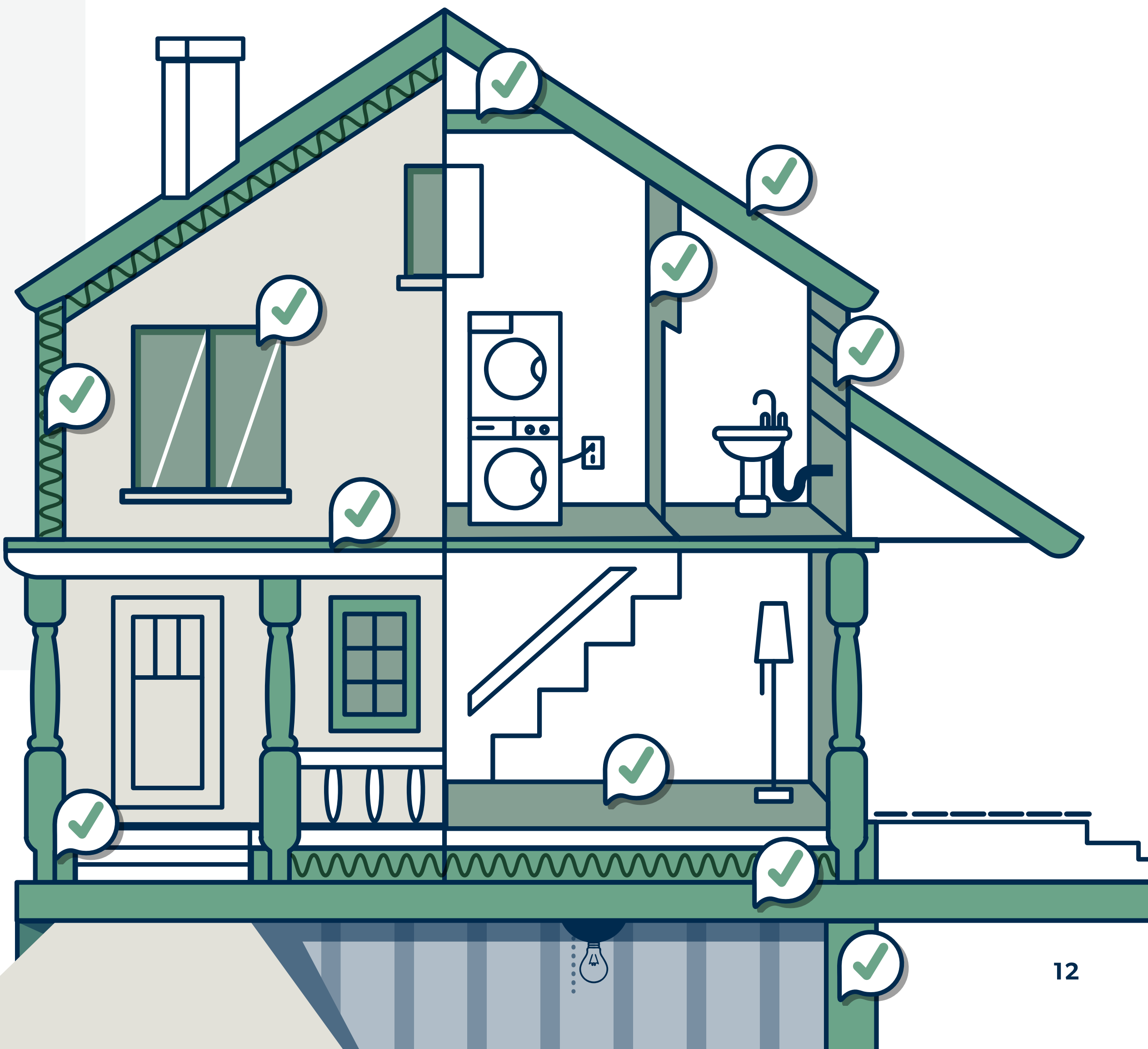


Figure 5. Materials included in the study.

These elements of the building were selected for four key reasons:

1. **They represent the majority of the overall material mass**
2. **There is good quality EPD and LCA data available for all common options in these categories**
3. **They typically have lifespans of at least 25-30 years and often last as long as the building**
4. **There are meaningful, immediately available design options and/or material substitutions available in each of these areas that allow a home builder to substantially alter the emissions profile of the building**

By addressing the bulk of a new home's emissions and focusing on those areas in which significant reductions can be achieved, we believe this approach maximizes the utility of the results.

Each set of plans was entered into BEAM by a member of the Builders for Climate Action team, familiar with the software. A review of each entry was conducted by a different team member to ensure accuracy.

The BEAM calculations for each individual set of plans were then compiled into a spreadsheet that enabled the researchers to examine the results by home, typology, location, size, material category and material type.

2.3.4 BEAM Limitations

The results derived from BEAM should be considered estimates of emissions, and not definitive quantities. Results from BEAM are similar in nature to those obtained from energy modeling software, from which comparative results from different materials and strategies can be accurately derived, but from which actual energy use may not be accurately predicted.

It is important to note that BEAM will underestimate the total emissions arising from materials for a new home because a number of significant material categories are not currently considered within BEAM, including:

- ✘ **Mechanical, electrical and plumbing (MEP) materials.** These are excluded due to a lack of available EPD data and lack of meaningful substitutions in each category. Material GHG emissions from MEP could range from 40-75 kg CO_2e/m^2, which could add an additional 26-49 percent to the average gross floor area MCI for homes in this study.[21]
- ✘ **Paints and surface finishes.** These are excluded because the lifespan of these materials is typically shorter than the minimum 25 year lifespan required for inclusion in BEAM. They do, however, contribute significantly to the MEC of a new house. A typical single detached house in this study has approximately 750 m^2 of wall and ceiling area that would be painted, and an average interior paint (all coats) has emissions of 3.5 kg CO_2e/m^2, resulting in an additional 2.6 tonnes of emissions or 6 percent of the average emissions for a home of this size.[22] Finishes for trim, doors and millwork would add to this total.
- ✘ **Fixtures and appliances.** These are excluded due to lack of available data and lack of meaningful substitutions. Many of the key components of fixtures and appliances (steel, stainless steel, copper, porcelain) are known to have substantial MCE but few EPDs or LCA studies of specific products exist.
- ✘ **Millwork, stairs, cabinetry and trim.** These are excluded due to lack of available data and lack of meaningful substitutions.
- ✘ **Decks, driveways, earth moving, excavations, and all site works.** These are excluded due to the variability and complexity of adding these to the study.

It is possible that with all of the above elements added into MCE calculations, the results in this study may represent as little as 50 percent of the total material emissions impact for new home construction. Any extrapolation of the total impact of new home MCE across the study region should be done with awareness of these omissions.

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kg CO2e ▶ Kilograms of carbon dioxide equivalent

t CO_2e ▶ Tonnes of carbon dioxide equivalent

Results & Discussion

The results from the EMBARC study provide insights at the level of the entire housing sector in the region, individual houses, material categories and specific materials.

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

Each set of plans entered into BEAM was assessed for its net material carbon emissions (MCE), the total of all material emissions minus any biogenic carbon storage. Table 4 summarizes the overall measured MCE results.

Table 4. Net MCE results for all measured materials

Net Material Carbon Emissions for 503 GTHA Sample Buildings		
Statistic Type	**MCE** [kg CO_2e]	**MCE** [t CO_2e]
Best / Lowest Home Result	9,517	9.5
Worst / Highest Home Result	827,117	827.1
Mean (Average)	56,163	56.2
Standard Deviation	104,188	104.2
Weighted Avg by Qty Built	40,006	40.0
Median	39,350	39.3
Total of individual sample homes (59)	3,313,557	3,314
Total of sample homes built (503)	**20,121,858**	**20,122**

Across the study's sample of 503 as-built housing units, an estimated 20,122 t CO_2e was emitted, giving a weighted average of 40 t CO_2e per unit. Extrapolating the study's average values to the 16,428 Part 9 homes typically built annually in the GTHA, and adjusting for the average archetypal floor areas for each region, the total annual MCE from new Part 9 homes may be roughly around 840,000 t CO_2e annually.

> **This is the equivalent of the annual emissions from more than 183,000 automobiles.**[23]

In comparison to other emissions sources in the region, this figure is slightly higher than GHGs from residential waste (724,337 t CO_2e) and well above agriculture (422,186 t CO_2e). Material carbon emissions assessed for these three archetypes of homes in the GTHA represents approximately 1.5 percent of total carbon emissions in the region in 2020[24].

As discussed in Section 2.3, the MCE measured in this study may represent as little as 50 percent of the total MCE for these building typologies, due to the exclusion of MEP equipment, appliances, finishes and millwork, suggesting a possible impact of 1.75 Mt (megatonnes) of embodied carbon emissions from new GTHA Part 9 residential building construction annually.

MCE by House Typology

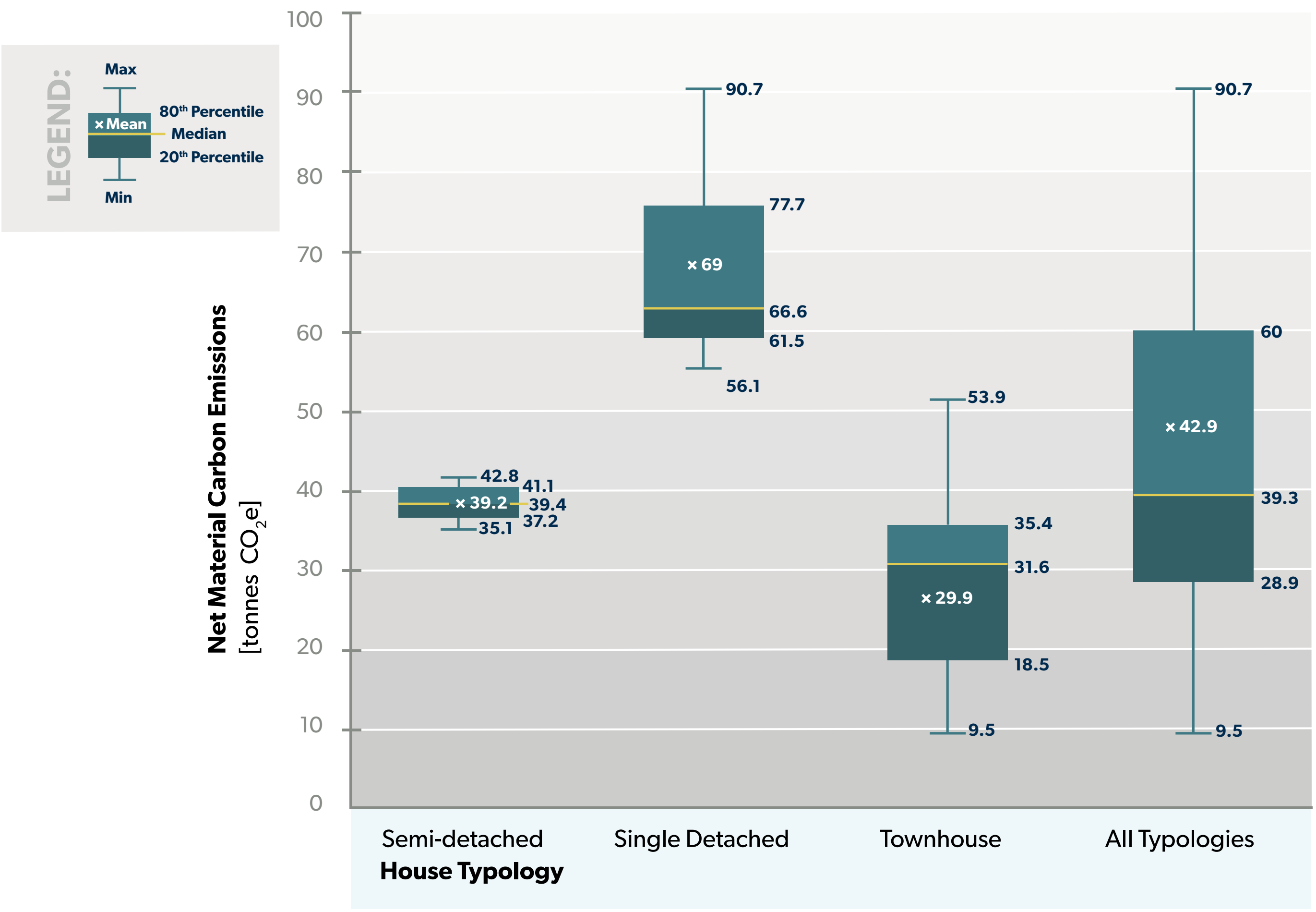
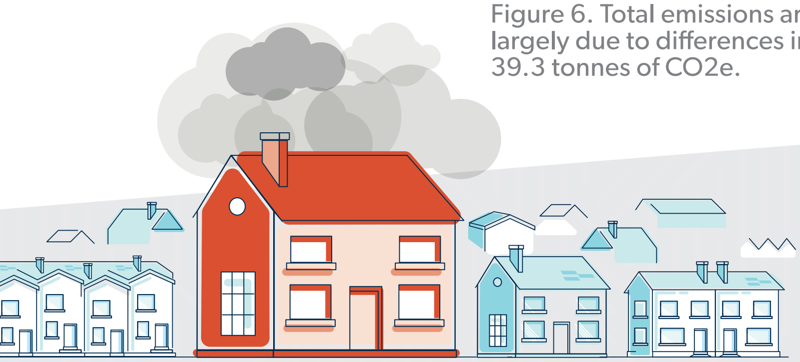
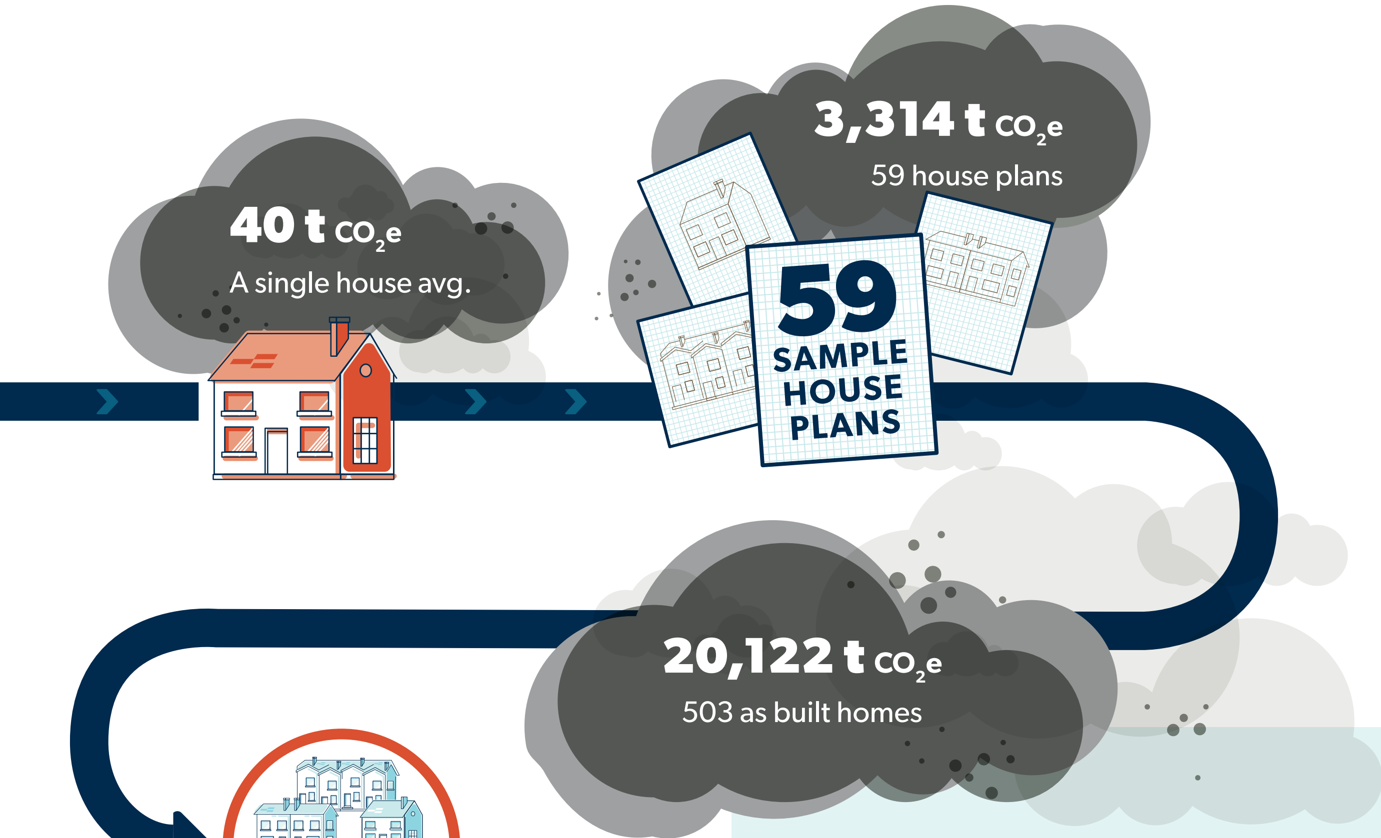
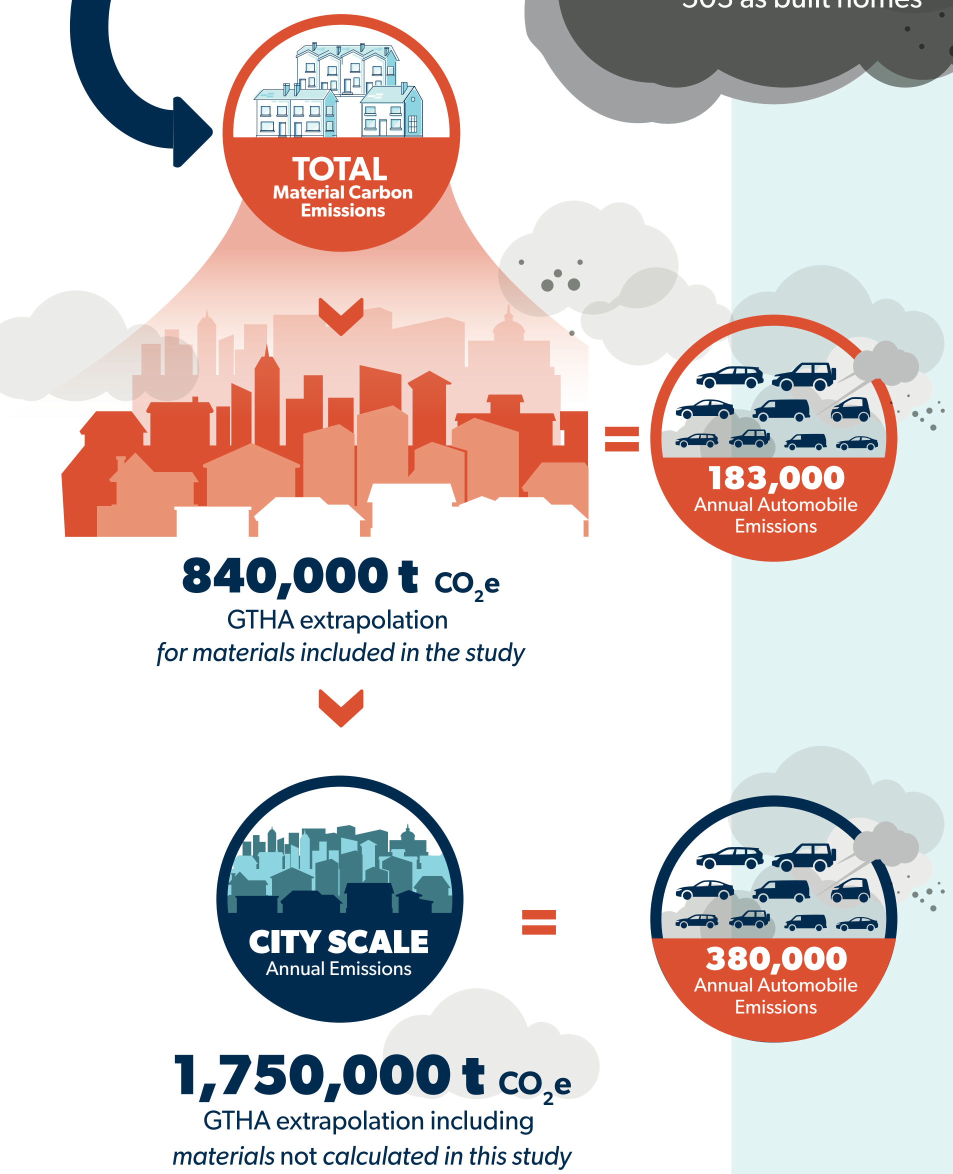


Figure 6. Total emissions are lowest for townhouses and highest for single detached, largely due to differences in size. For all typologies, the median for the 503 homes was 39.3 tonnes of CO2e.







Missing building types for a complete emissions inventory

This study examines only new residential buildings that meet the requirements of Part 9 of the Ontario Building Code, representing only 44 percent of residential units constructed annually in the GTHA. Part 3 (large) apartment and condominium units are built in greater quantities and are not captured in this study. A more complete assessment of overall residential-sector MCE in the GTHA region would also need to consider the impacts of renovation materials for existing buildings. A complete assessment of all building MCE emissions of the GTHA would need to include all non-residential buildings as well. A study from The City of Toronto, The University of Toronto and Mantle Developments[25] assesses MCE of some types of Part 3 (large) buildings in the region. The average A1-A3 emissions for 38 buildings in the study was 345 kg CO_2e/m^2, significantly higher than for the low-rise buildings studied in EMBARC.

TERMINOLOGY

MCE ▶ Material Carbon Emissions

MCI ▶ Material Carbon Intensity

Size matters

In the study, the smallest floor area belonged to a townhouse unit of just 48 m^2 (517 ft^2) and the highest to a single family home of 1,475 m^2 (15,880 ft^2), a 31-fold increase in floor area. As might be expected, such variation in home size has a direct influence on total MCE.

Table 5 shows results by housing typology (isolating an exceptionally large single family home outlier from the rest) and demonstrates the influence of home size on MCE. The floor area reported in this table is heated (also known as 'conditioned') floor area, which excludes garage areas.

Table 5. Home size and average MCE.

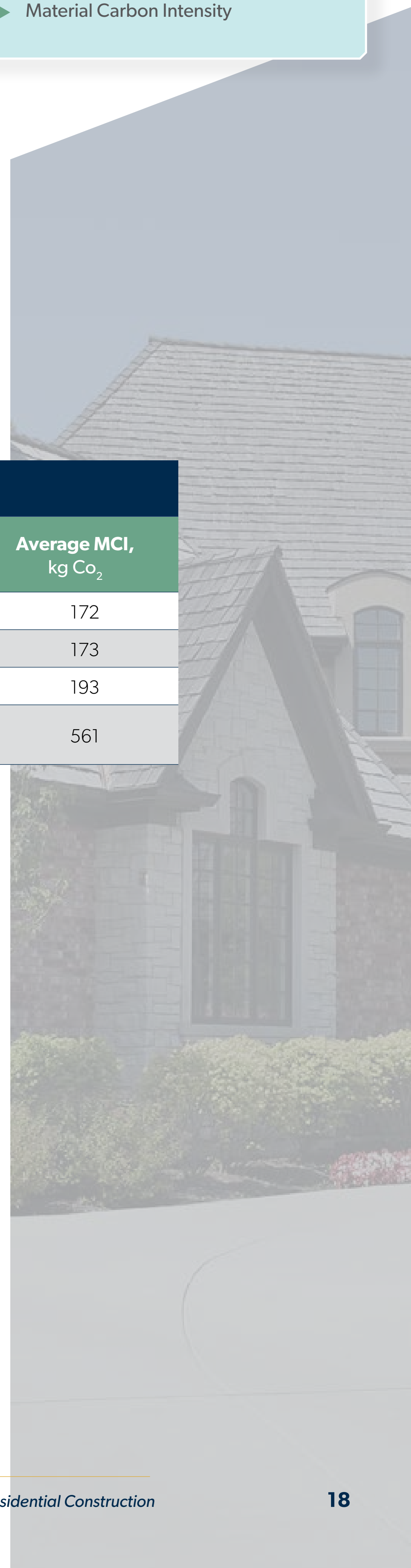
Home size and average MCE and MCI

Housing typology	Number of sample plan sets	Average MCE, kg CO_2e	Average heated floor area, m^2	Average MCI, kg Co_2
Single detached	18	69,010	411	172
Semi-detached	5	39,209	241	173
Townhouse unit	35	29,951	166	193
Large single family home	1	827,117	1,475	561

The MCE averages tend to vary proportionally with the size of the units. Excluding the large single family dwelling, the average size of a semi-detached home and a townhouse were 41 and 60 percent smaller than the average single detached, respectively. Their MCE averages were 43 and 57 percent lower than the average single family home, demonstrating a correlation between size and MCE.

MCE is a useful metric for assessing the total GHG impact of any particular house and of housing in the region. In order to recognize the clear relationship between home size and emissions Material Carbon Intensity (MCI) can be used. MCI is the result of total building MCE divided by floor area (in square meters). MCI allows a relative comparison of large homes to small homes and can be used to project how material changes might affect homes regardless of their size.

In this study, MCI was calculated using total building floor area, heated floor area (excludes garage) and habitable floor area (excludes garages and unfinished basements). Table 5 summarizes the MCI results.



MCI by Floor Areas

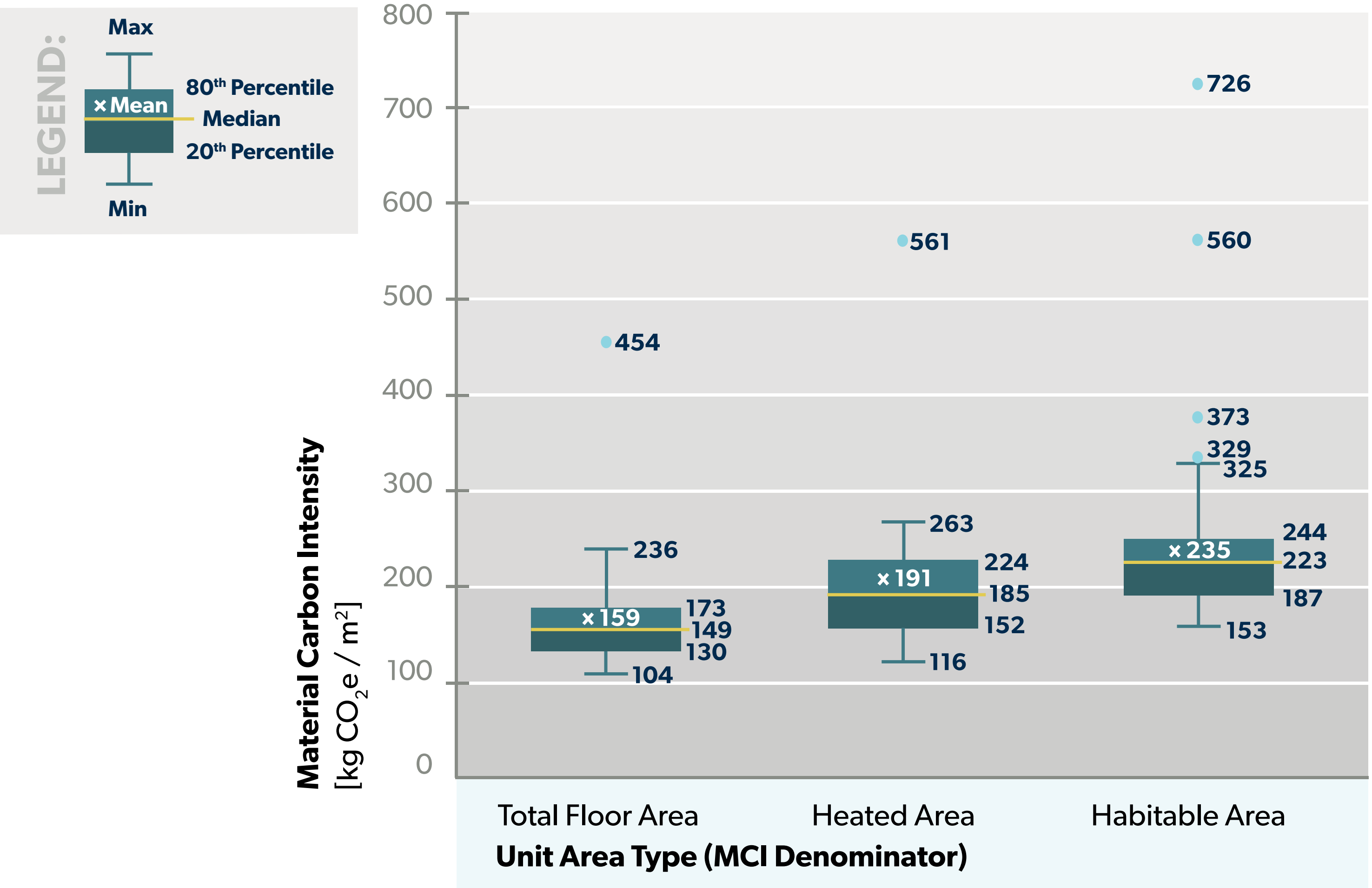
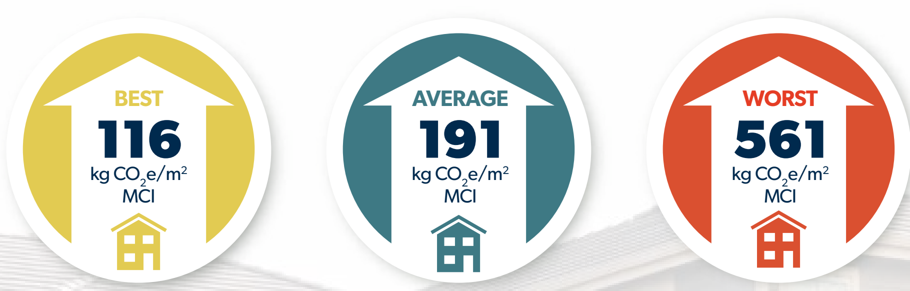


Figure 7. Material carbon intensity varies depending on the defination of floor area being used.

Total floor area MCI for the weighted average of the 503 homes is 159 kg CO_2e/m^2, which is 17 percent lower than MCI for heated floor area and 32 percent lower than habitable floor area (Figure 7). This points to the importance of identifying the metric used to calculate MCI when comparing results. The need for industry and regulators to agree on appropriate metrics for MCI is addressed in Section 6.3.

Best, average and worst MCI for Heated Floor Area



3.1.1 Housing Typology and MCI

Examining the MCI results by housing typology and by different definitions of floor area highlight how important the selection of metrics for MCI can be. Depending on the metric chosen, different typologies can be seen as best or worst.

Examined by total floor area, the difference in results for each typology are minimal, with semi-detached the lowest MCI at 144 kg CO_2e/m^2 and single detached and townhouses 5 and 8 percent higher.

Table 6. MCI can be considered by floor area designation and/or house typology. Defining these parameters will be important for policy makers.

	Material Carbon Intensity (MCI) [$kgCO_2e/m^2$] (weighted average)			
Area Type	**Single Detached**	**Semi-detached**	**Townhouse**	**All Types**
Total floor area	152	144	156	154
Heated floor area	167	156	199	189
Municipally defined gross floor area	209	216	185	193
Habitable floor area	229	213	224	225

Examined by heated floor area the differences get larger. The weighted average for semi-detached homes in this study had the lowest MCI, at 156 kg CO_2e/m^2, with single detached homes 7 percent higher and townhouses 22 percent higher.

Using a definition of gross floor area employed by some municipalities in the GTHA (which counts garage area but ignores basement area), the townhouse becomes the best result at 185 kg CO_2e/m^2, with single detached 11 percent higher and semi-detached 14 percent higher.

Using only habitable floor area as the basis for MCI semi-detached homes have the lowest result, 5 and 7 percent lower than townhouses and single detached, respectively.

Clearly, the choice of metrics for measuring MCI can have an important impact on the results for different types of homes. As discussed in Section 6.3, policy makers must weigh the impacts of the metrics they select carefully to ensure they support other municipal priorities such as density.

The study of material carbon emissions is relatively new. The intent of this study is to help inform potential policy action to incentivize or regulate these emissions in the home building sector. Effective policy will require appropriate metrics to ensure that policies do not create perverse incentives or negatively impact other policy priorities. As the results of this study demonstrate, changing the unit upon which emissions intensity is measured can dramatically alter the results. For example, calculating MCI by total floor area compared to heated or habitable floor area can change the MCI result by 19 and 32 percent, respectively.

Priorities such as increasing residential density, reducing uninhabited space or emission reductions through renewable energy systems could be incorporated into a new metric. The researchers explored Material Carbon Intensity by Function, or MCIF (see Sidebar XX) as an example of a metric that can combine desired outcomes.

3.1.2 Combining Material and Operational Emissions: Carbon Use Intensity

The EMBARC study did not include the operational carbon emissions (OCE) of the homes in the study. However, consideration of both MCE and OCE is critical to understanding a more complete scenario of emissions arising from new homes.

Carbon Use Intensity (CUI) is a metric that adds a home's operational carbon emissions (OCE) to its MCE to demonstrate the total impacts of both these significant factors. Since OCE accumulates annually, the CUI metric is usually associated with a particular time period. CUI can be expressed according to a number of years (ie. CUI_{30} would be the total of MCE and OCE over a 30 year period) or according to a fixed time window (ie. CUI_{2030} would be the total of MCE and OCE between the date of construction and the year 2030). Either version of the CUI metric would allow regulators to compare the combined operational and material emissions associated with a new home to their broader climate mitigation targets.

The NRCan report *Achieving Real Net Zero Emission Homes* discusses the importance of considering CUI: "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 holistic and offers more flexibility to the unique conditions that exist in every region where homes are built."[26] The "flexibility" refers to the options left to builders to weigh the impacts of energy efficiency measures, fuel choices and material selection to best meet the needs of their homeowners while adhering to the climate goals of the country, province and/or municipality.

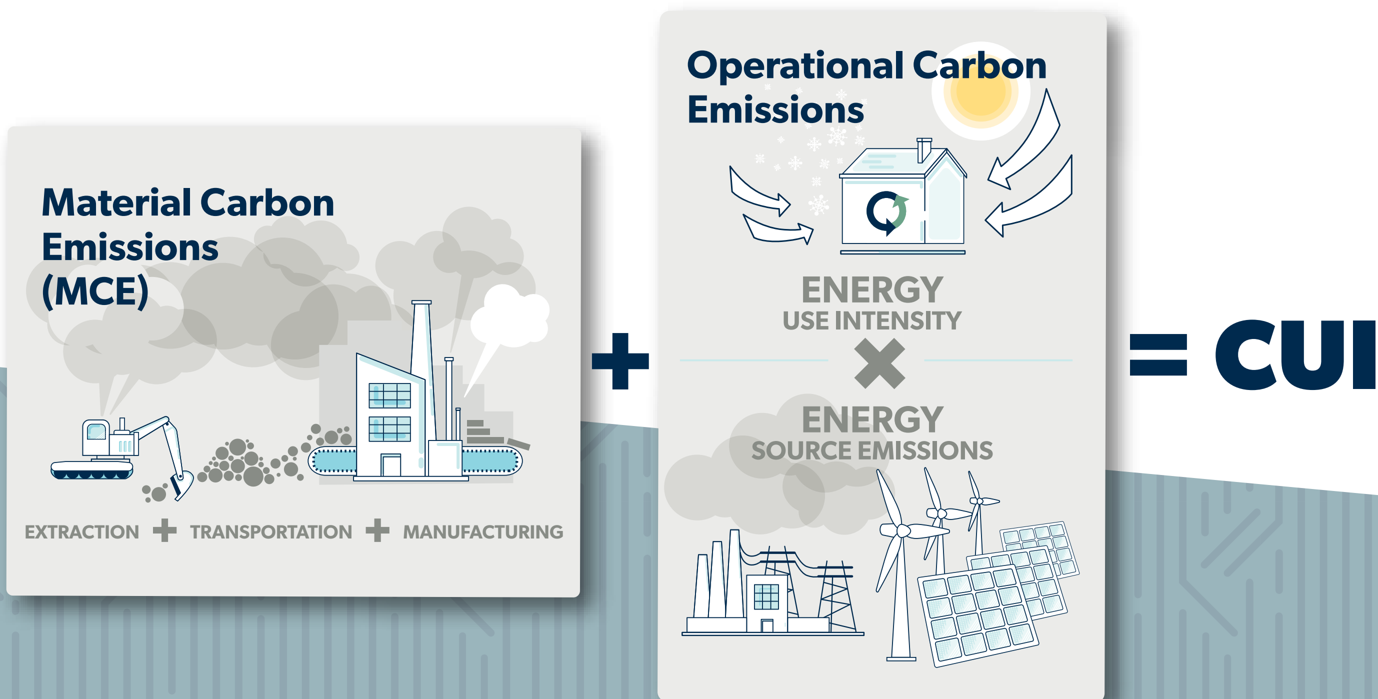


Figure 8 shows the CUI_{30} results from the NRCan study for a model two-storey home in Toronto and demonstrates how the variables of energy efficiency, fuel choice and MCE can impact overall emissions over a 30 year period. By working with a CUI metric, the builder could determine the best path to meeting a CUI target.

Consideration of MCE as an important factor in overall emissions from the homebuilding sector is very recent. The selection of a metric for calculating and reporting MCE will have an important impact on how MCE is addressed and potentially regulated and should be an important part of ongoing discussions.

CUI for Toronto 2-storey home scenarios

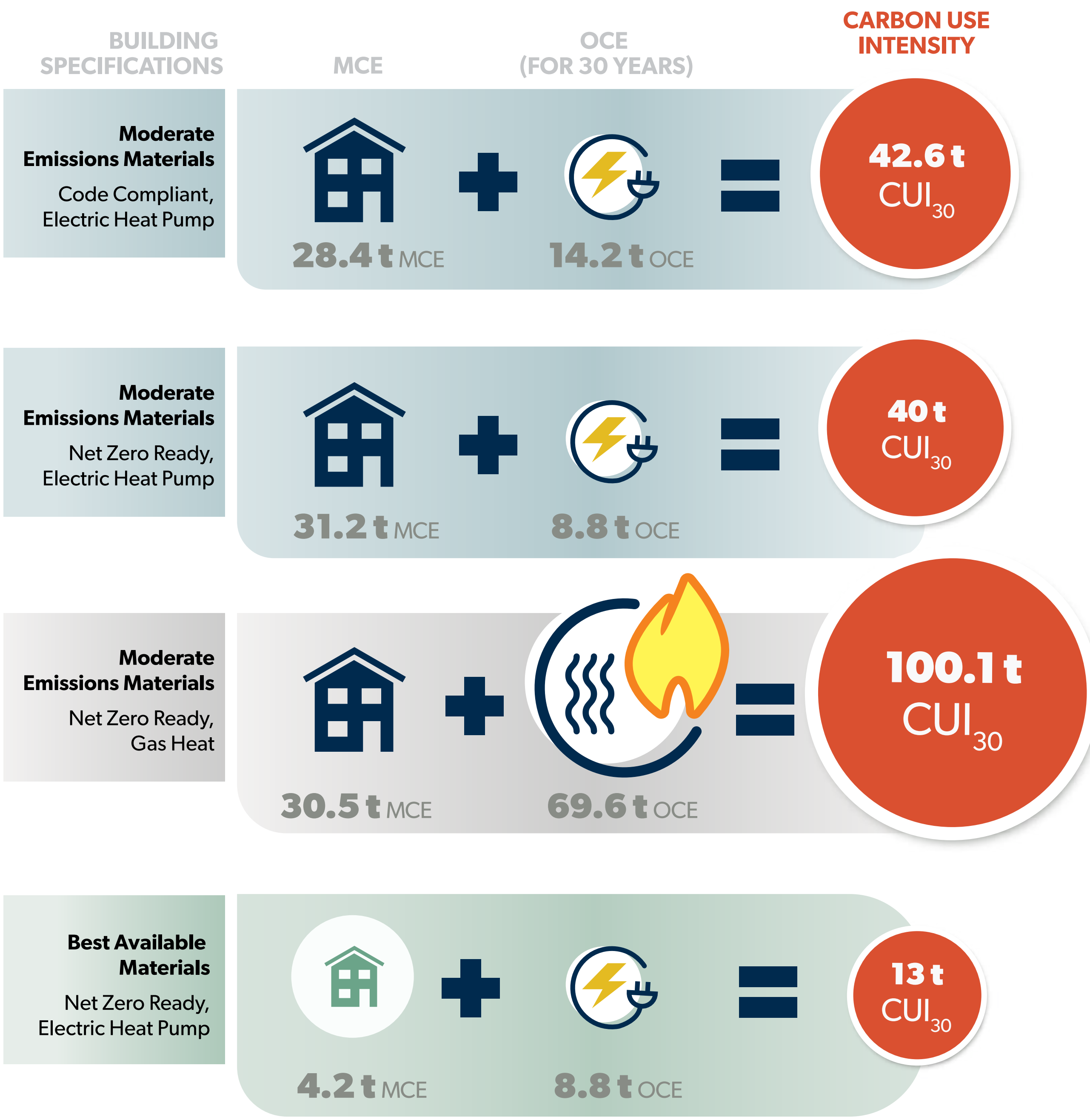


Figure 8. Carbon Use Intensity for the same home design is impacted by both MCE and OCE. Energy efficiency, fuel type and material selections all have an impact on CUI.

Exploring new metrics for MCE:

Four performance criteria were chosen by Erik Bowden, one of the study's authors, to be addressed by a new MCI metric, which aims to have positive carbon and housing availability impacts for regions that adopt it. These include increasing housing occupancy capacity, using the number of bedrooms as a proxy for occupancy, decreasing uninhabited space, decreasing gross building size relative to occupancy, and decreasing the building's overall MCE.

$$MCI_F = \frac{C \cdot A}{B \cdot A_h}$$

C = net MCE in t CO_2e,
B = quantity of bedrooms in the unit
A = gross area in m^2, and A_h = habitable area in m^2.

Using these factors, Bowden proposes a derived metric called Material Carbon Intensity by Function, or MCI_F, with the units of t CO_2e/bedroom.

The lower the value obtained, the better the building is at achieving the performance criteria, overall.

A ratio of gross floor area to habitable floor area was applied, rather than only dividing by floor area as is typical, to encourage the optimal use of constructed space. As this ratio decreases from one, the MCIF increases. For example, if half of the floor area is unfinished basement and garage space, the MCIF is doubled. In cases where all floor area is habitable (i.e. a 1:1 ratio), there is no impact on the metric.

To address housing needs in combination with material carbon, it is proposed that the number of bedrooms per housing unit be included in the MCIF metric as a proxy to occupancy capacity. All other factors being equal, a home with more bedrooms will have a proportionally lower MCIF value.

Unifying these four factors into MCIF is just one suggested method among many emerging ways of evaluating a home's emissions intensity. One downside of MCIF could be that with simplification, resolution of the contributing factors is lost. Though slightly more complex, it may prove to be better to use multiple separate metrics in coordination in order to maintain resolution, such as total MCE, MCI/bedroom and MCE/m2 of habitable floor space, each with their own benchmarks and bounds. Ultimately, as long as these separate metrics are used concurrently to focus evaluation on the desired goals, deleterious effects caused by any one metric should be constrained by the others.

3.2 Material Analysis

All new homes are amalgamations of many different materials. The BEAM models for each home in this study provide insights about material use that can be helpful at different levels: comparison of broad material categories, comparison within material categories, and materials with high per-use emissions or carbon storage. Each level can help focus regulatory, design and procurement attention where impacts can be greatest.

Material Categories

Material categories capture the impacts of materials that may show up in more than one assembly in a home, such as concrete (in slabs, basement walls, garage floors, and footings.) and insulation (in floors, walls and roofs). Figure 9 shows the total emissions attributed to each of the main materials categories in all 503 sample homes.

Concrete, insulation, and cladding are the three most emission-intensive categories of Part 9 home building material, together representing 72 percent of the measured MCE. Serious emission reductions in these three categories would be the most impactful interventions, and each is explored in more detail below.

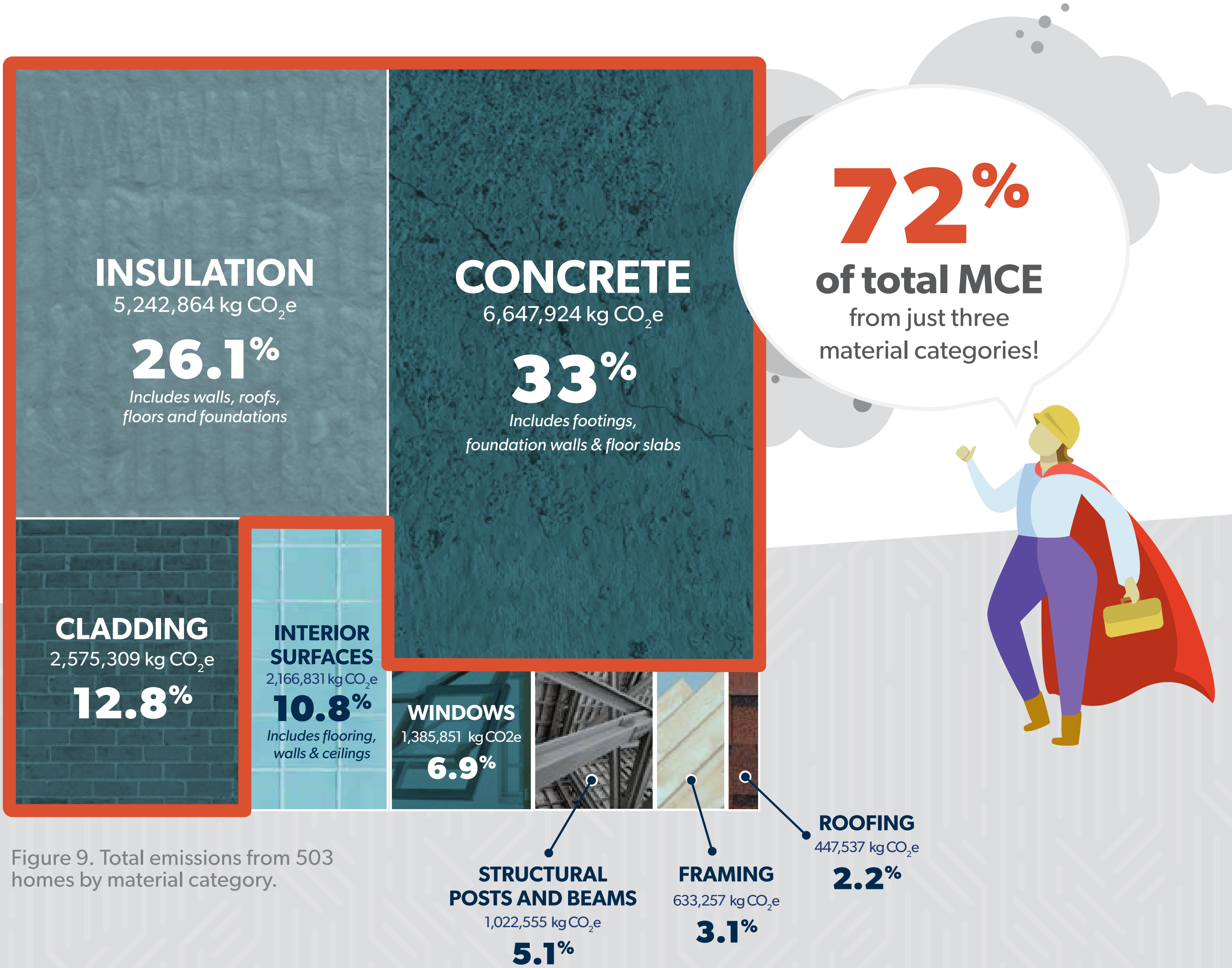


Figure 9. Total emissions from 503 homes by material category.

3.2.1 Concrete

Concrete plays an important role in new homes, as it is the dominant material choice for footings, foundation walls and floor slabs. Every home in the study used concrete for these elements. The pervasiveness of the material along with its relatively high MCE means that the concrete components of GTHA homes had the largest impact on overall emissions, representing 33 percent of total emissions from new homes. Figure 10 shows the contribution of concrete, rebar and reinforcing mesh to this total.

The impact of concrete emissions is sizable as calculated, but may be understated (or, less likely, overstated) due to a lack of product-specific data about concrete mixes in the building plans and from GTHA regional plants.[27]

For determining the carbon emissions of concrete, the BEAM tool uses an Environmental Product Declaration prepared by the Canadian Ready Mix Concrete Association[28] which presents industry-wide average data. For concrete in the 0-25 MPa (~3,000 psi) compressive strength category (typical for use in Part 9 homes), this EPD presents 19 different possible mix designs, each with different GWPs that range from a high of 327 to a low of 214 kg CO_2e/m^3. This EPD declares an "Industry Average Benchmark" of 305 kg CO_2e/m^3 and this is the figure selected in BEAM for all concrete calculations in this study.

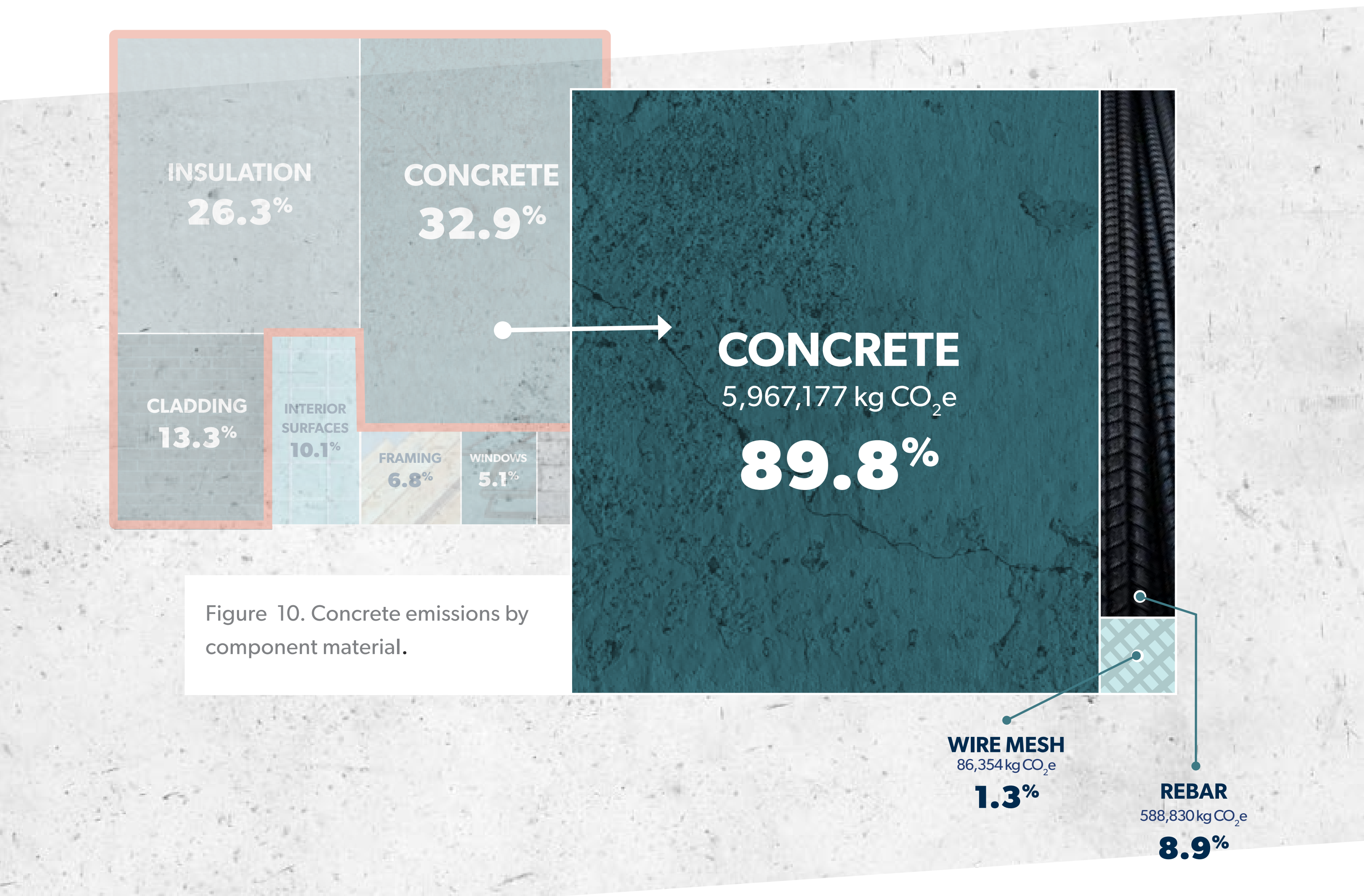


Figure 10. Concrete emissions by component material.

The EC3 (Embodied Carbon in Construction Calculator) tool[29] is the largest repository of construction material EPDs in North America, and while it contains 109 product-specific EPDs for 0-25 MPa (28 day compressive strength) concrete from Canadian manufacturers, none of these originate from Ontario. More broadly, the lowest GWP for Canadian concrete in EC3 is 93 and the highest is 828 kg CO_2e/m^3. EC3 calculated an average of 390 kg CO_2e/m^3 for Canadian concrete calculated using uncertainty factors arising from the quality of data used in generating EPDs. Table 7 shows the impact on overall concrete emissions in this study by applying different GWP factors for 0-25 MPa concrete.

Table 7. Comparison of possible GWP factors for 25 MPa concrete in Canada
*Total GWP for concrete only, does not include rebar or mesh

Concrete Mix	GWP Factor kg CO_2e/m^3	Emissions from 503 samples, kg CO_2e	Percentage change from benchmark
CRMCA - 0-25 MPa, Canadian Benchmark Avg.	**305**	**4,269,344***	
Butler Concrete N254	124	1,738,469	**-59%**
LaFarge ECOPact RMXUG35A3A8M	170	2,383,385	**-44%**
CRMCA Mix #19 - 0-25 MPa, 35-50% Slag, GUL	214	3,000,260	**-30%**
CRMCA Mix #18 - 0-25 MPa, 35-50% Slag, GU	234	3,280,660	**-23%**
CRMCA Mix #10 - 0-25 MPa, 30-40% Fly Ash, GU	250	3,50,478	**-18%**
CRMCA Mix #12 - 0-25 MPa, 25-34% Slag, GU	268	3,757,337	**-12%**
CRMCA Mix #6 - 0-25 MPa, 15-29% Fly Ash, GU	283	3,967,635	**-7%**
CRMCA Mix #1 - 0-25 MPa, 0-14% FA/SL, GU	327	4,584,512	**+7%**
EC3 Avg. for 107 Canadian 25 MPa concrete EPDs	390	5,467,766	**+28%**
EC3 Conservative estimate for Canadian 25 MPa	507	7,108,096	**+66%**
LaFarge RMXK925A21F	610	8,552,147	**+100%**

Concrete mix design can have a large impact on GWP factors. The use of supplementary cementitious materials (SCMs), including fly ash and blast furnace slag, account for 25 percent of the difference between results in the CRMCA EPD (it is important to note that availability of fly ash and slag quantities will diminish as the emissions-intensive industries that produce these byproducts are scaled down over the next decades). Use of Type 1L/GUL (Portland-Limestone) Cement offers a 5-15 percent reduction in GWP, and in combination with high percentages of SCMs can bring overall emission reductions of up to 35 percent, as seen with Mix #19.

If the EC3 average of 390 kg CO_2e/m^3 is applied to all 0-25 MPa concrete in this study, overall emissions would increase from the 4,269 t CO_2e assumed in the study to 5,468 t CO_2e, a 28 percent increase.

Today's best available concrete could eliminate 2,500 tons of emissions from new home construction annually.

At worst, 0-25 MPa concrete with a high GWP factor of 610 kg CO_2e/m^3 (as would be the case with five Canadian EPDs found in the EC3 database) would raise concrete emissions in this study to 8,552 t CO_2e, a 100 percent increase. If GTHA builders were able to access the best-possible 0-25 MPa Canadian concrete mix, emissions would be reduced by 2,531 t, a 59 percent reduction.

The wide range of results arising from different concrete GWP factors points to the importance of obtaining reliable, manufacturer-specific EPD data for concrete for GTHA homes. Without such data, taking quantifiable action on the largest source of emissions from new home construction will be difficult.

The BEAM tool enables users to input "User Defined Options" and this would enable information from any valid concrete EPD from a local supplier to be calculated in a model. The use of product specific EPDs in the concrete category is an essential step in properly assessing the emissions and reductions in this critical category.

While mix design offers opportunities for emissions reductions, it is possible for new homes to be designed to use less concrete by minimizing below-grade construction and/or substituting materials such as treated wood foundations. Homes built above-grade using pier or pin foundations can eliminate concrete use altogether. It is beyond the scope of this study to directly analyze the minimization or elimination of concrete, but while concrete is the largest contributor to MCEs these options may be worth further exploration.

Changes in concrete mixture formulation has implications beyond emissions. Mixes with high proportions of SCMs can take longer to cure and therefore impact construction schedules. While it is beyond the scope of this report to explore this issue, it certainly requires consideration.

The concrete industry may see innovations that will change the GHG-intensity of their products. CO_2 injection has been shown to reduce GWP by 4-6 percent[30] (on top of reductions available via cement substitution noted above) and is available on the market now. The use of captured CO_2 to make aggregate could result in concrete that stores more carbon than it emits.[31] The use of biochar as an aggregate can similarly reduce the MCE of concrete. Policy makers and builders will want to keep up with developments in this field as they could dramatically remake the emissions map for new homes.

3.2.2 Insulation

Insulation accounted for 5,242 tonnes of emissions in the study, representing 26.1 percent of all measured MCE. As the second highest impact category, addressing emissions from insulation is clearly important.

A leading strategy for reducing MCE in homes is to design to use less material. But with increasing (and important) demands for improvements in home energy efficiency to reduce operational emissions, new homes will likely be using more insulation, not less. So as we push to improve energy performance we risk driving the significant MCE from insulation ever higher.

The MCE of insulation products varies widely. There are 20 different insulation types in BEAM, many with multiple product brands or options. Figure 11 shows the average results for each type of insulation at the same level of thermal performance. While direct substitutions between products in Figure 11 cannot be simply assumed, due to differences in performance characteristics, there is an order of magnitude of difference between the emissions of the options. It is important to note that within a particular material type, the carbon emissions for specific products made can vary by over 50 percent (see Figure 11).

In some cases, a product with low emissions in its category may have a lower R-value per inch of thickness than another product with high emissions in its category, meaning a greater quantity of the product must be used to achieve an equivalent R-value. For net carbon emitting insulations, this generates higher emissions. Conversely, for net carbon-storing insulations, this achieves greater carbon storage.

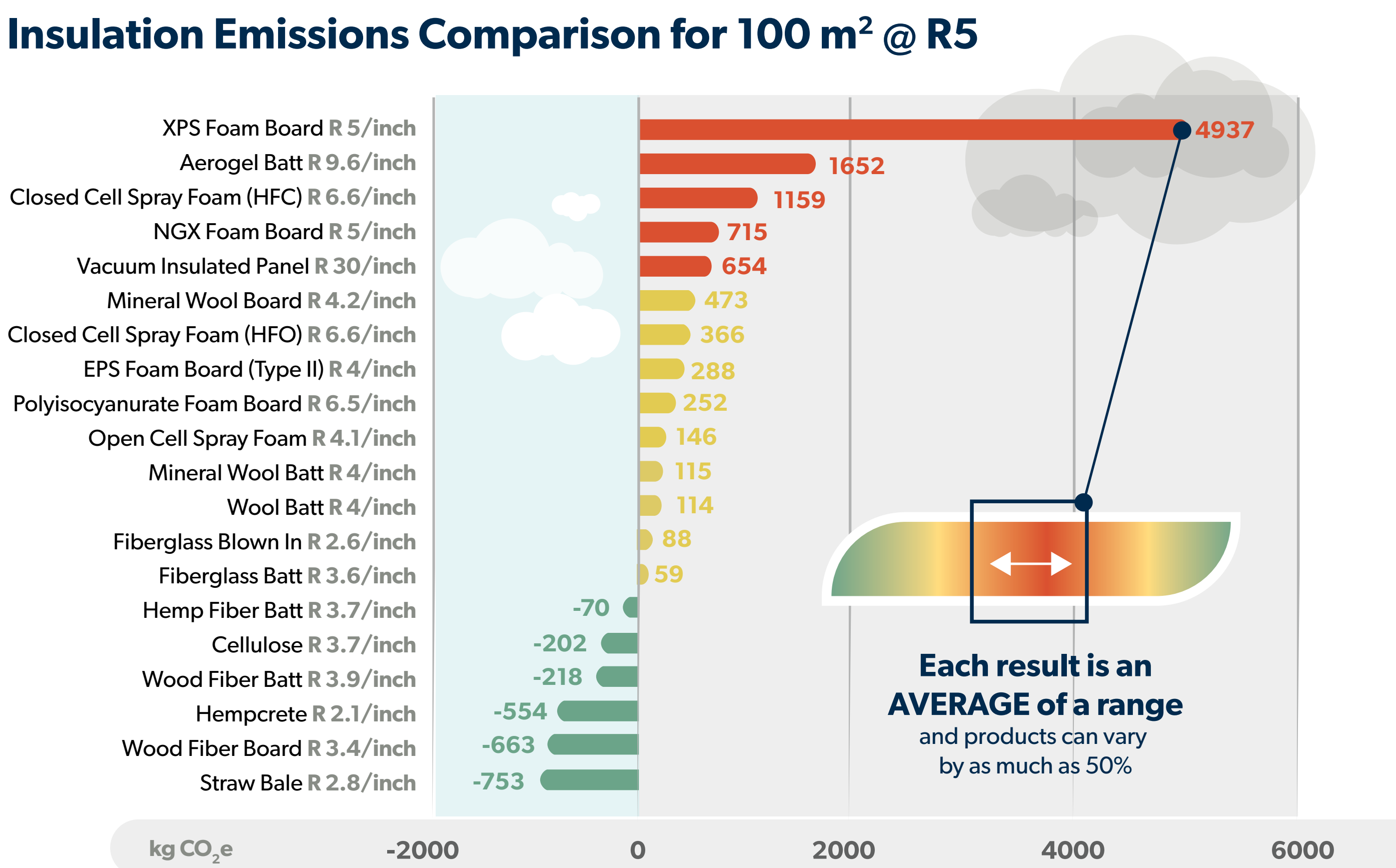


Figure 11. Range of net emissions for different insulation types from BEAM software.

Complicating the substitution of insulation materials is the different performance characteristics required of insulation products in different assemblies of the home. Foundation wall insulation is responsible for the majority of all insulation-related MCE, mostly due to the exterior application of rigid XPS foam. One possible solution for reducing foundation wall carbon emissions is to substitute exterior subgrade insulation with appropriate interior blanket or batt insulation with a lower carbon footprint. All insulation substitutions must be made using the best available building science principles.

Figure 12 shows the total impacts of different insulation types, regardless of their position in the building. There are different demands on insulation products depending on their location in building assemblies, and some types of insulation may be used successfully in multiple locations in the building while others may be limited to just one or two types of uses.

3.2.2.1 Carbon-storing Insulation

Of the insulations used in the buildings of this study, only two carbon-storing materials (cellulose and wood fiberboard) were used, which together stored just under 400 tonnes of plant-sequestered CO_2e emissions. The carbon storage of these two materials reduced the overall insulation category impact by 7.0 percent, while only contributing 2.0 percent to insulation emissions. These materials are composed primarily of biologically-produced matter, sometimes termed biogenic material. The carbon storage these materials claim was sequestered from the atmosphere by photosynthesis and made into physical carbon-based matter during the plant's growth. (see Section 2.3.2).

Due to the high volume of insulation used in homes (and the likelihood of increases in insulation volume to meet new energy efficiency requirements), the use of more carbon-storing insulation offers the most potential to dramatically reduce overall MCE. The potential results of using more carbon-storing insulation are explored in Section 4.

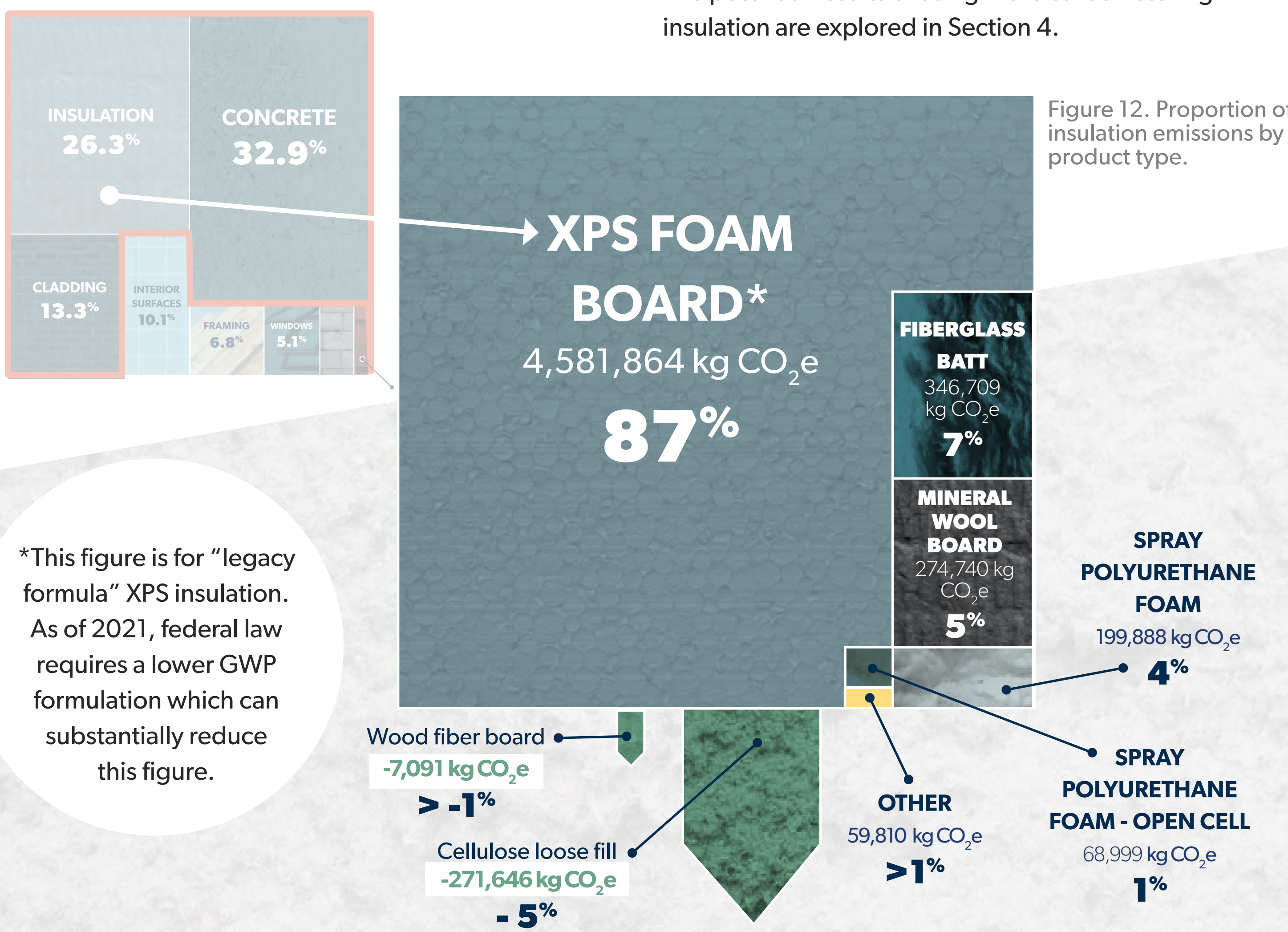


Figure 12. Proportion of insulation emissions by product type.

3.2.3 Cladding

The cladding category had the third highest emissions impact, with 2,575 t CO_2e representing 12.8 percent of the total MCE in the study. Figure 13 shows the relative emissions for the cladding options included in the BEAM tool.

Cladding is a relatively straightforward material category, with each option available in the BEAM tool having met all testing requirements for the purpose and most having long histories of use in the region, which should make direct substitutions a viable option. However, cladding is a material with a high aesthetic impact for a home – as well as major differences in durability and maintenance – and substitutions on the basis of emissions alone may not overcome decisions based on the desired visual appearance of the home.

Cladding Emissions, kg CO2e/100m2

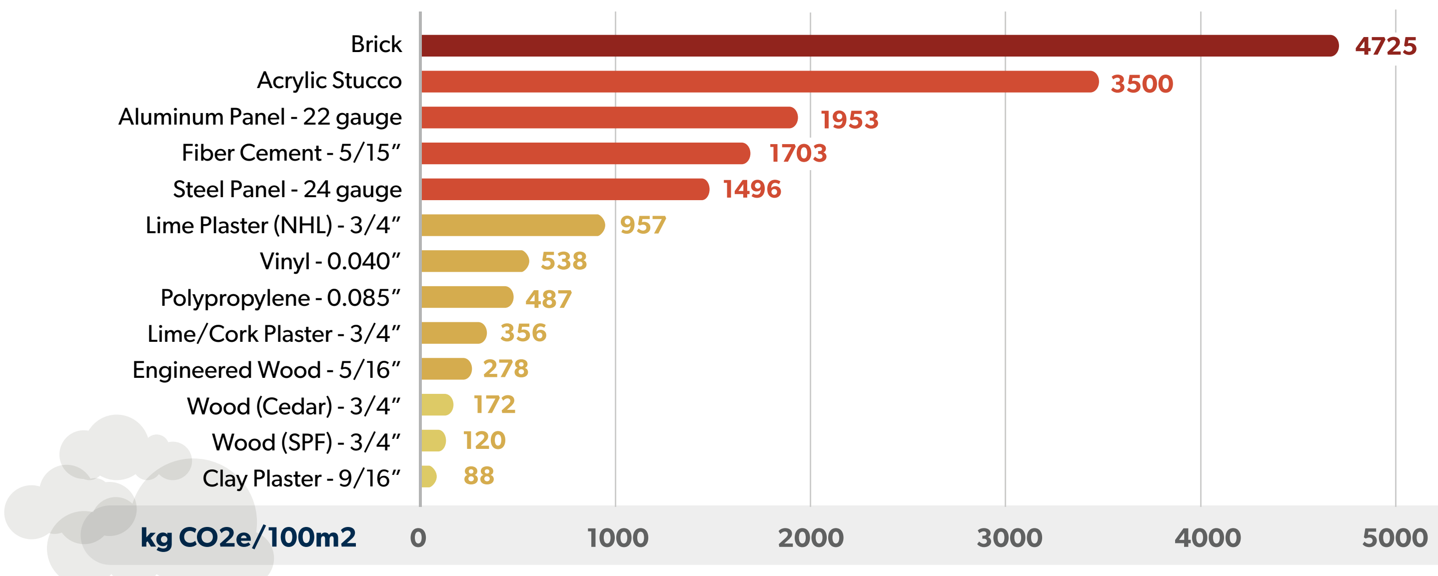


Figure 13. BEAM results for cladding

There are not currently any commercially available cladding options with significant net carbon storage, though some wood products may eventually have carbon storage attributed to them (see Section 2.3.2). However, even without carbon-storing options, it is possible to reduce emissions by orders of magnitude.

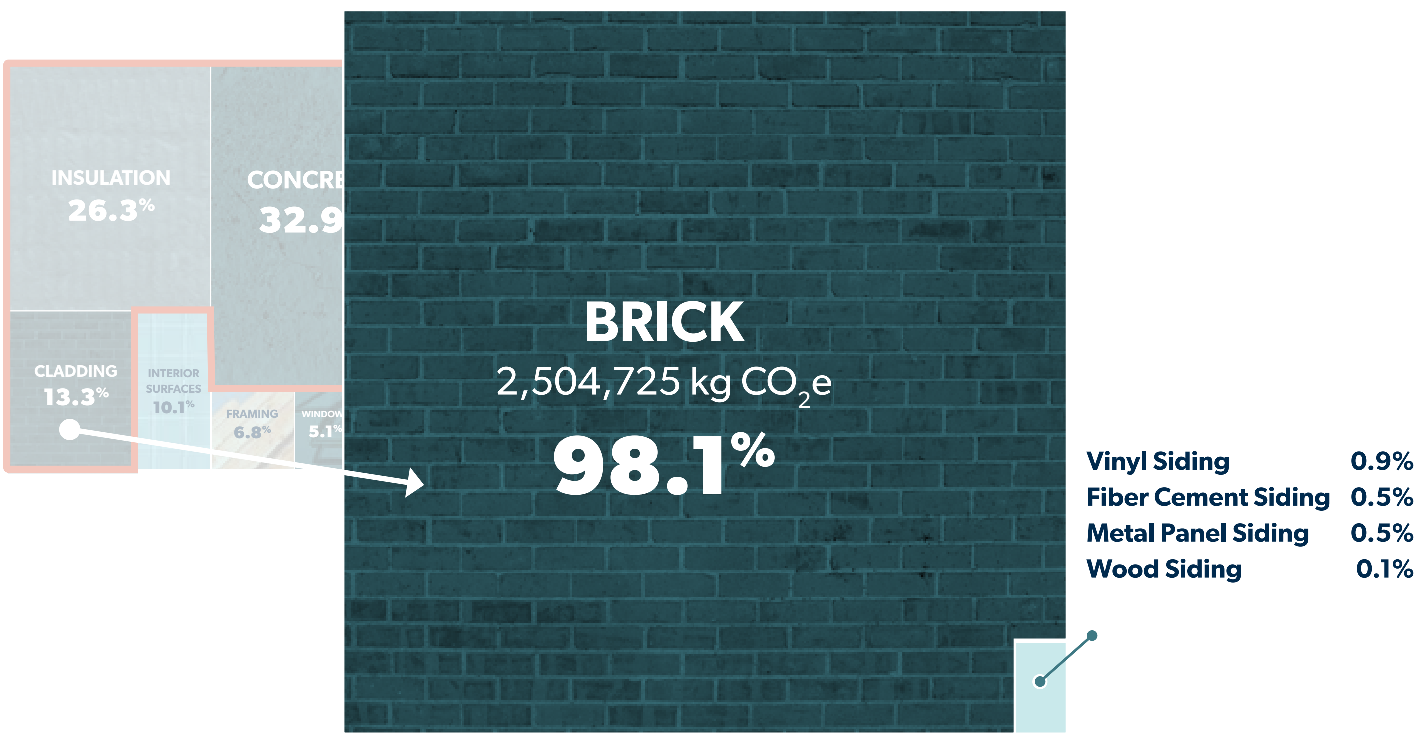
The GTHA region features brick as a common cladding material. All of the GTHA representative home plans sampled included brick cladding, except for one. Brick is by far one of the most emission-intensive cladding options, with the bulk of the embodied carbon emissions arising either from the kiln-firing of clay bricks or the cement content of concrete bricks.

While no low-emission brick products are currently available in the GTHA, it is worth noting that US manufacturer CalStar Brick issued an EPD for their fly-ash brick product that would have 472 kg $CO_2e/100\ m^2$, or one tenth of the emissions of typical bricks. If this brick substitution were made in all the buildings in this study, it would eliminate 1,200 t CO_2e of embodied carbon[32], the same carbon reduction as achieved by switching all 0-25 MPa concrete to the lowest carbon mix available, as discussed in Section 3.2.1 .

The testing of bricks using biochar as a high volume ingredient has demonstrated net carbon storage that would equate to -1,778 kg $CO_2e/100\ m^2$ in a cement/biochar brick of typical thickness.[33] This is an average reduction of 138 percent from the MCE of bricks used in this study's sample buildings. If this biochar brick were hypothetically substituted for all brick cladding in the sample homes, it would result in the net carbon storage (i.e. negative emissions) of 500 tonnes of CO_2e, approximately one tonne per home on average.

Until such low-carbon or carbon-storing brick replacements become available, a move to any other cladding choice that is under 1000 kg $CO_2e/100\ m^2$ would reduce emissions by at least 75 percent in this category. This includes using siding made of vinyl, polypropylene, wood, and engineered wood, and/or non-cement based plasters such as lime and clay plaster. After biochar bricks, the lowest emission cladding option is clay plaster at a mere 88 kg $CO_2e/100\ m^2$. Clay plaster has 98 percent lower carbon emission than the industry average brick emission of 4,725 $CO_2e/100\ m^2$.

Figure 14. Carbon emissions of cladding by type for all 503 as-built homes studied.



4. Effects of Material Substitutions on MCI

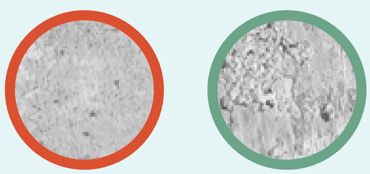
The results of this study indicate that material selections for new home construction can have a dramatic impact on material carbon emissions. To explore the potential extent of MCI reductions based on material selection, the researchers applied material substitutions in the BEAM models in areas where material impacts were shown to be highest.

The homes with the lowest and highest[34] MCI results were selected for material substitutions to examine whether any reductions might relate to the overall design of the building or the as-built material selections. Two new BEAM models were created for both samples. The first scenario focuses on materials that could feasibly be selected by builders today to explore how low MCI could go in the immediate future, while the second scenario is intended to demonstrate the possibilities for MCI reduction in the next 5-10 years.

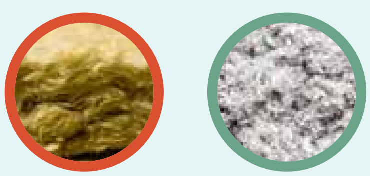
4.1a Best available materials (BAM) substitutions

Substituted materials were chosen to ensure that they are readily available in the GTHA marketplace and meet all current code requirements. Two kinds of substitutions were made in this model: switches to new material type and switches to best-in-type materials (ie. brand-specific change). These substitutions were chosen to reflect as much similarity in product application as possible (ie. if batt insulation was selected for the as-built model, another batt insulation was chosen to substitute) to ensure that substitutions would be practical for real-world applications.

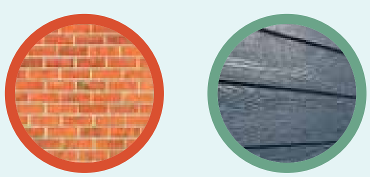
In the BAM model, major substitutions include:



✔ Concrete selection was changed from the Canadian benchmark average of 305 kg CO_2e/m^3 to the lowest emitting mix from the Canadian average EPD (Mix #19 at 214 kg CO_2e/m^3), as this type of mix should be available from regional suppliers.

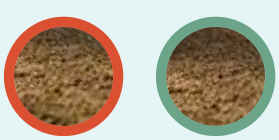


✔ Insulation was changed to cellulose batts (for walls) and loose-blown cellulose (for attics).

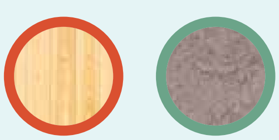


✔ Cladding was changed from brick to the lowest emitting low-maintenance option, engineered wood.

Minor substitutions include:



✔ Carpet flooring changed to best available option



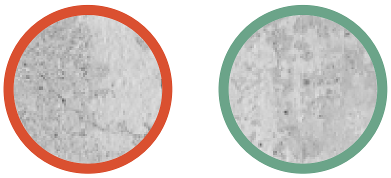
✔ Hardwood flooring changed to linoleum

✔ Drywall changed to best available brand

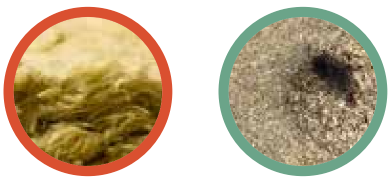
4.1b Best possible materials (BPM) substitutions

Materials were chosen to reflect the best possible emission results, regardless of whether or not the materials are market-ready. All materials are commercially available in other markets, and have demonstrated code compliance in those jurisdictions. Though this does not guarantee that such materials can be substituted in the GTHA currently, it indicates a likelihood that this should be possible with adequate testing. Such substitutions may require design changes and worker retraining for installation.

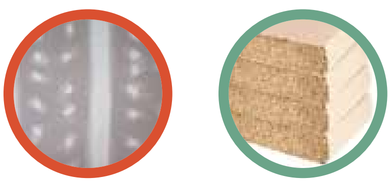
In the BPM model, major substitutions include:



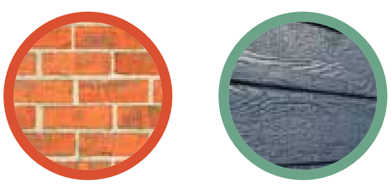
✔ Concrete selection was changed from the Canadian benchmark average of 305 kg CO_2e/m^3 to 150 kg CO_2/m^3, an average of the two best product-specific EPD results in Canada. While not necessarily widely available, this type of mix requires no new technology and should be able to be produced in the region.



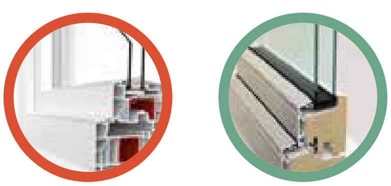
✔ Insulation was changed to straw-based material, based on baled straw wall insulation and loose-blown chopped straw insulation available in Europe.[35]



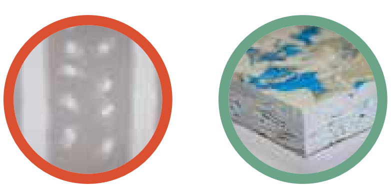
✔ Interior walls were changed to compressed straw board, based on modular interior partition systems available in Europe and Australia.[36]



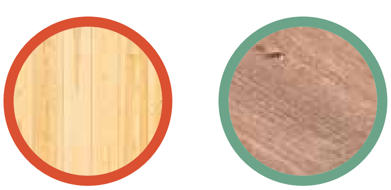
✔ Cladding was changed from brick to the lowest emitting low-maintenance option, engineered wood.



✔ Windows changed from vinyl frame to wood frame with aluminum cladding



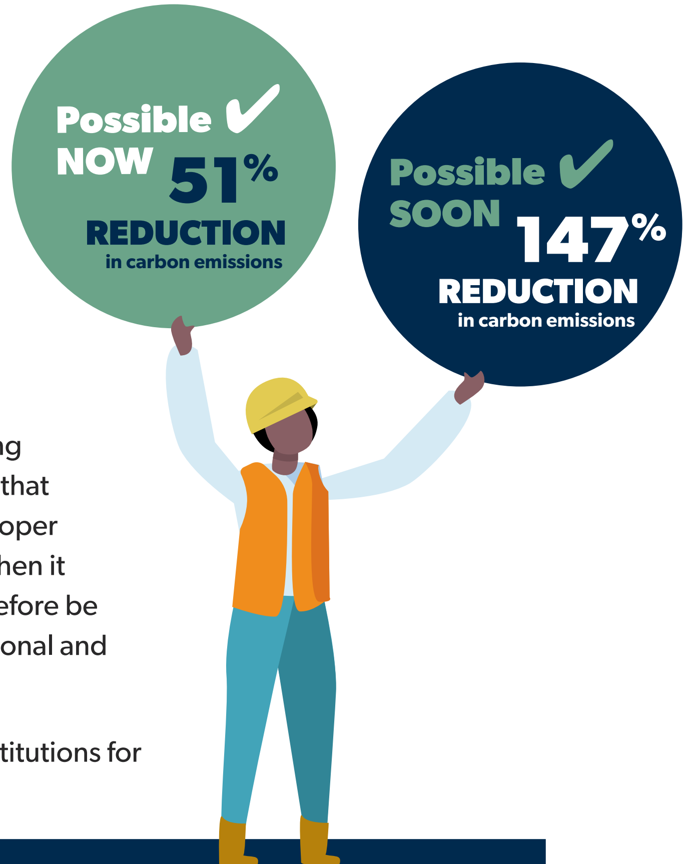
✔ Interior drywall was changed to sheets of compressed recycled drinking boxes, based on products available in the USA and Europe.[37]



✔ Flooring was changed to a mix of linoleum (for high-wear and wet areas) and cork.

Some of these substitutions would require new products to become available in the regional market and some efforts to both redesign aspects of the home and retrain crews to install new materials. However, the existence of homes in Europe and some examples here in Canada[38] using all of these materials indicates the potential, and one with significant emission implications, as it changes new homes from a source of emissions to a source of net carbon storage.

4.2 Results of material substitutions



The home with the lowest MCI in this study had an emissions intensity of 116 kg CO_2e/m^2 based on heated floor area. This result puts this home well under the weighted average of 189 kg CO_2e/m^2, for the same heated floor area critera. If all new Part 9 GTHA homes matched the MCI achieved by this as-built home, it could reduce the total carbon emissions by as much as 465,850 tonnes, roughly a 55 percent reduction from the current estimated emissions. This in itself would be a remarkable impact, equivalent to removing approximately 100,000 cars from the road. It is worth noting that this example was a typical townhouse unit from a large developer that presumably did not intend to achieve a low MCI score when it was designed or built. An MCI of 116 kg CO_2e/m^2 could therefore be considered an easily achievable minimum target for conventional and cost-competitive buildings.

Table 8 shows the results of the six BAM and seven BPM substitutions for the model with the lowest MCI based on heated floor area.

NET CARBON EMISSIONS by assembly [kg CO_2e]	Original model – Lowest MCI	BAM Substitutions	BPM Substitutions
FOOTINGS & SLABS	4,002	2,718	1,677
FOUNDATION WALLS	11,825	7,971	1,335
STRUCTURAL ELEMENTS	808	808	808
EXTERIOR WALLS	514	-397	-3,221
PARTY WALLS	818	166	-1,204
EXTERIOR WALL CLADDING	2,077	235	122
WINDOWS	1,285	1,285	800
INTERIOR WALLS	965	908	-6,357
FLOORS	3,250	1,593	838
CEILINGS	268	251	-1,061
ROOF	2,742	-242	-7,947
GARAGE	4,485	823	-1,361
NET TOTAL MCE	**33,039**	**16,120**	**-15,571**
NET MCI OF HEATED AREA (kg CO_2e/m^2)	**115.8**	**56.5**	**-54.6**
% CHANGE FROM INITIAL		**-51%**	**-147%**

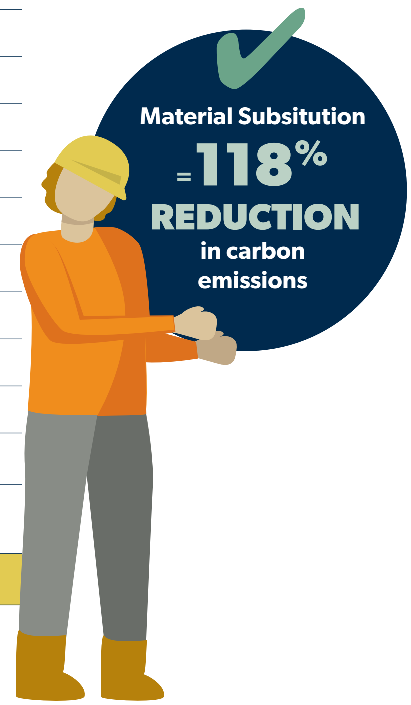
Table 8. Comparison of results for material substitutions for lowest MCI home (based on heated floor area).

The six BAM substitutions result in a reduction of MCI to 56.5 kg CO_2e/m^2, a 51 percent reduction from as-built emissions. The substitution of seven Best Possible Materials (BPM) provides an encouraging result: a home with net carbon storage in the measured materials, rather than emissions. The result of -54.6 kg CO_2/m^2 is a 147 percent reduction from the as-built model.

A home with high MCI was given the same set of material substitutions as the low MCI model. The results in Table 9 show that despite the higher initial MCI of 262.1 kg CO_2e/m^2, the BAM substitutions actually reduced this model's emissions by 196.6 kg CO2e/m2, a 75 percent reduction.

NET CARBON EMISSIONS [kg CO_2e]	Original model – Highest MCI	BAM Substitutions	BPM Substitutions
FOOTINGS & SLABS	5,793	4,648	3,093
FOUNDATION WALLS	36,805	7,805	2,030
STRUCTURAL ELEMENTS	1,349	1,349	1,349
EXTERIOR WALLS	12,481	-2,265	-9,076
EXTERIOR WALL CLADDING	10,756	1,105	806
WINDOWS	2,325	2,325	1,447
INTERIOR WALLS	702	660	-4,653
FLOORS	4,572	2,346	1,296
CEILINGS	533	437	-1,358
ROOF	1,648	1,276	-7,904
GARAGE	4,546	694	-1,662
NET TOTAL MCE	**81,510**	**20,380**	**-14,632**
NET MCI OF HEATED AREA (kg CO_2e/m^2)	**262.1**	**65.5**	**-47.1**
% CHANGE FROM INITIAL		**-75%**	**-118%**

Tabel 9. Material substitutions for second highest MCI home (based on heated floor area)



The BPM substitutions brought this home's total MCI to -47.1 kg CO_2e/m^2, a 118 percent reduction from the as-built result. This represents nearly 100 tonnes of CO2e emissions eliminated from a 252 m2 single family home as a result of only seven alternate material choices.

The similarity between the MCI results from BAM-substitution (56.5 and 65.5 kg CO_2e/m^2) and BPM-substitution (-54.6 and -47.1 kg CO_2e/m^2) indicates that material selection can drastically reduce MCI, regardless of home design, as the use of a similar material palette results in similar MCI outcomes.

The similarity between the material substitution results invites the calculation of a hypothetical estimate of the potential impact of such substitutions across all new Part 9 homes in the GTHA region. Reducing the weighted average MCI of 192.6 kg CO_2e/m^2 (based on municipal data floor area criteria) to the average BAM-substitution MCI of 80.1 kg CO_2e/m^2 (based on the same floor area criteria) would result in approximately 573,000 t CO_2e fewer emissions annually in the GTHA. Achieving average BPM-substitution results of -67.3 kg CO_2e/m^2 (again, based on the municipal data floor area criteria) would result in the reduction of roughly 1,065,000 t CO_2e. In this hypothetical scenario, new Part 9 homes built in the GTHA would pass beyond net zero carbon to store around 225,000 tonnes of carbon from the atmosphere during a single construction year.

In the near future, new Part 9 homes built in the GTHA could pass beyond net zero carbon to store around 225,000 tonnes of carbon from the atmosphere during a single construction year.

4.3 A carbon-storing future?

The BPM substitutions in this study had a dramatic impact on MCE, completely reversing the impact of home building materials measured in this study from a source of emissions to a potential pool of net storage. As selected for this study, the BPM category only included materials for which commercially available options exist in other markets. Carbon-storing materials that are currently in R&D would offer even further potential for net storage. Should a concerted effort be made to encourage the use, distribution and development of carbon-storing materials – including promising materials like carbon-storing concrete aggregate and biochar-based materials – it may be possible to achieve even more net carbon storage than this study indicates.

The home building sector may be unique in the potential for a relatively rapid transformation from a major source of GHG emissions into a zero-carbon or even carbon-storing sector. Combining the best efforts underway to achieve zero emissions in operations and the use of carbon-storing materials could result in the elimination of emissions from this sector.

4.4 No changes to home designs

This study did not examine the impact of design changes, such as moving space currently below grade to become above grade (either fully or partially), massing changes, solar orientation, window sizing, air tightness or mechanical systems. Any or all of these types of design changes could directly impact the MCE and OCE of the homes.

What does it cost to reduce MCE?

Though it was outside the scope of this report to comment accurately on the cost implications of material substitutions, correspondence with several regional concrete suppliers indicated that a low-carbon concrete mix substitution would not have any notable cost implications. Pricing from HomeAdvisor.com shows average installed prices for brick are $9-28 per square foot, compared to $7-12 for engineered wood. Cellulose insulation priced from three major Canadian retailers was less expensive than the as-built options, though installation costs may vary. On the whole it is encouraging that the most impactful substitutions on emissions do not appear to have significant negative cost implications and could potentially cost less. This factor would be valuable to study in more detail.

Conclusions

MCE is Substantial

The climate emergency has dire consequences for everyone in the GTHA and will require effective mitigation and adaptation efforts on behalf of every citizen and sector of the economy. Recognition of the importance of climate impacts has led to the study of material carbon emissions (MCE), and as this study demonstrates, these impacts are substantial.

The structural and enclosure materials calculated for the built sample plans in this study represent over 20,100 tonnes of CO_2e emissions annually. This would represent roughly 840,000 t CO_2e per year if extrapolated to all new Part 9 housing starts in the GTHA.

5.1 MCE is more substantial than reported in this study

While the materials included in this study represent a large portion of MCE from new homes, the excluded materials – such as mechanical, electrical and plumbing systems, millwork, paints and finishes – could add anywhere from 30-60 percent more emissions to those calculated in this study. That suggests that the total MCE for new homes in the GTHA could be as high as 1.2 -2.1 Mt CO_2e of (potentially avoidable) emissions per year.

5.2 MCE for Part 9 renovations and other building activities likely substantial

This study focuses on new homes that fall within Part 9 of the Ontario Building Code. The importance and scale of MCE would grow considerably if renovations to Part 9 buildings were included, especially in light of the proliferation of subsidy programs for retrofitting older homes to be more energy efficient. The conclusions of this study regarding the high emissions impact from insulation materials are perhaps even more relevant when it comes to retrofits where insulation is often the main material category being added. It is quite likely that a study of retrofit MCE compared to OCE reductions would find that, as with new buildings, the addition of high emission insulation materials may result in more total emissions over the next few decades, rather than the net reductions that are intended by subsidies.

Part 9 commercial buildings may have higher MCE than residential buildings, as they often feature large concrete slab floors and enclosure systems that use steel framing rather than wood, which has a much higher MCE. Frequent renovations and interior upgrades to commercial buildings likewise represent a potentially large pool of MCE.

MCE from Part 3 (large) buildings exceed that of the Part 9 buildings studied here with an average of approximately 345 kg CO_2e/m^2, due to the high volume use of impactful materials like concrete and structural steel, and would likewise add to the total MCE for the region.

5.3 MCE analysis should become standard practice

The measurement of MCE for new homes should become standard practice in order to collect more accurate and complete data and help to drive voluntary emission reductions and inform future regulatory interventions. Tools such as BEAM (used in this study) and Natural Resource Canada's MCE[2] are free and establish a common methodology for estimating MCE particularly for Part 9 buildings, that are relatively simple for policy makers, consultants, designers, and builders to use. Technical training for MCE calculation could be supported by regulators and the industry to normalize the practice and increase MCE literacy.

5.4 Carbon storing materials are an important strategy

This study created updated versions of two model homes (one with the low MCI and one with high) to examine the impact of material substitutions on overall emissions. The substituted materials that offer net carbon storage (i.e. more atmospheric carbon was stored in the materials than was emitted in manufacturing; see Section 2.3.2) offset substantial amounts of emissions from the other materials. Using the best available materials (BAM) in six categories, the carbon-storing materials reduced MCI by 51 percent for the low MCI model and 75 percent for the high MCI model. Using "best possible materials" (materials available in other markets but not necessarily code compliant or in wide use in the GTHA), the results were 147 and 118 percent reductions, bringing the homes into net carbon storage territory.

The "best possible materials" models do not include carbon-storing material options that are currently in development, such as concrete aggregate made from captured carbon and bricks made with biochar. The addition of these materials could offer a substantial increase in the net carbon storage possible in a new home.

Studying the cost implications of using more carbon-storing materials was not within the scope of this report. An initial exploration (see Sidebar XX) indicated that costs would not necessarily be higher for the BAM models, offering the possibility that deep cuts in MCE are possible with reasonable cost implications. Costs for the BPM models were difficult to assess, as many of the material options are priced for other markets and are not widely available in the local region.

The opportunity for new homes to be sites of net carbon storage rather than emissions offers a feasible pathway for achieving the net zero emission targets promised by national and regional governments. The development and promotion of existing and upcoming carbon-storing materials would be a crucial factor in reaching net zero emissions in the home building sector.

5.5 Carbon Use Intensity (CUI) is an important metric

Understanding the true climate impact of a new home necessitates understanding all its related emissions over a period of time. If a municipality or a building company has time-related targets (ie. 50 percent reduction in emissions by 2030, or net zero emissions by 2050), then accounting for the emissions from homes requires adding total MCE and OCE over that period to ensure that goals are truly being met. This is known as “carbon use intensity” (CUI), and is an important lens for considering emissions from the region’s homes.

As we **work to collectively reduce OCE for homes** in the GTHA, leaving MCE unadadressed will miss the bulk of a new home’s overall carbon use intensity within the next crucial next few decades.

5.6 Regional impact on Scope 3 emissions

Material carbon emissions (MCE) are not currently included in municipal or regional inventories, as they are the result of industrial and manufacturing operations that typically happen outside the region and as such are considered Scope 3 upstream emissions. Despite the dispersed nature of the emissions outside the boundaries of the region, policy makers and builders in the GTHA can have a major impact on these emissions, as the results of this study indicate. Given the urgency to reduce emissions globally, efforts to address MCE from new homes constructed within the region can have a large provincial, national and international impact even if that impact is not on the “emissions ledger” for the region.

Despite the urgency for immediate and measurable climate action, effecting change in the home building industry can be difficult, with competing impacts of cost, aesthetics, material supply, labour requirements, durability, performance and occupant health all needing to be addressed within the scope of the Ontario Building Code. MCE is a new factor that needs to be considered in balance with other demands. As policy-makers and builders have different priorities and responsibilities, we offer the following recommendations for addressing MCE that are specific to both stakeholders.

Recommendations for Policy Makers

6.1 Existing policy options

The researchers recommend that municipalities focus on establishing appropriate metrics and measurement for entire projects and avoid regulations that focus on specific high-emitting materials. The complexities of home building may dictate the need to use certain high-emitting materials, and if these uses can be offset by low-carbon and/or carbon-storing options elsewhere in the building, net targets can still be met. Additionally, innovation in material science (such as carbon-storing concrete and new bio-based materials) may turn options that currently have high emissions into low emitters or even carbon-storing materials.

Currently, neither the Ontario Building Code (nor the National Building Code of Canada) address MCE.

The Ontario Building Code does offer a potential doorway to the regulation of MCE in the form of Objective OE1.1:

"An objective of this Code is to limit the probability that, as a result of the design or construction of a building, **the natural environment will be exposed to an unacceptable risk of degradation due to emissions of greenhouse gases into the air.[39]"** (Emphasis added)

We recommend that GTHA municipalities request that the Ontario government consider introducing MCE requirements for Part 9 buildings in a future OBC update, either via integration in the base code or inclusion in an optional standard that municipalities can opt into under section 97.1 (1) of the Ontario Municipal Act. As noted above, we recommend any potential OBC requirements be based on whole project MCE/MCI metrics/targets rather than by a prescriptive approach.

Support for such efforts might be enhanced by recent developments in the regulation of operational carbon emissions (OCE) in the British Columbia Building Code. The province is also in early discussions with leading municipalities to include MCE in the relatively near future.

The City of Vancouver is embarking in early 2022 on the design of a program to reduce "embodied carbon" (material carbon emissions) by 40 percent by 2030. The report *Policy Research on Reducing the Embodied Emissions of New Buildings in Vancouver* contains excellent background information for developing embodied carbon policies, and includes a scan of global embodied carbon policies.[40]

The Cities of Nelson and Castlegar undertook the Low Carbon Homes Pilot in 2021 "to enhance its approach to reducing the impact of our buildings by taking embodied carbon emissions (also referred to as material carbon emissions) into consideration alongside operational carbon emissions."[41] The report is intended to inform the development of a municipal program to reduce MCE in 2022.

The City of Langford, BC, announced a "Low Carbon Concrete Policy" in 2021, focused specifically on reducing MCE from concrete. "Effective June 1, 2022, all concrete supplied to City-owned or solicited projects, and private construction projects greater than 50 cubic meters, will be required to be produced using post-industrial carbon dioxide (CO_2) mineralization technologies, or an equivalent which offers concrete with lower embodied CO_2."[42]

In Ontario, the Township of Douro-Dummer instituted the voluntary "Sustainable Development Program" in 2020. This program offers a "40 percent permit fee rebate on all approved projects that meet the required greenhouse gas reduction targets, or an 80 percent permit fee rebate with combined with net-zero ready construction"[43] and is the first program in North America to measure MCE and provide incentives for reductions.

Similarly, tier 2 of the Toronto Green Standard for low-rise residential projects (version 4) includes a requirement to meet an MCI target of 250 kg CO_2e/m^2 or less. Tier 2 is voluntary, but incentivized via a significant development charge refund. The City of Toronto is currently exploring potential to integrate MCE requirements in the mandatory tier 1 requirements in a future update to the Toronto Green Standards. This general approach of starting with municipal incentives for limiting MCE, and subsequently exploring a transition to municipal requirements, has the advantage of building industry familiarity with low MCE approaches in advance of future provincial and/or municipal regulations.

This report recommends an approach that uses an MCI "carbon cap". Part 9 homes share a relatively consistent design and construction approach, and as evidenced by this study, the MCI results fall within a reasonable close range. With sufficient stakeholder input, it should be feasible to agree upon targets for voluntary MCI "absolute targets" and to further incentivize builders who meet more stringent targets. The broad sample size of this study might be considered sufficient to establish such a cap or threshold.

The researchers discourage creating policies or programs that use baseline results as a benchmark for MCE/MCI reductions. As seen in Section 4.2, it is possible for homes with different designs to achieve very similar MCI results based on material selection, but that starting with a higher baseline would allow a home to show a very large percentage of emissions reduction without achieving low results.

6.2 Municipal EPD requirements

The researchers recommend that GTHA municipalities consider signaling an intention to first prefer and then, after a reasonable time, require Environmental Product Declarations for all construction materials used in municipal construction projects in order to encourage all manufacturers to begin producing product-specific EPDs. Increased product transparency would result in more complete and accurate data for tools that measure MCE. This is particularly true for concrete, where variations in emissions from different manufacturers and/or mixes can affect MCE by as much as 100 percent.

6.3 Metrics for MCE programs

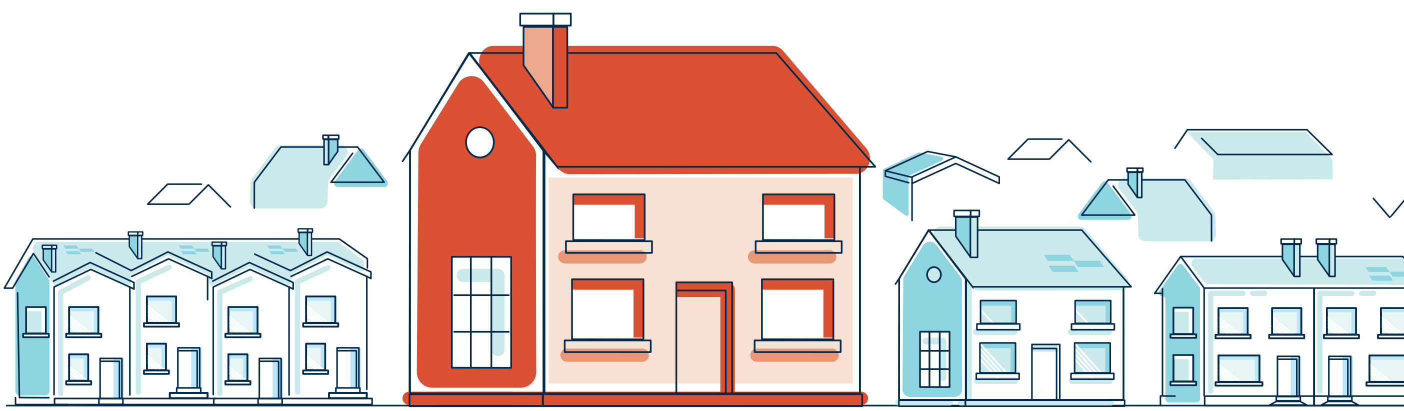
The researchers recommend that GTHA municipalities work to establish bold MCE metrics and caps/thresholds that bring about staged emission reductions over time. Following a similar strategy to the energy step codes in British Columbia, all homes would be required to meet the current target and incentives applied to encourage projects to meet the future higher targets earlier.

The choice of a metric for a relatively new field like material carbon emissions sets an important precedent that may be difficult to change, once established. It is possible to cause unintended consequences in choosing a metric. As seen in the results of this study, there is a significant difference between MCI calculated on gross floor area and habitable floor area. The use of habitable floor area as a basis for MCI deters homes from having large garages and/or unfinished basements, since the MCE arising from these materials is attributed to the habitable area, pushing MCI up by 32 percent in the samples studied. For this study, this decision was made as an effort to prioritize emissions based upon serving residents over space for cars and storage.

Municipalities seeking to incentivize reductions or regulate MCE could seek a metric that serves other priorities. The researchers experimented with a number of alternative metrics that could balance MCE with building size and number of bedrooms as a proxy for number of occupants "sharing" the carbon emissions of a house. While these priorities may not align with those of each GTHA municipality, we encourage policy makers to clearly identify priorities that might be combined with MCE to bring about the desired impacts.

One potential metric to consider is known as "carbon use intensity" (CUI). This metric combines the material carbon emissions of a house with the anticipated operational emissions over a defined period of time. Choosing a timeframe that matches the climate targets of a municipality enables policies to be aligned with overarching targets. For example, a metric of CUI_{2030} would include the MCE of a home and all operating emissions until 2030. If the municipality's overall goal is 40 percent reduction in emissions by 2030, then the CUI_{2030} would need to be 40 percent less than today's benchmark.

CUI is a useful metric, as it allows for flexibility for municipalities and builders to meet the CUI threshold in different ways, concentrating on electrification, improved materials and/or energy efficiency to degrees that are practical and meet local needs. As noted in NRCan's *Achieving Real Net Zero Emission Homes*, "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."[44] The GTHA region has already established methodologies and inventories for the OCE from homes, and this study provides a basis on which to begin considering MCE so that the two metrics can, ideally, be combined for new homes.



6.4 Incentives for reducing MCE

The researchers recommend municipalities explore incentives with relatively low program costs and complexity that enable municipalities to signal leadership in MCE reduction and encourage the building community to engage in MCE reductions.

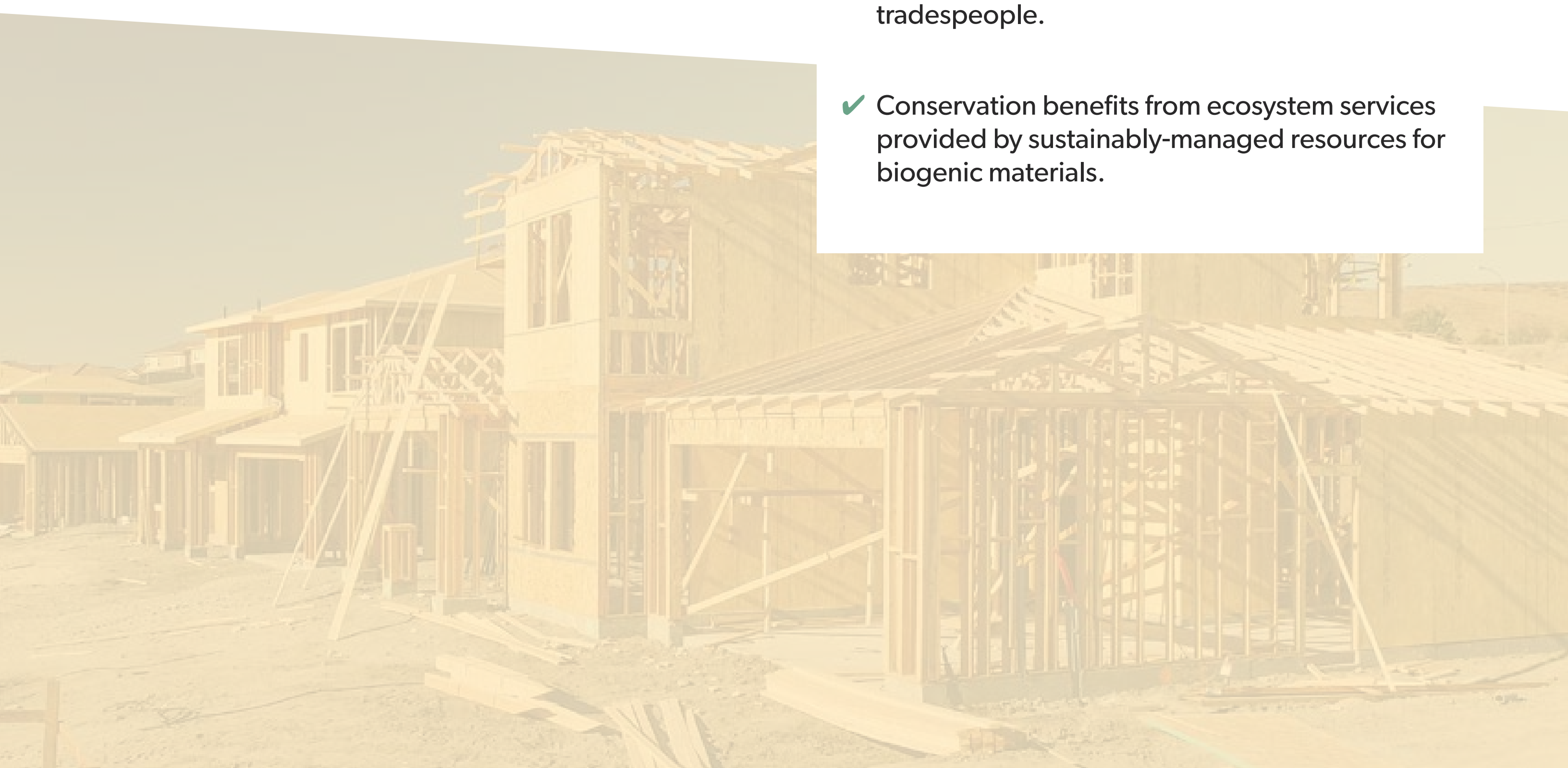
Voluntary incentives have been used in municipalities around the world to encourage early action on MCE reductions. These incentives include:

- ✔ **Reduction in planning/permit fees and/or faster timelines for approvals for projects reporting MCE/MCI/CUI with submission**
- ✔ **Reduction in planning/permit fees and/or faster timelines for approvals for projects voluntarily meeting a MCE/MCI/CUI cap/threshold**
- ✔ **Recognition/awards for projects meeting a MCE/MCI/CUI cap/threshold and/or projects with lowest recorded MCE/MCI/CUI in category**
- ✔ **“Low-carbon” designation offered to projects and/or builders meeting a MCE/MCI/CUI cap/threshold**

6.5 Stacked benefits for reducing MCE

The researchers recommend that municipalities explore the additional opportunities that may exist in conjunction with policies to reduce MCE and include such benefits when proposing policies. GTHA municipalities may be able to achieve numerous stacked benefits from pursuing MCE reductions, including:

- ✔ Economic opportunities from new regional manufacturing of low-carbon and carbon-storing materials. The region has a large supply of the raw materials required for improved materials and the manufacturing and transportation infrastructure to support.
- ✔ Healthier indoor environments for building occupants. Carbon-storing materials are typically free of off gassing and dangerous chemical content.[45]
- ✔ Reduced landfill waste volumes. Carbon-storing materials can more easily be diverted to composting facilities rather than landfill.
- ✔ Training opportunities for leading educational institutions in the region. These include courses and programs in low-carbon construction at universities, community colleges and private career colleges, educating architects, engineers, home designers, builders and tradespeople.
- ✔ Conservation benefits from ecosystem services provided by sustainably-managed resources for biogenic materials.



MCE and the City of Toronto's Green Standard, V4

The Toronto Green Standard is Toronto's sustainable design and performance requirements for new private and city-owned developments since 2010. Version 3 has been in effect since 2018 and Version 4 comes into effect May 1, 2022 for new planning applications. The Standard consists of tiers of performance with Tier 1 being mandatory and applied through the planning approval process. Financial incentives are offered through the Development Charge Refund Program for eligible and verified Tier 2 or better, high performance, low emissions projects.

The Toronto Green Standard Version 3, included a performance pathway to high performance, low emissions new construction by 2030 based on absolute performance targets related to greenhouse gas (GHG) emission limits, energy use intensity and thermal energy demand intensity. The staff report and the City's Zero Emissions Building Framework study that supported this change set out a stepped approach to increasingly higher energy and GHG performance measures with each Toronto Green Standard update for large Part 3 Buildings (which comprise over 85 percent of projected new construction in Toronto).

In the TGS v4 (2022) a new voluntary requirement has been added for Tier 2 and 3 projects to conduct a materials emissions assessment of the upfront embodied carbon of structural and envelope components. This requirement recognizes the importance of the carbon footprint of building materials and the role of the Toronto Green Standard in planning and decision making. A requirement for Tier 2 projects to calculate the embodied carbon and the carbon sequestration within landscape designs has also been added.

The researchers suggest that the TGS v4 could consider using the data from this study to implement a Part 9 MCI threshold requirement for Tier 2 and 3 projects. The average MCI result of approximately 190 kg CO2e/m2 (based on the 'gross floor area' definition used in municipal reporting) represent an achievable threshold. Limiting the maximum MCI of homes to this threshold would reduce emissions in the study by 14.3 percent across all new Part 9 homes in the region.

"Stretch goals" for Tier 3 of the TGS could also be set to encourage greater innovation. 61 homes in this study achieved MCI for heated floor area of less than 150 kg CO2e/m2, suggesting that this may be an appropriate stretch goal. 28 homes had less than 125 kg CO2/m2 of heated floor area, suggesting an even more ambitious stretch goal.

Industry Recommendations

7.1 Measuring MCE

The researchers recommend that all new home designs undertake early MCE measurements during design development to lower emissions as much as possible, and use MCE tools to ensure procurement prioritizes the material brands with the lowest MCE. Free tools such as BEAM and MCE2 enable designers and builders to obtain MCE results for projects with relative ease and simplicity.

7.2 Request EPDs from manufacturers

The researchers recommend that designers and builders send requests to manufacturers for product-specific EPDs. Increased product transparency would result in more complete and accurate data for tools that measure MCE and in turn provide builders with more options.

7.3 Explore immediate potential for material substitutions

The researchers recommend that builders seek to implement all feasible 1:1 material substitutions that can reduce overall MCE. Modeling home designs with free tools such as BEAM and MCE2 offers opportunities to compare the MCE for materials that can be easily substituted for one another.

7.4 Plan for future material substitutions

The researchers recommend that builders set MCE/MCI/CUI targets that are achievable within a 2-5 year window and begin design and supply chain work to support such changes. Free tools such as BEAM and MCE2 offer opportunities to explore material options that may require additional design and/or procurement changes in order to use a material with lower MCE.

7.5 Examine design options for reduced MCE

The researchers recommend that builders explore design options that reduce MCE in addition to directly substituting materials. While this research did not directly address design options to reduce MCE, the high impact of concrete suggests that designs that minimize below-grade space and reduce or eliminate concrete floor slabs will achieve large MCE reductions, as will multi-unit homes that share party walls and therefore require less insulation. Further design analysis using MCE tools could highlight other opportunities for reductions.

7.6 Declare and promote reduced MCE

The researchers hope that home builders will undertake MCE modeling of their new homes, make all efforts to reduce emissions and publicize their achievements. The 52 percent of Canadians who are extremely concerned or quite concerned about climate change[46] are among the customers for new homes. New homes that can declare themselves to be low-carbon or zero-carbon will be attractive to such buyers.

Endnotes

1 IPCC report: 'Code red' for human driven global heating, warns UN chief https://news.un.org/en/story/2021/08/1097362

2 Pan-Canadian Framework on Clean Growth and Climate Change (2017). Cat. No.: En1-77E-PDF ISSN: 2561-4169 https://www.canada.ca/content/dam/themes/environment/weather/climatechange/PCF-FirstSynthesis_ENG.pdf

3 Canada's Climate Actions for a Healthy Environment and a Healthy Economy, 2021. https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/climate-plan-overview/actions-healthy-environment-economy.html

4 Explanation: The "up front" emissions for buildings include transportation to the building site and construction activities, which are not included in this analysis. All of the emissions in this study are directly associated with the manufacturing of materials, so we use the term "material carbon emissions"

5 Simonen, K., Rodriguez, B., McDade, E,. Strain, L. (2017) Embodied Carbon Benchmark Study: LCA for Low Carbon Construction. http://hdl.handle.net/1773/38017

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7 Magwood, C., Ahmed, J., Bowden, E., Racusin, J. (2021) Achieving Real Net Zero Emission Homes. https://www.buildersforclimateaction.org/uploads/1/5/9/3/15931000/bfca-enercan-report-web.pdf

8 According to the National Building Code of Canada, each of the five energy performance tiers have two compliance metrics, overall percent improvement and heat loss reduction. Both of these are calculated in terms of percent improvement over the Reference House based on minimum prescriptive requirements. The targets for Tier 3 are 20 percent overall improvement and a 10 percent reduction in gross space heat loss.

9 Establishing the Average Up-Front Material Carbon Emissions in New Part-9 Residential Home Construction in the City of Nelson & the City of Castlegar (2021). https://www.nelson.ca/DocumentCenter/View/5586/Benchmarking-Report?bidId=

10 Residential Housing Stock and Floor Space, NRCan (2018). https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=HB&sector=res&juris=00&rn=11&page=0#sources

11 Negative emissions or carbon dioxide removal (CDR) "is the removal of greenhouse gases (GHGs) from the atmosphere by deliberate human activities, i.e., in addition to the removal that would occur via natural carbon cycle or atmospheric chemistry processes" according to IPCC, 2021: Annex VII: Glossary [Matthews, J.B.R., V. Möller, R. van Diemen, J.S. Fuglestvedt, V. MassonDelmotte, C. Méndez, S. Semenov, A. Reisinger (eds.)]

12 Residential Housing Stock and Floor Space, NRCan (2018). https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=HB&sector=res&juris=00&rn=11&page=0#sources

13 Milton floor area averages, determined by examination of data from Milton.

14 International Organization for Standardization. (2017). Sustainability in buildings and civil engineering works ; core rules for environmental product declarations of construction products and services. https://www.iso.org/obp/ui/#iso:std:iso:21930:ed-2:v1:en

15 Archtoolbox: Environmental Product Declarations (EPDs): A Guide for Architects. https://www.archtoolbox.com/materials-systems/sustainability/environmental-product-declarations.html

16 Additional emissions from the installation and/or use phases of a product are included (and noted in BEAM) in cases where emissions are significant and arise from the product's material itself and not the installation period, so that regardless of the specifics of the installation, a quantifiable amount of emissions will occur. These additional emissions are typically from direct off-gassing of GHGs from the product during construction and/or occupancy of the home.

17 ECN Phyllis Classification. https://phyllis.nl/Browse/Standard/ECN-Phyllis

18 An equivalence factor between CO2 avoidedemissions and sequestration.Pedro Moura Costa, Charlie Wilson. (2000)

Environmental Science Mitigation and Adaptation Strategies for Global Change. DOI:10.1023/A:1009697625521

19 Adapted from Srubar et al., A Methodology for Building-Based Embodied Carbon Offsetting (2021) https://www.aureusearth.com/documents

20 https://www.istructe.org/IStructE/media/Public/Resources/istructe-how-to-calculate-embodied-carbon.pdf , https://www.leti.london/ecp

21 Life Cycle Assessment of Mechanical, Electrical, and Plumbing in Commercial Office Buildings. Carbon Leadership Forum (2019). https://carbonleadershipforum.org/office-buildings-lca/

22 Based on an average of acrylic interior paint EPD results from Behr, Kelly Moore and Sherwin Williams EPDs collected in 2019.

23 US EPA, 2018, Greenhouse Gas Emissions from a Typical Passenger Vehicle. https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle

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25 Embodied carbon benchmarks for Part 3 buildings in the Greater Toronto-Hamilton Area. https://drive.google.com/file/d/13vU61c7_0UINI_LjzODykqAE0sXgNL9S/view

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27 New, Ontario-specific concrete EPD data is due to be published in Summer, 2022

28 CRMCA member industry-wide EPD for Canadian ready-mixed concrete, EPD10092. NSF (2017). https://info.nsf.org/Certified/Sustain/ProdCert/EPD10092.pdf

29 https://www.buildingtransparency.org/ec3

30 CarbonCure's Impact on the Global Warming Potential (GWP) of Concrete. https://go.carboncure.com/rs/328-NGP-286/images/CarbonCure%20Impact%20on%20Global%20Warming%20Potential%20of%20Concrete.pdf

31 As an example, Blue Planet makes aggregate from waste stream CO2 that the company claims mineralizes 440 kg of CO2 per tonne of aggregate. https://www.blueplanetsystems.com/

32 CalStar Brick SMaRT Environmental Product Declaration. http://mts.sustainableproducts.com/CalStar%20EPD%20Document_Final.pdf

33 Hans-Peter Schmidt, Kathleen Draper, Biochar building material for a climate neutral future (2020). https://www.mikrobihotelli.fi/wp-content/uploads/2020/10/Biochar-based-building-materials.pdf

34 The researchers used the second-highest MCI sample, as the highest MCI sample is a very large custom home and does not represent a typical typology in the study.

35 Iso-Stroh blown-in insulation made from 100% wheat straw. https://www.iso-stroh.net/

36 https://durrapanel.com/, https://kodukuubis.com/en/about-straw-panel/, https://ekopanely.co.uk/, https://coobio.com/

37 Continuus Materials Everboard. https://www.continuusmaterials.com/, https://www.cmdgroup.com/documents/FS/catalogs/ReWallCeilingTile_120612.pdf

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