

Embodied Carbon: A Primer for Buildings in Canada



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Embodied carbon refers to the carbon emissions associated with materials and construction processes throughout a building's life cycle.

The embodied carbon from building construction is responsible for 10 percent of all energy-related emissions globally,¹ and must be addressed if Canada is to meet its climate change goals.

This document provides the building sector with the information needed to understand embodied carbon and address it in new and existing buildings. Canada's building sector can already design buildings that operate without operational carbon emissions and several examples exist from the Canada Green Building Council's (CAGBC) Zero Carbon Building Program. However, addressing embodied carbon is a significant challenge, and more work remains.

For the building sector, most embodied carbon stems from the raw material extraction, manufacture, transportation, and installation of materials used in construction. Referred to as **upfront carbon**, these emissions are released into the atmosphere well before a building is operational, re-enforcing the need for immediate action to reduce embodied carbon.

Increasingly, construction projects are performing life cycle assessments (LCAs) to quantify embodied carbon. Often, it is primarily a skill building and awareness exercise – but that is changing. In 2019, the World Green Building Council called for a 40 percent reduction in embodied carbon by 2030.² Canada's building sector is transitioning from the basic quantification and reporting of embodied carbon to a stage where reductions must be demonstrated. The LEED™ and Zero Carbon Building – Design™ certification programs already reward projects for reductions in embodied carbon, as will the next iteration (v4) of the Toronto Green Standard. Recently, the City of Vancouver set an embodied carbon reduction target for new construction of 40 percent by 2030. It is currently developing the programs needed to achieve this target.³ Clearly, the time for meaningful reductions has arrived.

**Between 2022 and 2050,
embodied carbon can
represent over 90% of a new
building's emissions.**

Helping this transition will be the National Research Council's *Low Carbon Assets through Life Cycle Assessment Initiative*, also known as (LCA)². (LCA)² was launched to assist the government in procuring infrastructure projects (including buildings) with lower embodied carbon. In support of this goal, (LCA)² is developing:

- Whole-building life cycle assessment (wbLCA) guidelines
- High quality life cycle inventory (LCI) datasets for Canadian construction materials
- A Canadian LCI database
- Support for the integration of LCA into procurement processes

¹ GlobalABC, 2021 Global Status Report for Buildings and Construction, accessed at <https://globalabc.org/resources/publications/2021-global-status-report-buildings-and-construction>.

² World Green Building Council, Bringing Embodied Carbon Upfront, accessed at https://www.worldgbc.org/sites/default/files/WorldGBC_Bringing_Embodied_Carbon_Upfront.pdf.

³ City of Vancouver, Climate Emergency Action Plan Summary 2020-2025, accessed at <https://vancouver.ca/files/cov/climate-emergency-action-plan-summary.pdf>.

Embodied Carbon in Context

Buildings certified to CAGBC's **Zero Carbon Building – Design Standard** have demonstrated that highly energy-efficient buildings powered solely by electricity are possible in Canada. The combination of electrification and efficiency can significantly reduce operational carbon emissions in building projects, even in regions with relatively carbon-intensive electricity grids. As operational carbon decreases, the significance of embodied carbon is more apparent.

To highlight the importance of embodied carbon across Canada, CAGBC has leveraged the embodied carbon benchmarking work done by the Carbon Leadership Forum⁴ and data from its own **Making to Case for Building to Zero Carbon** research report.⁵ For this example, we chose data for mid-rise office projects.

In provinces with low-carbon electricity grids such as British Columbia, Manitoba, Ontario, Quebec, and Newfoundland & Labrador, the case for immediate and significant action is startling. The Toronto and Vancouver data shown in **Figure 1** and **Figure 2** represent buildings that are highly energy-efficient and have electrically powered geo-exchange heating systems. A value of 400 kg CO₂e/m² has been used as an average benchmark for upfront embodied carbon, which results in a total upfront embodied carbon of 21,451 tonnes CO₂e for the archetype studied.⁶ The analysis shows that embodied carbon represents the vast majority of building emissions through to 2050. Designers of buildings in clean electricity grids must focus on reducing embodied carbon – without sacrificing deep operational carbon reductions.

Figure 1: Vancouver High Performance Building
(Cumulative Tonnes CO₂e)

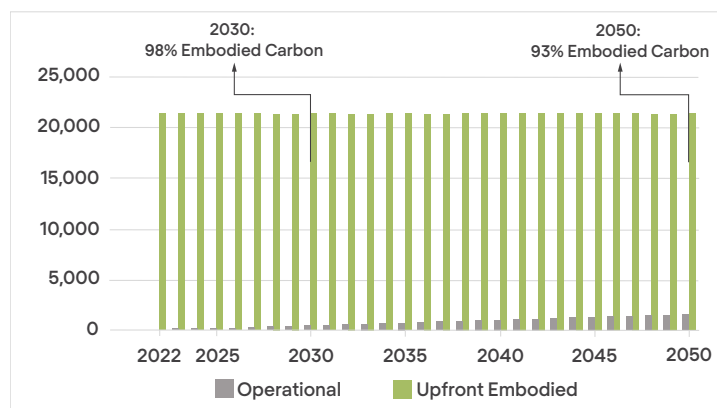


Figure 2: Toronto High Performance Building
(Cumulative Tonnes CO₂e)

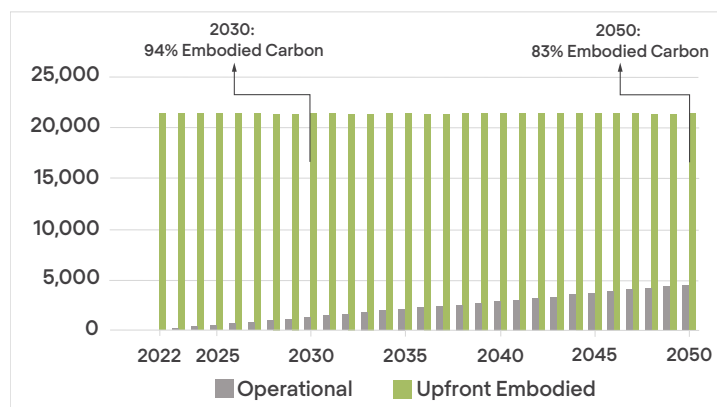
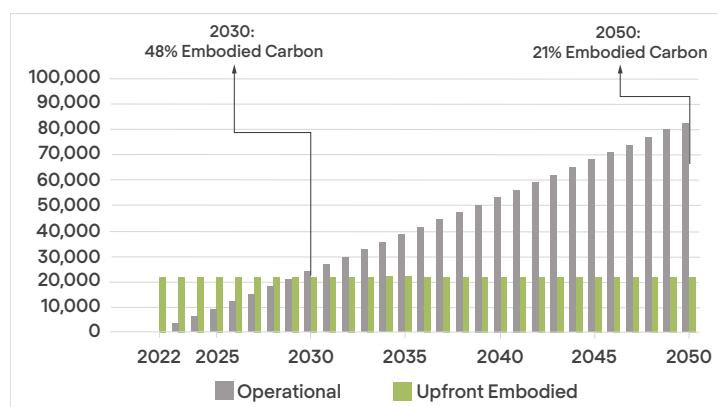


Figure 3: Calgary High Performance Building
(Cumulative Tonnes CO₂e)



⁴ Carbon Leadership Forum, Benchmark and Database for Carbon, accessed at <https://carbonleadershipforum.org/lca-benchmark-database/>.

⁵ Canada Green Building Council, Making the Case for Building to Zero Carbon, accessed at <http://www.CAGBC.org/makingthecase>.

⁶ Carbon Leadership Forum, Benchmark and Database for Carbon, accessed at <https://carbonleadershipforum.org/lca-benchmark-database/>.

The relative proportion of embodied carbon is lower for provinces with more carbon-intensive electricity grids such as Alberta, Saskatchewan, New Brunswick, Prince Edward Island, and Nova Scotia. Despite this, the Calgary data shown in **Figure 3** makes a clear argument that embodied carbon will be critical to meeting Canada's 2030 targets under the Paris Agreement, as embodied and cumulative operational carbon emissions will be approximately equivalent in 2030. Furthermore, as the electrical grids in these regions decarbonize over time, the relative significance of embodied carbon will continue to increase. As a result, the quantification and reduction of embodied carbon cannot be delayed in any region of Canada.

Embodied Carbon and Building Materials

To date, efforts to quantify and reduce the embodied carbon of buildings have focused mainly on structural and enclosure materials – primarily wood, concrete, and steel. These materials, discussed below, represent a significant portion of overall embodied carbon and offer opportunities for cost-effective reductions.

Additional structural and enclosure materials such as insulation and aluminum, are also being evaluated more closely.

Data transparency is vital to quantifying and reducing embodied carbon, and asking product manufacturers for environmental product declarations (EPDs) helps reinforce the importance of transparency in the market. Critically, EPDs allow for like-to-like comparisons of products that are outside the current scope of whole-building life cycle assessment, such as fit-up materials.

Wood and Mass Timber

Forestry is one of Canada's oldest industries, and wood is the predominant building material for low-rise construction in Canada. The entry of mass timber to the market has expanded the opportunities for wood construction, particularly in the 5-12 storey range.

Mass timber is defined as thick, compressed layers of wood, creating strong, structural load-bearing elements that can be constructed into panelized components.⁷ Examples of mass timber products include cross-laminated timber (CLT) and glue-laminated timber (glulam).

⁷ Naturally Wood, What is Mass Timber, accessed at <https://www.naturallywood.com/topics/mass-timber/>.

The key benefits of wood and mass timber construction include low embodied carbon and the potential for faster and more predictable construction times. The low embodied carbon of wood products stems from the fact that the manufacturing process is not energy-intensive and relies predominantly on electricity. Production does not require the high temperatures needed for cement or steel manufacturing. When sustainable forestry practices are observed, forest regrowth also sequesters carbon – although this is not always accounted for when performing life cycle assessment.

Mass timber should be considered for any building of 12 storeys or less.

High-profile examples of mass timber construction in Canada, such as the **Brock Commons Tallwood House** student residence building⁸ at the University of British Columbia and the **Wood Innovation and Design Centre** at the University of Northern British Columbia,⁹ have created market optimism for mass timber construction in the institutional sector. Canada will need more completed commercial projects to gain wider adoption of mass timber in this sector, but experience is rapidly growing: today, there are over 40 large (5+) storey commercial office and residential projects at various stages of development in Canada.¹⁰

Canada is an international leader in forest stewardship with the most third-party certified sustainably managed forest area globally.¹¹

Sustainably managed forests have many benefits, including ensuring that all trees are replaced when harvested and that biodiversity is protected. Sustainably harvested Canadian wood is a valuable resource for the building sector.

Mass timber production has increased in recent years, and there are now over 20 facilities in Canada that manufacture mass timber products.¹²

Mass timber should be considered for any building of 12 storeys or less. With many forms of hybrid construction available, developers and design teams unfamiliar with mass timber construction can gradually increase their comfort and confidence.

Concrete

Concrete is the second most-consumed material in the world, surpassed only by water.¹³ Canada produces approximately 60 million tonnes of concrete each year.¹⁴ Cement serves as the binder in concrete and is responsible for 10-15 percent of its material volume and approximately 88 percent of its embodied carbon.¹⁵ Canada produces 13 million tonnes of cement each year.¹⁶

Concrete is, by nature, a customizable product, made up of different components that can be adjusted to produce different strengths and cure times. Not only can component proportions be adjusted, but the components and production methods can vary. As a result, there are several viable means to reduce the embodied carbon of the concrete used in buildings. The first step is engaging with concrete suppliers early on in a project to discuss low-carbon options.

⁷ Naturally Wood, What is Mass Timber, accessed at <https://www.naturallywood.com/topics/mass-timber/>.

⁸ Think Wood, Brock Commons Tallwood House, accessed at <https://www.thinkwood.com/projects/brock-commons-tallwood-house>.

⁹ Think Wood, Wood Innovation and Design Centre, accessed at <https://www.thinkwood.com/projects/wood-innovation-and-design-centre>.

¹⁰ Natural Resources Canada, SMTG Geospatial Platform, accessed at <https://nrcan-ncan.maps.arcgis.com/apps/dashboards/041e338d2a4d4b3a82ff2c238a9f0f93>.

¹¹ Naturally Wood, Forest Certification in British Columbia, accessed at https://www.naturallywood.com/wp-content/uploads/2020/08/forest-certification-in-british-columbia_factsheet_naturallywood.pdf.

¹² Natural Resources Canada, Mass timber Construction in Canada, accessed at <https://www.nrcan.gc.ca/our-natural-resources/forests/industry-and-trade/forest-products-applications/mass-timber-construction-canada/23428>.

¹³ Science Direct, Cement and Concrete as an Engineering Material: An Historic Appraisal and Case Study Analysis, accessed at <https://www.sciencedirect.com/science/article/abs/pii/S1350630714000387>.

¹⁴ Innovation, Science and Economic Development Canada, Joint statement: Canada's Cement Industry and the Government of Canada announce a partnership to establish Canada as a global leader in low-carbon cement and to achieve net-zero carbon concrete, accessed at <https://www.ic.gc.ca/elc/site/icgc.nsf/eng/07730.html>.

¹⁵ Portland Cement Association, Environmental Life Cycle Inventory of Portland Cement Concrete, accessed at https://www.nrmca.org/taskforce/item_2_talkingpoints/sustainability/sustainability/sn2137a.pdf.

¹⁶ Cement Association of Canada, Economic Contribution, accessed at <https://cement.ca/economic-contribution/>.

One strategy used to reduce the embodied carbon of concrete is to add supplementary cementitious materials (SCMs) to concrete mixes, thereby reducing the amount of cement. While some SCM use is common in Canada (typically 10-15% of the concrete mix, with some regional differences),¹⁷ there is potential to go higher (40%+).¹⁸

Increasing curing time can allow more SCMs to be used in concrete mixes. Even without SCMs, extending curing time can lower embodied carbon by reducing the required amount of cement. On the other hand, extending the curing time may not be possible for elements that require early strength, such as foundations, columns, and walls.

Supplementary cementitious materials, Portland limestone cement, and extended curing times are readily available solutions for reducing embodied carbon.

Portland limestone cement (PLC) is a substitute for Portland cement, the latter being the standard binder used in concrete. It contains a higher limestone content and provides an average reduction in embodied carbon of 10 percent.¹⁹ PLC has the same functional properties as Portland cement and can be substituted at a 1:1 ratio, which means that existing concrete mix designs may not need to change. PLC is widely available across Canada, approved by regulators, and often carries no cost premium.

Depending on the project location, there may be products available that store mineralized carbon in the concrete, sequestering carbon (keeping it out of the atmosphere) and sometimes even strengthening the concrete simultaneously.

Cement vs Concrete

These words are often used interchangeably; however, they are not the same.

Cement is the binder and key ingredient in concrete, which is a mix of cement, water, and aggregate.

These technologies can be combined with other strategies, such as those above, to maximize embodied carbon reductions.

Specifying low embodied carbon concrete can be done prescriptively or based on performance. Using prescriptive specifications, such as requiring a given SCM content or the use of Portland Limestone Cement, is simpler for both specifiers and manufacturers. However, it can limit the pool of qualifying products.

¹⁷ CAGBC Embodied Carbon Roundtables.

¹⁸ Athena Sustainable Materials Institute, NRMCA Member National and Regional LCA Benchmark (Industry Average) Report – V 3.0, accessed at https://www.nrmca.org/wp-content/uploads/2020/02/NRMCA_REGIONAL_BENCHMARK_Nov2019.pdf.

¹⁹ Portland Limestone Cement, Portland Limestone Cement Fact Sheet, accessed at https://b910efcb-b4f5-4088-990d-b624f092391e.filesusr.com/ugd/f3d485_bf593dd744f049d98cbd293109fc42ce.pdf.

Steel

Canada produces 12.8 million metric tons of steel each year,²⁰ manufactured using either a basic oxygen furnace (BOF) or an electric arc furnace (EAF). BOFs rely on fossil fuels for the smelting process. EAFs produce the heat needed using an electric arc, which allows the manufacturing process to take advantage of Canada's clean electricity. EAFs can also produce steel from much higher proportions of scrap materials, which uses less energy and decreases the impacts of extracting iron ore. Despite these advantages, most of the steel produced globally uses BOFs.

Steel manufactured in Canada generally has a smaller embodied carbon footprint – and there is significant investment in further decarbonizing Canada's steel mills.

Due to production methods, efficiencies, and reduced shipping distances, steel manufactured in Canada will generally have a smaller embodied carbon footprint. However, projects seeking to reduce the embodied carbon of steel further will find a limited supply of low-carbon steel.

While there have been recent announcements of investments in EAF technology,²¹ it will take time for additional production capacity to become available. In addition, although steel is 100 percent recyclable,²² the supply of recycled steel cannot meet current demand. Therefore, only 40 percent of steel in Canada is manufactured using recycled steel.²³ The steel industry in Canada will require significant investment to improve the supply of low-carbon steel over time.

Innovations may provide additional ways to produce low-carbon steel in the future. For example, the hydrogen reduction method could become a viable alternative once green hydrogen (hydrogen produced using renewable electricity) becomes available. While BOF steelmaking forces oxygen through molten iron, removing carbon from the iron and creating CO₂, the hydrogen reduction method removes carbon using hydrogen and does not produce CO₂.



²⁰ International Trade Administration, Global Steel Trade Monitor, May 2020, accessed at <https://legacy.trade.gov/steel/countries/pdfs/exports-Canada.pdf>.

²¹ In 2021 funding was announced for EAF technology at the Algoma Steel facility in Sault Ste. Marie and the ArcelorMittal Dofasco facility in Hamilton.

²² Canadian Steel Producers, Canada's Steel Industry: A Sustainable Choice, accessed at https://canadiansteel.ca/files/resources/CSPA_Climate-Call-to-Action-EN.pdf.

²³ Natural Resources Canada, Benchmarking Energy Intensity in the Canadian Steel Industry, accessed at <https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/oeefiles/pdf/Industrial/SteelBenchmarkEnglish.pdf>.

Conclusions

Decarbonizing Canada's built environment will require decisive action on both operational carbon and embodied carbon. Embodied carbon must be treated with the same urgency as operational carbon, and owners and developers, designers and builders, and governments all have a role to play.

Owners and developers must require a life cycle assessment (LCA) of all major projects to quantify and reduce embodied carbon. The lessons learned from larger projects should be applied to all projects. Embodied carbon should be included in carbon emissions inventories and reported in Environmental, Social, and Governance (ESG) reporting.

Embodied carbon must be treated with the same urgency as operational carbon. Fortunately, there are exciting opportunities for innovation and meaningful, timely carbon reductions.

Designers and builders must rise to the challenge and offer clients LCA services to quantify and reduce embodied carbon as early as possible in the design process.

They should reach out to suppliers for environmental product declarations (EPDs) and select low-carbon products whenever possible. When considering thermal energy demand measures such as insulation, designers must balance decreasing embodied carbon with keeping thermal energy demand low enough to make the electrification of space heating cost-effective.

Local governments must include embodied carbon requirements in all building-sector carbon policies. There are no significant barriers to requiring quantification for larger buildings (5,000 m² and larger) built to Part 3 of the Building Code. As skills in the region develop, embodied carbon reductions can be mandated. This change must not be delayed in regions with carbon-intensive electricity grids.

Governments at the federal and provincial levels also have a critical role to play. By making strategic investments in industry, they can help increase the availability of low-carbon building materials and make Canadian products more competitive internationally. Government action can also provide incentives for mass timber construction and low-carbon concrete.

All tiers of government should lead by example, work together to drive emission reductions, and spur Canadian innovation through their procurement policies.

CAGBC's Zero Carbon Building – Design Standard is a tool project teams can use to help analyze and reduce the whole life carbon (embodied carbon plus operational carbon) of a building and provide third-party assurance. The Standard provides a compass to guide project teams through design and operations and is leveraged by governments in their procurement and incentive programs.

To achieve a zero-carbon society by 2050, all sectors of the economy must decarbonize. Reductions in embodied carbon are a part of this necessary work and must be pursued with the same urgency as reductions in operational emissions. Despite the challenges surrounding embodied carbon, there are exciting opportunities for innovation and meaningful, timely carbon reductions.

