Low-Rise Buildings as a Climate Change Solution

BUILDERS FOR CLIMATE ACTION

Low-Rise Buildings as a Climate Change Solution

2019
1. Executive Summary
2. Key Considerations
3. Up-front Embodied Carbon
4. Combined Up-front & Operational Carbon
5. Key Findings
6. Next Steps
EXECUTIVE SUMMARY
HOW

- Two sample buildings are modeled with a wide array of conventional and alternative building materials to determine the GHG impact on “up-front” embodied carbon emissions
- The sample buildings are modeled at two levels of energy efficiency using two different fuel sources to determine effects on operational emissions
- Results from embodied and operational emissions are combined to determine best practice to reduce or eliminate building emissions between 2020 and 2050
- Up-front embodied carbon, fuel source emissions and energy efficiency measures are ranked by their impact on overall carbon footprint

WHY

- Buildings are a leading contributor to greenhouse gas emissions, and no climate action plan can succeed without adequately addressing this key sector
- The response to building-related emissions has been to focus solely on energy efficiency, but this may result in initiatives and policies that will raise emissions rather than lower them
- We can feasibly and affordably capture and store vast amounts of carbon in buildings, transforming the sector from a major emitter to a major carbon sink

Buildings contribute to climate change in three distinct ways:

1. **Up-front embodied carbon:** the emissions arising from the harvesting, manufacturing and transportation of building materials
2. **Energy efficiency:** the amount of energy consumed by buildings expressed as energy use intensity or EUI
3. **Fuel source emissions:** the emissions profile of the fuel used to heat, cool and power appliances in buildings

All three factors must be considered in order to address emissions from the building sector.
<table>
<thead>
<tr>
<th>WHAT WE FOUND</th>
<th>SO WHAT</th>
<th>NOW WHAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical low rise buildings have high up-front embodied carbon emissions, ranging from 90-420 kgCO₂e per square meter of building area</td>
<td>Up-front embodied emissions are a much larger issue than previously considered, and must be reduced to address overall sector emissions</td>
<td>Up-front embodied emissions for buildings materials must be measured and policies enforcing caps developed for fast reductions</td>
</tr>
<tr>
<td>Available, affordable material options can reduce net up-front carbon to zero, eliminating this large source of emissions</td>
<td>Zero up-front emissions is a realistic option for the sector requiring no changes in codes or construction methodology and creating vast emission reductions across the sector</td>
<td>Building sector leaders should be ambitiously move to make buildings with zero up-front emissions.</td>
</tr>
<tr>
<td>Feasible, affordable material options can be used to achieve net carbon storage in buildings, with up to 170 kgCO₂e/m² of net storage demonstrated</td>
<td>Carbon-storing buildings are an exciting and practical way to transform buildings from a leading driver of climate change to a leading means of CO₂ drawdown</td>
<td>Opportunities to develop building materials from widely available agricultural residues, waste fibers and forestry by-products should be actively encouraged</td>
</tr>
<tr>
<td>Fuel switching to clean, renewable electricity provides the largest overall emission reductions, with annual savings of 70-75% compared to natural gas</td>
<td>The most meaningful investments in emission reductions are at the grid level, where clean energy will greatly reduce the carbon footprint of buildings</td>
<td>Clean energy is critical for the building sector to meaningfully reduce its carbon footprint and policy efforts must be focused on this goal</td>
</tr>
<tr>
<td>Material selection is the most impactful intervention at the individual building level, with reductions of up-front emissions of 150%</td>
<td>Designers and builders can completely transform the carbon footprint of their buildings through carbon-smart material choices</td>
<td>Collective action is required to understand and promote carbon-smart material choice</td>
</tr>
<tr>
<td>Energy efficiency beyond current code minimum in Ontario is the least effective and most costly means of reducing building emissions</td>
<td>Net zero energy building codes will not adequately address emissions from the building sector within a meaningful time frame</td>
<td>Policy makers and regulators must aim for true net zero carbon buildings, not net zero energy buildings</td>
</tr>
</tbody>
</table>
Time is a Critical Factor

**TIME is a critical factor**
Emissions averted today contribute more to slowing climate change than emissions averted in the future.

**From 2020-30**
Upfront embodied carbon contributes more than the ongoing operational emissions.

**DAY 1**
A building will have emitted 100% of its embodied carbon the day it is built.

**TODAY to 2030**
Embodied carbon is the largest contributor of GHGs.

**BY 2050**
Embodied carbon can still be the majority of emissions.

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**Total Carbon Emissions of Global New Construction**
Every Year from 2020 • Business as Usual Projection

- **Upfront Embodied Carbon**
- **Operational Emissions**

IPCC target for major emission reductions:

- **2020-2030**

Emissions averted today contribute more to slowing climate change than emissions averted in the future.

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Materials Matter
The same building can have very different up-front embodied carbon emissions (UEC)

<table>
<thead>
<tr>
<th>High UEC</th>
<th>Typical UEC</th>
<th>Best Conventional UEC</th>
<th>Best UEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assembly includes:</td>
<td>Assembly includes:</td>
<td>Assembly includes:</td>
<td>Assembly includes:</td>
</tr>
<tr>
<td>High carbon concrete</td>
<td>Average carbon concrete</td>
<td>High SCM concrete</td>
<td>Iso-Span ICF with high SCM concrete</td>
</tr>
<tr>
<td>XPS &amp; closed cell spray foam</td>
<td>Mineral wool insulation</td>
<td>Cellulose &amp; wood fiberboard insulation</td>
<td>Expanded glass sub-grade insulation</td>
</tr>
<tr>
<td>Brick cladding</td>
<td>Fiber cement cladding</td>
<td>Wood cladding</td>
<td>Straw &amp; wood fiberboard insulation</td>
</tr>
<tr>
<td>Steel interior framing</td>
<td>Wood &amp; TJI interior framing</td>
<td>Wood interior framing</td>
<td>Wood cladding</td>
</tr>
<tr>
<td>Drywall</td>
<td>Drywall</td>
<td>Drywall &amp; wood walls</td>
<td>Compressed straw panel interior walls</td>
</tr>
<tr>
<td>Vinyl windows</td>
<td>Vinyl windows</td>
<td>Aluminum clad wood windows</td>
<td>ReWall interior cladding</td>
</tr>
<tr>
<td>Tile &amp; carpet flooring</td>
<td>Engineered wood &amp; vinyl flooring</td>
<td>Engineered wood &amp; FSC hardwood flooring</td>
<td>Wood windows</td>
</tr>
<tr>
<td>Clay tile roofing</td>
<td>Asphalt shingle roofing</td>
<td>Steel roofing</td>
<td>Linoleum &amp; FSC softwood flooring</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cedar shake roofing</td>
</tr>
</tbody>
</table>

Total Net Carbon EMISSIONS
High UEC: 241 kgC02e/m2
Typical UEC: 90 kgC02e/m2
Best Conventional UEC: -11 kgC02e/m2
Best UEC: -137 kgC02e/m2
This result indicates the seriousness of up-front carbon emissions from low-rise buildings. **At these rates of emissions, buildings cannot be part of a climate change solution.**
**What This Means at Scale**

CARBON EMISSING BUILDING

Avg of 225 kgCO₂e/m² emissions

+ Adding emission equivalent of 15 coal plants

= 54 million tonnes of carbon emissions

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CARBON STORING BUILDING

= 36 million tonnes of carbon storage

- Removing emission equivalent of 10 coal plants

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Total 2017 U.S. Low-rise Construction:
241 million m² of new low-rise residential construction*

Business-as-usual will result in massive annual up-front emissions.

Carbon-storing buildings eliminate all up-front emissions and can result in meaningful carbon drawdown.

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*U.S. Census Bureau/U.S. HUD, CB19-21
Combining Up-front and Operational Emissions

**Carbon Emitting Building**

Using Natural Gas

Buildings can continue to **DRIVE** climate change...

**Carbon Storing Building**

Using Renewable Electricity

Buildings can help to **REVERSE** climate change.

614 tonnes of avoided emissions after 30 years
A Clear Pathway to Zero Carbon or Carbon Storing Buildings

We can set realistic thresholds for combined up-front and operational emissions - carbon use intensity - to steer the low-rise building sector in a climate positive direction that is measurable and achievable.
KEY CONSIDERATIONS
We should be examining all three aspects of GHG emissions from the low-rise building sector:

**Up-front embodied carbon emissions**
the emissions arising from the harvesting, manufacturing and transportation of materials

**Operational carbon emissions**

- **Energy efficiency/Energy use intensity**
  the amount of energy consumed by buildings
- **Energy source emissions**
  the emissions profile of the fuel used to power buildings

**Carbon Use Intensity (CUI)**

Only by considering all three emission factors can we design truly “zero carbon” buildings. Ignoring any one of these aspects of building emissions raises the possibility that our efforts are, at best, incomplete and at worst, counterproductive.

A zero carbon building needs to have a CUI of zero.
Carbon Use Intensity

\[
\text{CUI} = \text{Up-front Embodied Carbon Emissions} + \text{Operational Carbon Emissions}
\]

- **Up-front Embodied Carbon Emissions**
  - Extraction
  - Transportation
  - Manufacturing

- **Operational Carbon Emissions**
  - Energy Use Intensity
  - Energy Source Emissions

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A New Paradigm: Carbon Storing Materials

The results of this study demonstrate that we are capable of making low-rise residential buildings with a net zero embodied carbon footprint, and that we can even surpass this threshold and create buildings that actually have net carbon storage rather than net emissions.

Plant-based materials STORE more atmospheric carbon than was emitted in harvesting and manufacturing.

This opens a whole new category of building materials with CARBON REMOVAL AND STORAGE POTENTIAL!

CARBON CAPTURE
During photosynthesis, plants capture gaseous carbon from the atmosphere. That carbon is stored in the plants themselves, as well as in the soil.

Plant-based building materials prevent this stored carbon from returning directly to the atmosphere, providing meaningful storage for the duration of a building’s lifespan.
Plant-based building materials made from agricultural residues and waste fiber streams offer particularly high storage potential as we already produce these materials in vast quantities and do not need to create new sources of emissions in order to procure the source material.

The building industry already produces numerous plant-based materials, and many others could be scaled up to provide a potentially vast carbon sink within the built environment.
2.16 billion tons of grain straw were grown globally in 2016 drawing down almost 8 billion tonnes of CO₂. That’s enough carbon storage to offset all annual transportation GHG emissions and replace all current insulation materials.

There are many straw-based building products that are ready to become mainstream options.
UP-FRONT EMBODIED CARBON EMISSIONS
METHODOLOGY

Up-front Embodied Carbon Emissions

Eight examples of two types of common low-rise building are examined using the Global Warming Potential (GWP) figures from Environmental Product Declarations (EPDs).

Total up-front emissions are based on material takeoffs for code-compliant foundation, exterior walls, interior walls, floor & roof assemblies and windows.

Over 350 materials were modelled, with four representative examples created that were typical of high, typical, best conventional and best up-front embodied carbon.

Total Up-front embodied carbon emissions:
expressed as kilograms of CO₂ equivalent per square meter of floor area (kgCO₂e/m²)
RESULTS

Up-front Embodied Carbon Emissions

There is an extremely wide range of embodied carbon results, showing that material selection can have a dramatic impact on up-front emissions.

There are large reductions in emissions between each of the four building examples…

- **High UEC** to **Typical UEC** = 57% avg reduction
- **Typical UEC** to **Best Conventional UEC** = 90% avg reduction
- **High UEC** to **Best UEC** = 148% avg reduction

Up-front embodied carbon emissions kgCO$_2$e/m$^2$

**SINGLE UNIT**
- **Net Zero Ready**
- **Code Compliant**

**MULTI-UNIT**
- **Net Zero Ready**
- **Code Compliant**
OPERATIONAL CARBON EMISSIONS
METHODOLOGY

Operational Carbon Emissions

Energy models were generated using Energy-10 (E10), a US Department of Energy-developed dynamic hourly simulation energy modeling program, based on Toronto, Ontario climate data.

<table>
<thead>
<tr>
<th>Thermal Performance Values for Model Buildings</th>
<th>Single unit, code compliant</th>
<th>Single unit, net zero ready</th>
<th>Mult-unit, code compliant</th>
<th>Mult-unit, net zero ready</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof</td>
<td>R-60</td>
<td>R-80</td>
<td>R-60</td>
<td>R-80</td>
</tr>
<tr>
<td>Walls</td>
<td>R-19 plus R-5 continuous</td>
<td>R-40</td>
<td>R-13 plus R-10 continuous</td>
<td>R-30</td>
</tr>
<tr>
<td>Basement walls</td>
<td>R-12 plus R-10 continuous</td>
<td>R-30</td>
<td>R-15 continuous</td>
<td>R-20</td>
</tr>
<tr>
<td>Slab</td>
<td>R-10</td>
<td>R-20</td>
<td>R-15</td>
<td>R-15</td>
</tr>
<tr>
<td>Windows</td>
<td>U-0.28</td>
<td>U-0.18</td>
<td>U-0.29</td>
<td>U-0.20</td>
</tr>
<tr>
<td>Doors</td>
<td>U-0.28</td>
<td>U-0.18</td>
<td>U-0.45</td>
<td>U-0.20</td>
</tr>
<tr>
<td>HRV efficiency</td>
<td>75%</td>
<td>89%</td>
<td>75%</td>
<td>89%</td>
</tr>
<tr>
<td>DHW min. efficiency</td>
<td>Electric 0.93 Gas 0.80</td>
<td>Electric 0.93 Gas 0.80</td>
<td>Electric 0.93 Gas 0.80</td>
<td>Electric 0.93 Gas 0.80</td>
</tr>
</tbody>
</table>

Jacob Deva Racusin, author of *Essential Building Science* and energy modeler for New Frameworks Natural Design/Build in Vermont, executed the energy models for this study using Energy-10 (E10), a US Department of Energy-developed dynamic hourly simulation energy modeling program, with Andrew M. Shapiro of Energy Balance, Inc. performing a technical review of the models.
RESULTS

Operational Carbon (OC) Emissions

The difference in OC emissions for the two fuel sources is remarkable, averaging 96 percent lower for the all-electric versions compared to those heated with natural gas.

As expected, net zero ready buildings produce significantly less emissions, regardless of fuel type. The single-family building generates 69 percent less emissions in the all-electric version and 47 percent less when using natural gas. The multi-unit building reduces OC by 75 percent with electric heat and 53 percent with natural gas.

The effect of airtightness is significant. Modeled at 1.0 ACH/50 without any upgrades in insulation or window quality, the single-family building reduces OC by 38 percent (electric) and 23 percent (gas) while the multi unit sees OC reductions of 58 percent (electric) and 40 percent (gas).

<table>
<thead>
<tr>
<th>Description of Building</th>
<th>Heating CO2e, Electric ASHP, Ontario Grid</th>
<th>Heating CO2e, Natural Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kgCO2e/yr</td>
<td>kgCO2e/yr</td>
</tr>
<tr>
<td>Single-unit, code compliant</td>
<td>160</td>
<td>3,000</td>
</tr>
<tr>
<td>Single-unit, code compliant, air-tight</td>
<td>100</td>
<td>2,300</td>
</tr>
<tr>
<td>Single-unit, net zero ready</td>
<td>50</td>
<td>1,600</td>
</tr>
<tr>
<td>Multi-unit, code compliant</td>
<td>750</td>
<td>15,000</td>
</tr>
<tr>
<td>Multi-unit, code compliant, air-tight</td>
<td>330</td>
<td>9,000</td>
</tr>
<tr>
<td>Multi-unit, net zero ready</td>
<td>190</td>
<td>7,100</td>
</tr>
</tbody>
</table>
COMBINED UP-FRONT & OPERATIONAL CARBON EMISSIONS
Results with **natural gas heating**
Combined up-front & operational carbon emissions

Bigger emission reductions can be made by addressing up-front embodied emissions than by moving to higher levels of energy efficiency.

**Operational carbon reductions:**

<table>
<thead>
<tr>
<th>Code Minimum</th>
<th>NET ZERO</th>
<th>= 60 tonne avg reduction over 30 years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Code Minimum</td>
<td>NET ZERO</td>
</tr>
<tr>
<td></td>
<td>Typical UEC</td>
<td>Best Conventional UEC</td>
</tr>
<tr>
<td></td>
<td>Best UEC</td>
<td>Best UEC</td>
</tr>
</tbody>
</table>

**Embodied carbon reductions:**

We can build AND operate the **Best Conventional UEC** building for 30 years with fewer emissions than just the up-front embodied emissions of the **High UEC building**.

We can build AND operate the **Best UEC** building for 30 years with fewer emissions than just the up-front emissions of the **Typical UEC** building.
Combined up-front & operational carbon with electric heat pump
Tonnes CO₂e for 8-unit building

Results with heat pump (using Ontario electrical grid)
Combined embodied and operational carbon

Clean electrification means that up-front embodied emissions from conventional buildings are the majority of overall emissions in 30 years.

Operational carbon reductions:

<table>
<thead>
<tr>
<th>Code Minimum</th>
<th>NET ZERO</th>
<th>= 6tonne avg reduction over 30 years</th>
</tr>
</thead>
</table>

Embodied carbon reductions:

- **Up-front Emissions**:
  - High UEC
  - Typical UEC = 103tonnes Immediate Reduction!

- **Typical UEC**:
  - Best Conventional UEC = 129tonnes Immediate Reduction!

- **Best Conventional UEC**:
  - Best UEC = 119tonnes Immediate Reduction!

Improvements in energy efficiency from Ontario code minimum to Net Zero ready standards do not result in meaningful carbon reductions when clean electricity is the fuel source. In fact, the additional insulation materials in the High UEC and Typical UEC examples result in a higher overall carbon footprint despite the energy savings.

The Best UEC model remains in a state of net storage of 72-85 tonnes by 2050, and will continue to be a site of net storage until the end of the century, a truly remarkable achievement and a great contribution to limiting climate change if we can achieve these results at a large scale.
KEY FINDINGS
Low-rise buildings can store a significant amount of carbon

The results from the Best UEC examples for both the single- and multi-unit buildings indicate that this type of residential construction can provide net carbon dioxide removal and storage of $137-171 \text{ kgCO}_2\text{e/m}^2$ using a viable material palette.

Compared to expected net emissions of 90-191 $\text{ kgCO}_2\text{e/m}^2$ from the Typical EUC and 241-418 $\text{ kgCO}_2\text{e/m}^2$ for the High UEC examples, the volume of net storage capacity indicates a major paradigm shift from GHG emitting to carbon storing buildings.

We should not set our expectations at mere carbon reductions. We should aspire to this type of realistic net carbon storage in our buildings.
Buildings can feasibly reach zero up-front embodied emissions today

The Best Conventional UEC example exhibited an average of -12 kgCO₂e/m² for the multi-unit building and 39 kgCO₂e/m² for the single-unit, making this type of building carbon neutral.

The key materials selected to create this model represent options that are commercially available, competitively priced and code-compliant:

- Use of cellulose insulation in walls and attics. This product is widely manufactured and distributed in North America.
- Use of wood fiberboard exterior insulation. This product is widely available in Europe, and has limited production in North America.
- Specification of concrete mixes with high percentages of supplementary cementitious materials (SCM). These mixes can be specified from most concrete batching plants.

Designers and builders could realistically move to implement this type of zero up-front carbon building with few impediments, and in doing so dramatically alter the embodied carbon emissions of the building industry, bringing residential UEC climate impacts close to zero.
The carbon storage potential of wood is significant, but difficult to accurately quantify

Timber has a very important role to play in a low-carbon built environment. The replacement of high UEC materials like concrete and steel with a low UEC and renewable material is a key strategy for the building industry to adopt. However, the attribution of carbon storage in timber products must be carefully considered, and counted only when enough is understood about a specific product and its life cycle to correctly assume that meaningful net storage is occurring.

In this study, the sample building assembly with the highest up-front carbon storage has cross-laminated timber (CLT) walls with wood fibreboard insulation, resulting in 45 tonnes of storage. However, if carbon storage in the CLT is not counted, the same walls have just 7.8 tonnes of storage.

Sustainably harvested wood with quantifiable levels of carbon storage can provide a path to buildings with high amounts of up-front carbon storage. We need to undertake collective action to ensure that carbon-positive forestry practices quickly become the norm.
Carbon-storing materials have numerous co-benefits

This study focuses on the Global Warming Potential (GWP) of materials, but the Environmental Product Declarations used in this study show that the materials with the best carbon storage capabilities also tend to have the best results in the other impact categories, which include acidification, eutrophication, smog and ozone generation, fresh water use and hazardous waste generation. This is worthy of further study, but would indicate that, in most cases, overall environmental improvements would follow from replacing high GWP materials with alternatives with lower GWP.

Additionally, none of the carbon storing materials in this study contains ingredients found on the International Living Future Institute’s chemical Red List*. An initial exploration of carbon storing materials using the Data Commons of the Healthy Building Network** does not indicate any content that falls in the High or Very High hazard levels. As the indoor environment quality of buildings is of growing concern, the move to a materials palette that includes more carbon-storing options appears likely to correspond with improvements in occupant health and safety. Materials with less potentially dangerous chemical content also have benefits at end of life, with fewer opportunities for environmental contamination through landfill, recycling or combustion.

* https://living-future.org/declare/declare-about/red-list/
** https://pharosproject.net/
The emissions profile of the energy source has a greater impact than the energy efficiency of the building.

A switch from natural gas as the heating fuel to electric air source heat pumps using the Ontario, Canada electrical grid can reduce 246 tonnes of emission reductions between 2020 and 2050 (8.2 tonnes per year) in the code compliant versions, and 192 tonnes in the net zero examples (6.4 tonnes per year). This far outweighs the 60 tonne improvement from making the natural gas model more energy efficient, and the 6 tonnes from improving energy efficiency for the electric heat pump model.

This indicates that we can achieve greater emissions reductions from aggressively moving to clean energy grids than from improving the energy efficiency of individual buildings. The building industry can and should encourage the move to clean energy grids as a key part of its own emissions reduction efforts.
A narrow focus on operational emissions can be counterproductive and have unintended climate consequences.

The term “energy efficiency” misses the point when it comes to climate change: energy and GHGs are not necessarily synonymous, and we need to think about Carbon Use Intensity (CUI) rather than Energy Use Intensity (EUI). Energy efficiency is just one consideration in an overall GHG reduction strategy, but not a stand-alone solution to GHG emissions.

Reducing up-front embodied carbon is a more effective intervention than improving energy efficiency from current code minimums in Ontario to net zero ready levels. Each “step” between the four levels of embodied carbon explored in this study represents a drop in emissions of 98-139 tonnes of UEC per building, while the energy efficiency improvements are 60 tonnes if fueled by natural gas and 6 tonnes with Ontario electricity.

The move to cleaner energy reduced emissions by 246 tonnes for the code compliant version and 192 tonnes for the net zero, compared to reductions of 60 and 6 tonnes for the code compliant and net zero versions. If the energy source produces low or no emissions, we won’t achieve meaningful reductions by reducing the amount of clean energy we use. If we insist on increasing insulation using high UEC materials, we will actually cause overall emissions to increase rather than decrease.
Air tightness is an easy intervention for reducing operational emissions

Buildings insulated to meet minimum code requirements in Ontario can improve energy efficiency from 23-56% by increasing air tightness from code minimum standards of 2.5-3.0 ACH/50 to 1.0 ACH/50.

These results suggest that air tightness alone is a highly effective GHG reduction strategy. All low-rise buildings in Ontario already incorporate the air control layers required for achieving 1.0 ACH/50, including exterior weather resistant membrane and interior vapour control layer. An improvement in the installation procedures for these materials and a greater emphasis on achieving and protecting air tightness can result in overall reductions in operational emissions that do not require investments in more insulation and better windows.

This is the easiest intervention for reducing operational emissions without requiring the use of more insulation materials.

<table>
<thead>
<tr>
<th>Description of Building</th>
<th>Heating CO2e, Electric ASHP, Natural Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Heating CO2e, Natural Gas</td>
</tr>
<tr>
<td></td>
<td>kgCO₂e/yr</td>
</tr>
<tr>
<td>Single-unit, code compliant, 2.5ACH/50</td>
<td>160</td>
</tr>
<tr>
<td>Single-unit, code compliant, 1.0ACH/50</td>
<td>100</td>
</tr>
<tr>
<td>Single-unit, net zero ready, 1.0ACH/50</td>
<td>50</td>
</tr>
<tr>
<td>Multi-unit, code compliant, 3.0ACH/50</td>
<td>750</td>
</tr>
<tr>
<td>Multi-unit, code compliant, 1.0ACH/50</td>
<td>330</td>
</tr>
<tr>
<td>Multi-unit, net zero ready, 1.0ACH/50</td>
<td>190</td>
</tr>
</tbody>
</table>
Renovations of existing buildings should consider embodied carbon in addition to energy efficiency

The high carbon footprint of many conventional insulation materials and windows – two of the main upgrades in efficiency renovations – indicates that climate policy for reducing GHGs from existing buildings must consider the up-front embodied carbon implications or the resulting renovations may be responsible for more emissions than will be saved over many decades of reduced operational emissions.

Renovations performed with carbon-storing insulation materials will have an immediate climate drawdown effect in addition to providing additional energy efficiency. The stored carbon in such renovations could buy time for the buildings to transition to cleaner energy sources.

Since existing foundations, structural walls and roof framing are typically preserved – and therefore don’t require additional up-front emissions – the use of carbon-storing insulation materials is likely to make the net carbon storage per square meter of renovation projects much higher than for new buildings. Renovated buildings could become key sites of net carbon storage.

Opportunities exist for significant carbon storage in commercial, institutional and high-rise buildings

Although this study focuses on low-rise residential construction, many of the material options that provide the most significant up-front emissions reductions (high SCM concrete, cross laminated timber, rammed earth) and carbon storage (cellulose, compressed straw wall panels, ReWall, cement-bonded wood wool, cork) can be used in any building typology. Though it may be more difficult to get these types of buildings into net storage balance, this study indicates that mass timber structures with carbon-storing partition walls, ceiling panels, cladding and/or finishes could dramatically reduce the up-front emissions of larger buildings, and should be the focus of further study.
NEXT STEPS
NEXT STEPS - GENERAL:

**Builders/designers** — Understand the extent to which our activities are responsible for climate change and make firm commitments to intentionally reduce emissions at an aggressive pace.

**Manufacturers** — Understand the role that material emissions play in global climate change and make commitments to lower emissions immediately and aim to move toward low-carbon or carbon-storing materials.

**Policy-makers** — Signal an intention to require net carbon storage in buildings within a reasonable frame. Offer incentives to innovators and manufacturers to develop carbon-storing materials.
NEXT STEPS - UP-FRONT EMISSIONS:

**Builders/designers** — Specify and install carbon-storing materials whenever possible. Seek out education about sourcing, installing and maintaining these materials. Have conversations with clients about your reasons for wanting to use carbon-storing materials.

**Manufacturers** — Generate EPDs for products, and include biogenic carbon quantities as an identifiable element of the total GWP. Lower the GHG emissions of existing products. Develop market awareness of low-carbon and carbon-storing options. Seek reliable and ecologically-sound sources of biogenic carbon for materials. Develop healthy products with the highest carbon storing potential.

**Policy-makers** — Require designers to generate a building-specific emissions profile as part of the permitting process. Create a staged series of emission caps for buildings. Offer incentives to builders for making significant reductions in GHG emissions.
NEXT STEPS - CARBON USE INTENSITY:

**Builders/designers —**

- Stop using fossil fuels for heating buildings. Where grid electricity is carbon-intensive, purchase clean energy from third party providers.

- Set goals for improving air tightness. Train crews to achieve air tightness targets. Perform on-site testing of all buildings to confirm targets are being met.

**Policy-makers —**

- Move away from requirements for energy efficiency and begin requiring Carbon Use Intensity as the performance metric. Ensure that net zero energy requirements are aligned with actual reductions in emissions, rather than requiring simple mathematical achievement of net zero energy.

- Signal intent to require on-site air tightness testing of all buildings.
Carbon Storing
-20 to -250 kgCO₂e/m²

3-5 year goal
Zero Carbon
50 to -20 kgCO₂e/m²

5-10 year goal
Moderate Carbon
250-50 kgCO₂e/m²

2-3 year goal
High Carbon
500-250 kgCO₂e/m²

Stop doing this now!
Builders for Climate Action will be undertaking a number of initiatives aimed at helping the low-rise sector move to becoming a site of net carbon storage:

**Distribution of this white paper**

We hope the case presented in this study is compelling, and encourages people in the building industry to begin taking important steps toward carbon positivity.

**Carbon calculator**

We will build on the research compiled for this study and develop a simple and effective embodied carbon calculator tool that will enable building designers and material specifiers to understand the up-front emissions in their buildings and make conscious choices to meet lower thresholds with their buildings.

**Specification & guidebook**

We will create a guidebook that covers the most effective, affordable actions for reducing up-front emissions in buildings on a cost-per-tonne basis, and provide specifications and details for incorporating these choices in building designs.

**Carbon Storing Building Challenge**

We will sponsor a nationwide contest for buildings that are certifiably carbon storing.

**Municipal incentive policy**

We will use a cost-per-tonne calculations to help municipalities offer appropriate incentives to builders for creating fewer GHG emissions.

**Low carbon curriculum**

We will help develop curriculum for design and building schools to help a new generation understand how they can make choices that ensure a carbon positive balance in the building industry.

**Code development**

We will help to develop building codes that mandate thresholds for up-front embodied carbon emissions.

**Supply chain development**

We will help innovators and manufacturers create low-carbon and carbon-storing materials and to support those materials in the market.
CASE STUDIES
Canada’s Greenest Home - Urban infill, near net-zero design
Design: Endeavour Centre
210m² three bedroom home

5 tonnes net carbon storage

Key carbon storing materials: Prefab straw bale walls, cellulose roof insulation, Nexcem ICF foundation, FSC wood siding, subflooring and flooring, sustainably harvested cedar shingles, clay plaster.

Energy: 85% on site generation of solar electricity
0.8 ACH/50 air tightness

24kgCO₂e/m²
Zero House - Prefab modular home, net zero design
Design: Ryerson University & Endeavour Centre
100m² single unit two-bedroom
Designed to be one unit in a 16-unit development

25 tonnes net carbon storage in a single unit
400 tonnes storage potential in 16-unit development

Key carbon storing materials: Prefab straw bale walls, prefab cellulose wall, roof & floor panels, MSL Fibreboard exterior insulation board, ReWall interior sheathing, Mycofoam insulation, cork sheathing panels, FSC wood floor and plywood interior wall cladding.
Offices & Meeting Hall - Urban infill, net-positive design
Design: Endeavour Centre
225m² three offices, large meeting room, staff room

81 tonnes net carbon storage

Key carbon storing materials: Straw bale and cellulose wall insulation, cellulose floor and roof insulation, Nexcem ICF foundation, FSC wood siding and flooring, clay plaster, sustainably harvested timber frame.

CASE STUDIES

360 kgCO₂e/m²

Energy: 105% on site generation of solar electricity
0.6 ACH/50 air tightness
Carbon storage at larger scales
Jules Ferry Apartment Complex, Saint-Die-des-Vosges, France
Design: ASP Architecture
1350m² seven story residential building

1100 tonnes net carbon storage
(Embodied carbon accounting was not performed using the same protocol as this study)

Key carbon storing materials: Prefab straw bale wall panels, sustainably harvested timber structure.
This study outlines three important elements required to bring GHG emissions from low-rise buildings to zero, or better:

1. Reduced up-front embodied carbon and maximized carbon storage in materials
2. Reduced GHG intensity of fuel sources for buildings
3. Energy efficiency as required to meet GHG targets

Of these three aspects, up-front embodied carbon and GHG intensity of fuels is shown to have the largest impacts. GHG intensity of fuels is something that is most effectively tackled at the government level, while up-front embodied carbon is the aspect for which individual designers, builders and homeowners have the ability to make the most difference.
Builders for Climate Action is a project of:

Supporters:
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Ontario Natural Building Coalition
Building Alternatives
LETT Architects
Great Northern Insulation
Ashburnham Realty

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To view the complete research paper Opportunities for Carbon Dioxide Removal and Storage in Building Materials, go to:
https://www.researchgate.net/publication/336171374_Opportunities_for_CO2_Capture_and_Storage_in_Building_Materials