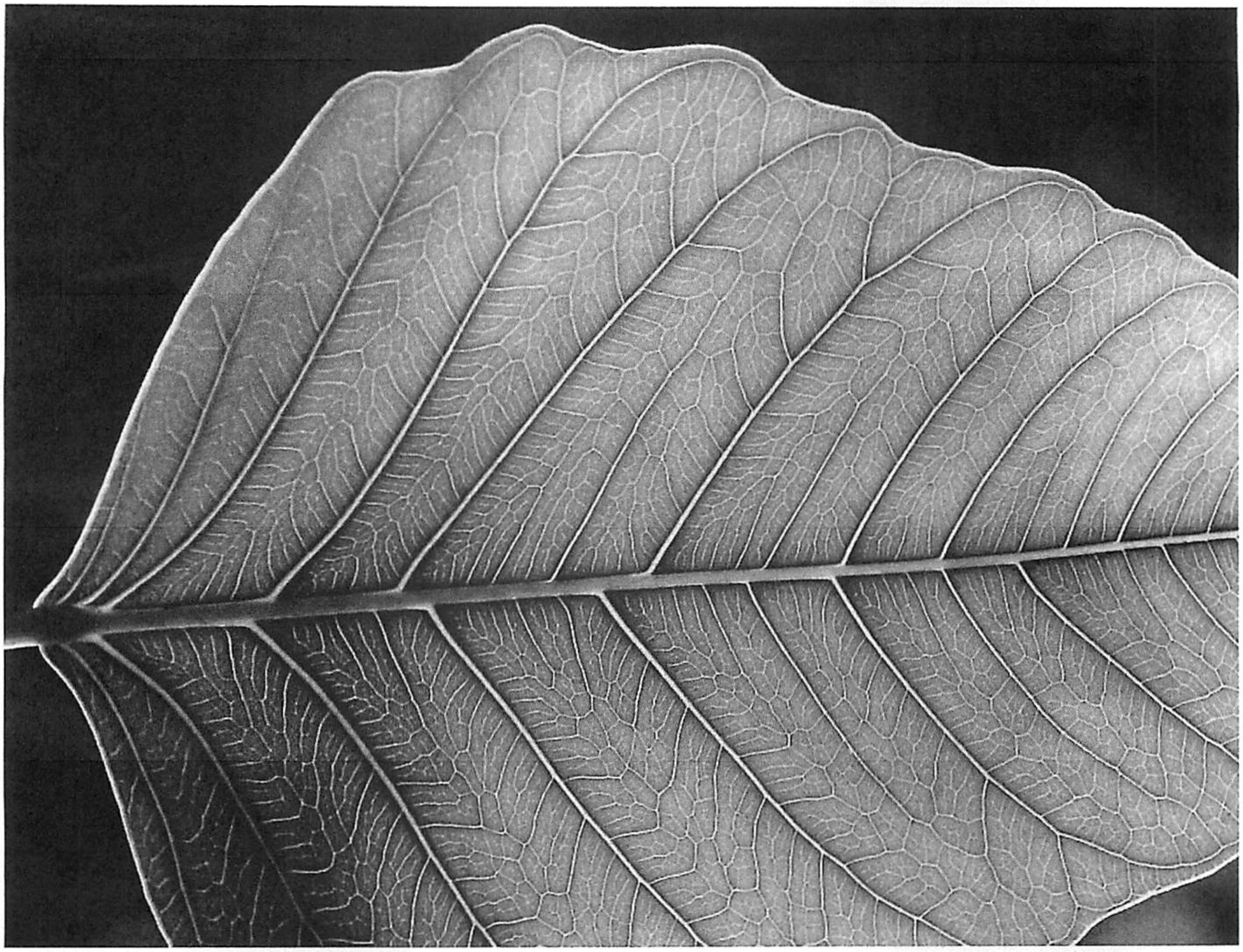
BEYOND ENERGY EFFICIENCY: WHY EMBODIED CARBON IN MATERIALS MATTERS



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THE CONTEXT OF CARBON

Approximately 30% of global carbon dioxide (CO_2) emissions are linked to the building industry.[1] Because of our work as building professionals, the atmosphere is filling up with CO_2 and other greenhouse gasses. Yet the building industry has the potential to switch from being a problem to being a part of the solution. To make this switch, we must turn our energy and attention to both reducing the amount of CO_2 we release into the atmosphere throughout the operational lifecycle of buildings and to designing and building to remove CO_2 from the atmosphere with plant-based building materials that store that carbon in their cells and facilitate its storage in the soil.

EMBODIED AND OPERATIONAL CARBON: A BIGGER PICTURE

Our industry has made great strides in addressing operational energy consumption (the amount of energy used to run the building). However, calculations around the carbon footprint of work often don't account for embodied carbon: the carbon emissions produced as a result of the harvest/extraction, refinement and production/ manufacturing of a material. The embodied carbon value of a material reflects the amount of emissions released for that phase of a material's lifecycle.[2]

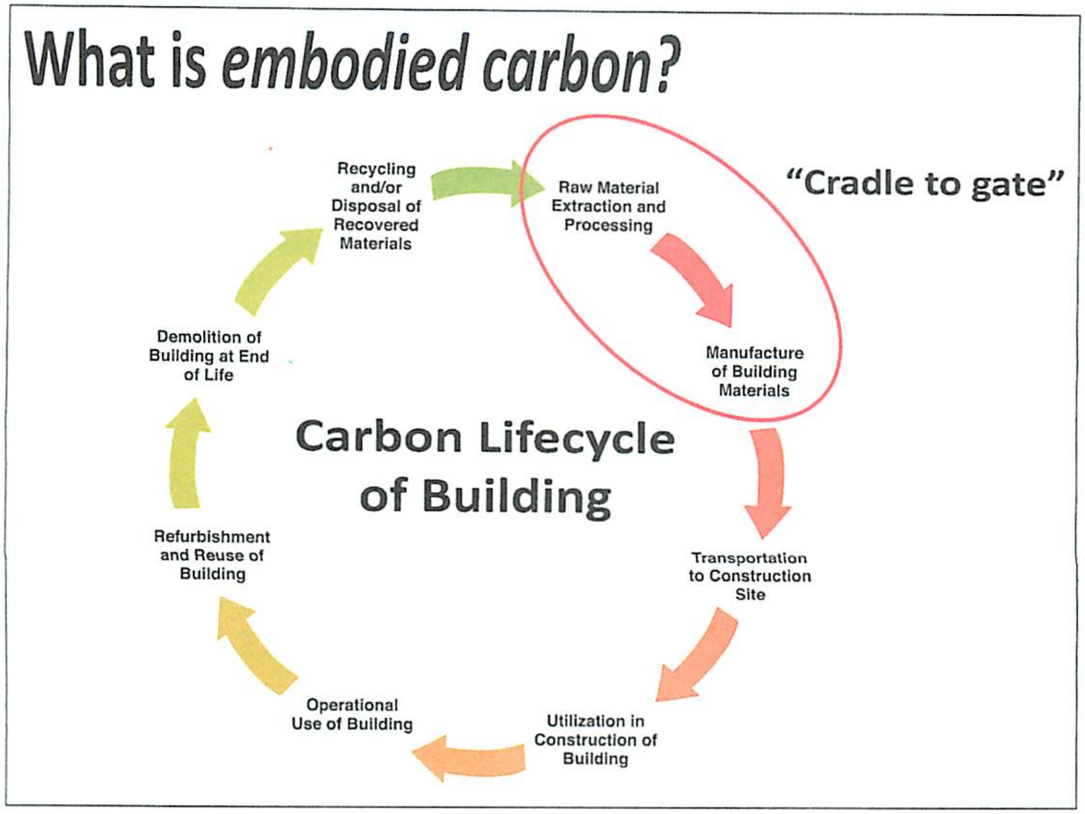

FIGURE 1: THE CARBON LIFECYCLE OF THE BUILDING.
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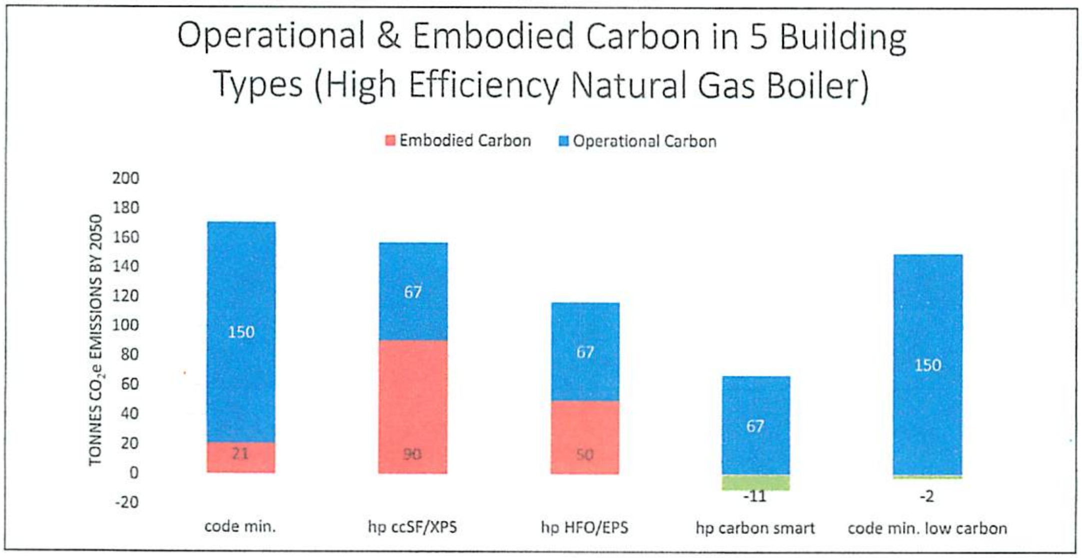

FIGURE 2: THIS GRAPH ILLUSTRATES THAT THE CARBON FOOTPRINT OF A HIGH-PERFORMANCE BUILDING USING FOAM IS ONLY SLIGHTLY LOWER THAN CODE MINIMUM.
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Here are seven reasons why embodied carbon matters:

1. The goal of reaching net zero carbon emissions by 2050, set by the World Green Building Council in response to targets outlined in the 2015 Paris Agreement,[3] can only be achieved by addressing embodied carbon, especially as operating emissions are dramatically reduced.
2. Embodied carbon has been released – and the climate damage done – before the building is even occupied; it cannot be recovered or offset. Given the "zero carbon by 2050" goal, the early-phase timing of these emissions is of critical importance.
3. There will be lower carbon emissions from operating energy consumption as the grid "decarbonizes" through increased renewable-sourced electricity production and as mechanical equipment becomes more efficient.
4. A building using high embodied carbon insulation to reduce operating carbon emissions may release more cumulative carbon emissions than a building with lower insulation levels and higher operating emissions within the 2050 timeframe. More insulation isn't always "better" from a climate perspective.
5. By using carbon-storing materials, buildings have the potential to actively reverse carbon emissions – as opposed to passively "doing less harm" – and to do so immediately, not after many years of renewable energy production.

FIGURE 3: FIVE MODELED BUILDINGS THE CODE-MINIMUM BUILDING EMITS LESS CUMULATIVE CO_2E THAN EITHER OF THE FOAM-BUILT STRUCTURES WHEN SHIFTING TO A PV-POWERED AIR SOURCE HEAT PUMP FOR HEATING.
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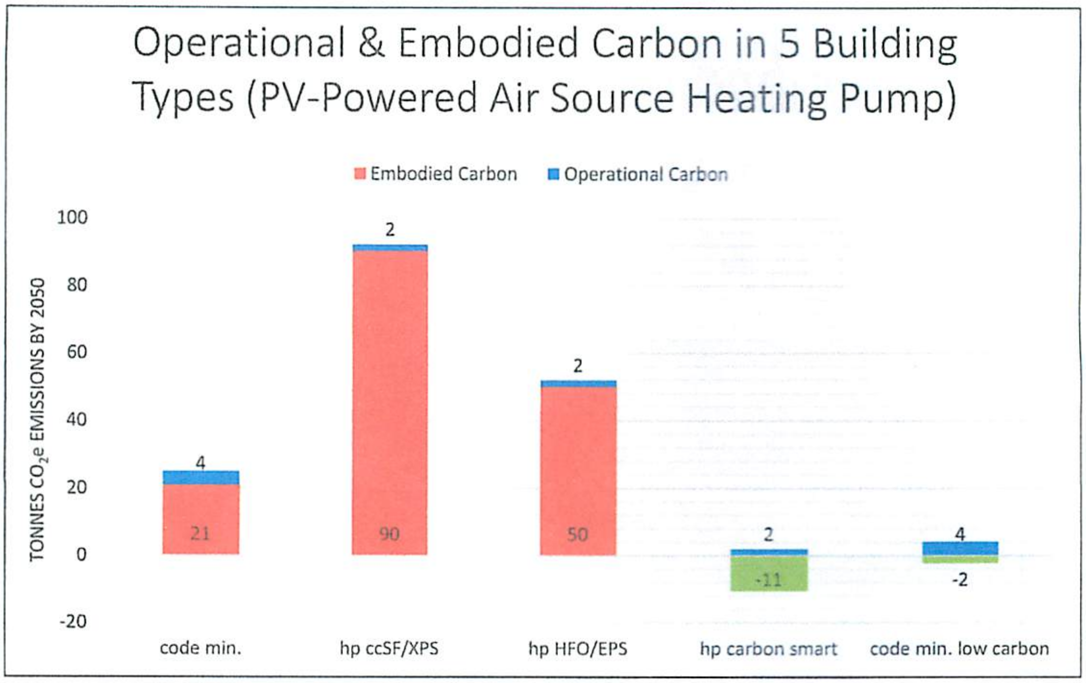

FIGURE 4: "CARBON SMART" BUILDING MATERIALS & A LOW-CARBON HEATING SOURCE ACT AS A CARBON SINK, OR NEGATIVE CARBON FOOTPRINT.
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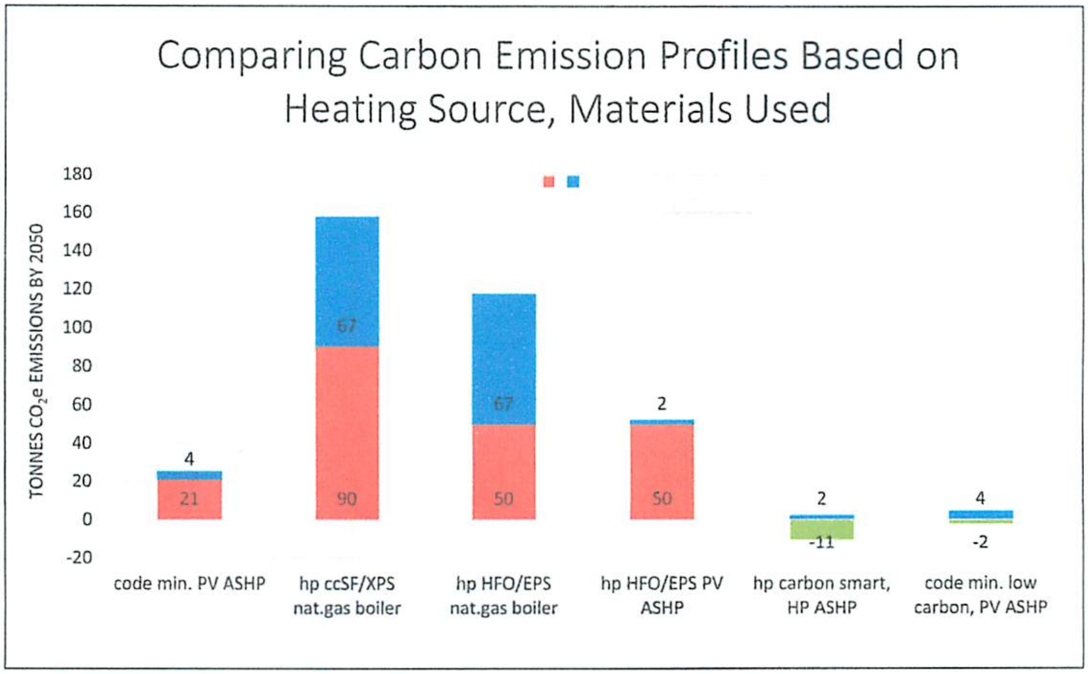

6. Using carbon storing materials can have an amplifying effect on carbon reduction and storage by supporting sustainable silvicultural and agricultural systems.[4]
7. Use of biologically-sourced materials such as wood, cellulose and agricultural fibers offers the greatest storage potential. This also supports working landscapes and localized, scale-appropriate economies in our region, providing myriad additional benefits beyond climate impact.

COUNTING CARBON: METHODS

To see how embodied carbon affects a building's cumulative carbon impact, we calculated both embodied and operational CO_2 equivalent (CO_2e) emissions from 2018-2050 for a theoretical 1,000 square-foot home in Zone 6 (cold climate). We looked at two different building performance levels: Ontario Building Code standard (labeled "code min." on graphs) and High Performance levels (labeled "HP" on graphs) of 1 ACH50 air tightness, R-5 windows/doors, R-20 sub-slab, R-30 foundation walls below grade, R-40 walls above grade and R-60 roof. We also varied the fuel source and heating equipment between a 90% operating efficiency natural gas boiler and a net zero PV-sourced air-source heat pump (COP 2.3).[6] Finally, we varied the material types of the enclosure materials (described below). Embodied CO_2e data comes from Environmental Product Declarations (EPDs). When EPDs were not available, we used data from the Inventory of Carbon and Energy (ICE v. 2.0).[7] Carbon storage values were calculated for all materials except framing lumber, due to variable management practices.

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COMPARING MATERIALS, PERFORMANCE, AND FUELS

As Figure 2 illustrates, we compared five different enclosure profiles:

- a code-minimum building using conventional building materials ("code min")
- a high-performance building using carbon-intensive materials such as high-density closed cell polyurethane spray foam and XPS insulation ("hp ccSF/XPS")
- a similar building using HFO closed cell polyurethane spray foam and EPS insulation ("hp HFO/EPS")
- a high-performance building using ultra-high carbon-storing materials such as straw, cellulose and earth ("hp carbon smart")
- a code-minimum building using conventional carbon-storing materials such as cellulose wood fiberboard and low-Portland concrete ("code min. low carbon")

In this comparison, the high-performance building using conventional foams is only slightly lower than the code-minimum building (157 tonnes vs. 171 tonnes CO_2e); however, most of the foam building's emissions are released at the beginning of the building's life. Meanwhile, the code-minimum building using low-carbon materials releases comparable emissions (148 tonnes CO_2e) by 2050.

When we changed the heating source to a PV-powered air-source heat pump (ASHP), we found the code-minimum building emits less cumulative CO_2e than either of the foam-built structures, while the "carbon smart" building stores a net of 9 tonnes of CO_2e (shown as a negative value) (Figure 3). The code-minimum low-carbon building is effectively net zero carbon.

There are a few important patterns to note, shown in Figure 4:

- Changing the heating/fuel system for the code-minimum building from a natural gas boiler to a PV-powered ASHP drops emissions by 85% by 2050. It may not practical for a heating solution at that performance level,[8] but it demonstrates that switching to a low-carbon emission fuel source impacts the embodied/operational carbon emission balance.
- Factoring in embodied CO_2e, the foam-built high performance buildings – even lower-impact foams like HFO spray foam and EPS foam board – have the largest total CO_2e footprint. Even with the better fuel source, the lower-impact foam building is barely comparable to the code-minimum building, which is alarming given foam's prominence in our industry and reputation as a "green" product.
- The "carbon smart" building using materials selected to optimize carbon storage, coupled with a low-carbon fuel/heating source, acts as a carbon sink – a direct reversal of the impact profile of the foam-based buildings built to the same standard using the same fuel/heating source.
- The code-minimum building using conventional carbon-storing materials, coupled with a low-carbon fuel/heating source, is effectively net zero carbon by 2050. This charts a compelling path towards achieving net zero carbon buildings using available technologies and more moderate levels of enclosure performance, and it begs further exploration as a scalar approach.

MATERIALS TO COOL THE PLANET

There are a range of carbon-storing and low-embodied carbon building materials, from the familiar and commercially-available to the new and innovative, across all scales of building:

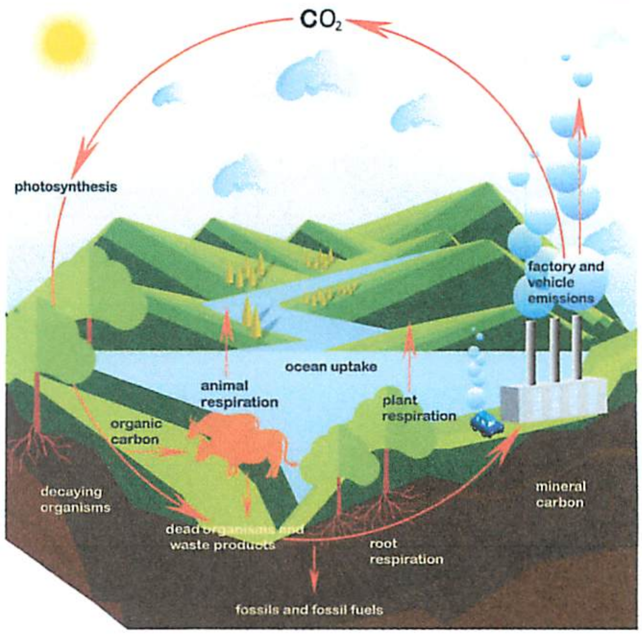

FIGURE 5: THE CARBON CYCLE, OF WHICH OUR BUILDINGS ARE A PART.
CREDIT: NEW FRAMEWORKS

BASIC/ACCESSIBLE SOLUTIONS:

- Insulation
  - Cellulose fiber: dense-pack or damp-spray
  - Wood fiberboard sheathing (structural or non-structural): ~R-4/inch using high recycled content. Examples include Gutex, Steico, MSL Fiberboard

- Structure
  - Stud framing with lumber from regional, sustainably-managed forests
  - Timber: cross-laminated timbers (CLT), whole tree timber, and sawn timber
  - Concrete options: add fly ash to your next concrete order from the plant; engineer structures to use less concrete; alternative foundations such as slabs, pier foundations and non-Portland cement ICFs such as Durisol

- Finishes
  - Wood: regionally-milled solid wood hardwood flooring, softwood siding, cedar roofing
  - Cork: flooring harvested from living trees that, in order to flourish, must be harvested
  - Paints and plasters: clay and lime finishes and paints without titanium dioxide Producers include LimeStrong, American Clay, Bioshield, Old Fashioned Milk Paint Company, Ecos Paint

INSPIRED/ADVANCED SOLUTIONS:

- Straw walls: Prefabricated panels or site-built walls. R-30 - R-50, vapor permeable, especially carbon-storing due to being a short-cycle crop. 1-2-hour fire rating
- Hempcrete: Lime mixed with hemp hurd, ~R-3/inch, stores carbon, vapor open, moisture resistant, fire resistant

- Mycelium insulation: "foam" insulation panels, mushrooms grown on an inert medium of hemp hurd and dried. Example: Ecovative Design
- Alternatives to concrete: rubble trench and helical pier foundations; cement-comparable masonry materials biomineralize CO_2 to make lightweight aggregate. Examples include Blue Planet, CarbiCrete, CarbonCure, BioMASON
- Recycled structural panels: made of recycled plastic-coated cartons. Example: ReWall
- Earthen floors: clay and aggregate mixture, finished with natural oils. Example: Claylin

THINK, BUILD, AND DESIGN TO COOL THE CLIMATE

Carbon is not a problem; it forms the basis of life on Earth. The carbon cycle describes the movement of carbon, in its many forms, between the reservoirs that exist in the atmosphere, oceans, biosphere and geosphere. Mining oil and gas reserves extracts reservoirs of sequestered carbon in the geosphere and releases them into the atmosphere. In the biosphere, plants pull CO_2 from the air and convert it into sugar for food. When a tree is sustainably harvested for timber,[9] the CO_2 that tree absorbed in its lifetime is "fixed" or "stored" as carbon-bearing compounds into the structure of that timber. As long as it is kept dry and does not rot or burn, that carbon will remain stored in that timber or board and in that building. Understanding the carbon cycle of our building materials helps us participate in the global carbon cycle in a positive way to maintain a healthy planet. Constructing carbon-smart buildings becomes an opportunity to do just that.

ABOUT THE AUTHORS

Ace McArleton *founded New Frameworks Natural Design/Build in 2006 to offer green remodeling and new construction services blending natural building materials and methods with high-performance design. Ace instructs in the Natural Building Certificate Program at the Yestermorrow School, is co-author of* The Natural Building Companion *(Chelsea Green, 2012) and led his business' conversion to a worker cooperative in 2016. Ace is passionate about finding practical, regional solutions to build healthy, just communities now into the future.* BUSINESS MEMBER

Jacob Deva Racusin *is co-owner of New Frameworks Natural Design/Build, offering services in green remodeling, new construction, consultation and education featuring low-impact high-performance building technologies. Through his work as a designer, builder, consultant and educator, Jacob is able to merge his passions for fine craft, ecological stewardship, relationship to place and social justice. Jacob is Program Director of the Certificate in Building Science and Net Zero Design at the Yestermorrow Design/Build School and is a BPI-certified contractor and Certified Passive House Consultant. Jacob is the author of the books* Essential Building Science *and* The Natural Building Companion, *which he co-authored with Ace McArleton.* BUSINESS MEMBER

ABOUT THE PEER REVIEWER

Andrew Shapiro, *President of Energy Balance, Inc., has provided high performance building energy analysis, design and monitoring consulting services for over 30 years. He provides guidance and technical expertise along the path of conceptualization, design, construction, commissioning and post occupancy assessment, for optimizing environmental impact of the building, indoor environmental quality, operating and maintenance costs and building durability. He is also the Director of Science and Engineering for the Vermont Energy Education Program, teaching energy literacy to the next generation.* LIFETIME MEMBER

ENDNOTES

1. "From Thousands to Billions – Coordinated Action towards 100% Net Zero Carbon Buildings By 2050", World Green Building Council report, 31st May 2017, www.worldgbc.org/news-media/thousands-billions-coordinated-action-towards-100-net-zero-carbon-buildings-2050.
2. Note that the full embodied carbon life cycle of a material includes transportation to site, as well as reuse/repurposing, demolition, and disposal/recycling. We are looking at "cradle to (factory) gate," from raw material sourcing through manufacturing, due to the time-sensitive release of emissions in this boundary, and greater ease of comparing data across different materials. Note that transportation of materials and people to site may be a significant carbon impact and should also be closely evaluated, but is beyond the scope of this article, as are end-of-life emissions.
3. Ibid.
4. Note that confirming source conditions of raw materials may be difficult at scale, and further work across sectors must be done to confirm the true carbon impact of management practices for specific materials.
5. We express the global warming impact of materials as "CO_2e," which combines the global warming potential of different greenhouse gases to a single metric – that of a molecule of carbon dioxide (CO_2). CO_2 accordingly has a CO_2e value of 1, whereas methane has a CO_2e value of approximately 86 within a 20-year period.
6. For operating CO_2e, we looked only at heating loads for this analysis as they are the most greatly affected by enclosure material and fuel changes. Referencing research from Andrew Shapiro of Energy Balance, we used values of 260 and 8 lbs CO_2e/MMBTU for natural gas and PV electricity, respectively (PV operational carbon is the CO_2e from panel fabrication through installation, divided by lifetime kWH.
7. Data varies widely across products and averages were used in some cases. Closed-cell polyurethane spray foam (ccSF) and XPS values are given primarily in full "cradle-to-grave" life cycle analysis, not "cradle-to-gate" as per other materials; ccSF also releases a significant portion of its embodied CO_2e emissions on site during application, unlike other insulations. All best efforts were made to assign comparable values, as a standardized protocol for this has not been established.
8. In code-minimum houses in cold climates, air-source heat pumps generally require an additional heating source for peak heating loads, which would increase the operational CO_2e output.
9. Whether or not a timber or wood product actually has a net positive carbon storage has everything to do with the manner in which the tree was grown and harvested. Detrimental forest management practices degrade soils and biomes, releasing carbon into the atmosphere and downgrading the benefits of carbon storage in the plant itself. Look to FSC (Forest Stewardship Council) or comparable certified lumber and timber for your projects.