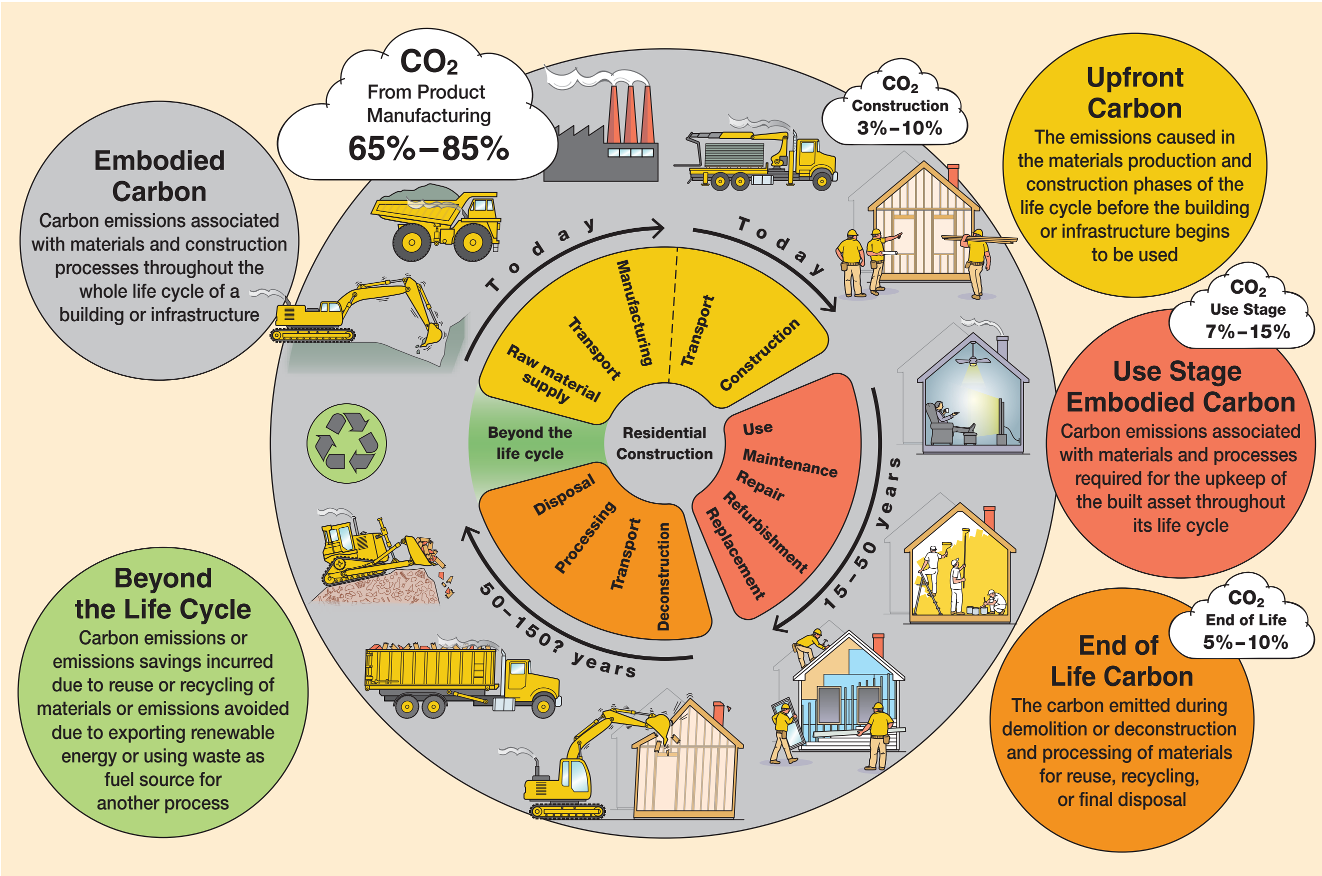


Illustration adapted by Tim Healey from the World Green Building Council report "Bringing Embodied Carbon Upfront"

Reducing Carbon

A Builder's Guide to Carbon-Neutral Building Practices

BY CRAIG SAVAGE

As a custom homebuilder in North Idaho in 1978, I wasn't thinking about carbon, I was thinking about saving energy. To build my first superinsulated house, I used double, staggered 2x4 studwalls stuffed with fiberglass pink stuff and wrapped with newfangled plastic white stuff—Tyvek. Driven by skyrocketing fuel costs (sound familiar?), I was trying out innovative techniques and materials to make my houses energy efficient.

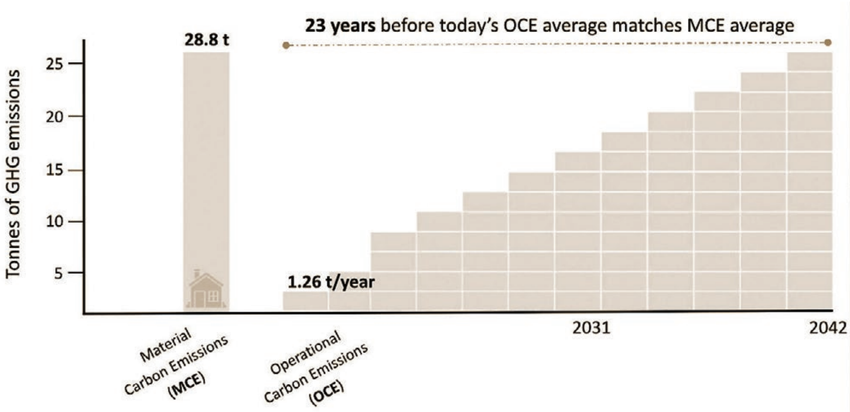
Some 40 years later, energy efficiency has become just one part of constructing green, resilient, and sustainable buildings, which the Environmental Protection Agency defines as "... creating structures ... that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction."

New building codes require tighter, better insulated buildings, which use less energy to heat and cool and, as a byproduct, put less CO_2 into the atmosphere. This category of CO_2 savings is referred to as "operational carbon."

Now, however, there's a growing awareness of reducing a second—many believe, more critical—type of CO_2 emissions known as "embodied carbon" or "upfront carbon," which consists of the total CO_2 emitted when we extract, manufacture, transport, and install all the materials that go into our buildings. (See "Carbon and the Carbon Cycle," page 37.)

What is eye-opening to those of us who have struggled to squeeze out every extra Btu through energy-efficient construction (as with Passive Houses, for example) is that the amount of embodied carbon in a new building is huge. In fact, the quantity of upfront carbon released into the atmosphere to construct even a zero-energy home can equate to more than 30 years of the CO_2 emitted (operational carbon) by using that house. So, builders striving to make a large and immediate reduction to CO_2 going into earth's atmosphere must find ways to lower the amount of embodied carbon going into their buildings. Looked at another way, construction material emissions are "today" emissions; they are released into the atmosphere even before the building is built. If our goal is to reduce emissions now, these are the emissions that are happening now.

In this article, I'll look at design and material choices that designers, builders, and remodelers can use to reduce the amount of embodied carbon in both their new and remodeled buildings. I will also explore strategies that won't force you to abandon your favorite building systems such as SIPs, ICFs, or studwalls.



A study prepared by Builders for Climate Action examining the carbon emissions from homes built in two Canadian cities showed that it would take 23 years for the operational carbon emissions to reach the level of material carbon emitted during construction.

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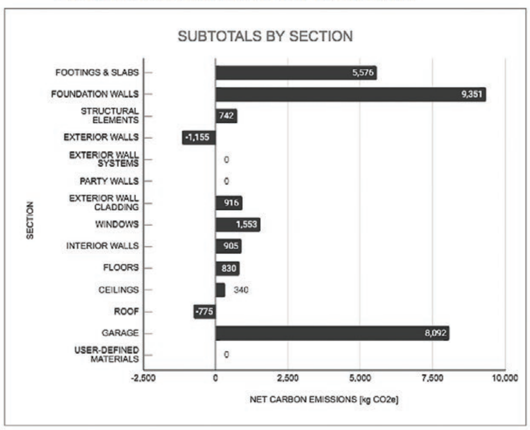
BUILDING EMISSIONS ACCOUNTING FOR MATERIALS

CARBON RESULTS

Scenario A - Lot 13-36

SECTION	NET CARBON EMISSIONS [kg CO2e]
FOOTINGS & SLABS	5,576
FOUNDATION WALLS	9,351
STRUCTURAL ELEMENTS	742
EXTERIOR WALLS	-1,155
EXTERIOR WALL SYSTEMS	0
PARTY WALLS	0
EXTERIOR WALL CLADDING	916
WINDOWS	1,553
INTERIOR WALLS	905
FLOORS	830
CEILINGS	340
ROOF	-775
GARAGE	8,092
USER-DEFINED MATERIALS	0
NET TOTAL	26,376
NET TOTAL PER SQ. METRE	73

EMBODIED CARBON BY SECTION



A sample calculation of the embodied carbon in various building components clearly shows that assemblies with concrete and steel account for the largest carbon emissions.

KEY STRATEGIES

There are three key strategies to lower—to zero and even negative—the amount of embodied carbon in our buildings: reusing infrastructure, designing to minimize carbon emissions, and using lower-carbon materials. And since reducing upfront carbon is an additive process, you can use these approaches individually or in any combination to reduce a building's overall carbon footprint.

Use existing infrastructure to lower embodied carbon. When it comes to building with low embodied carbon, the best thing you can do is reuse a building or its parts. It may not be cheaper, but whole-building renovation and reuse have been calculated to save up to 75% of embodied carbon emissions compared with constructing a new building. This is because most embodied carbon resides in the foundation and the structure—especially if they are concrete and steel. By retaining those, that carbon is already accounted for.

If you cannot reuse the whole building, look to salvage and reuse its materials—brick, metals, broken concrete, and wood. Reclaimed materials, in general, have a much lower embodied-carbon footprint than new materials because the carbon to manufacture them has already been spent. Even the additional carbon impact of salvaging materials and making them fit for reuse is often lower than manufacturing new materials.

For example, not only does reclaimed wood siding save the energy that would have been spent cutting, transporting, and processing new siding, but the tree you didn't cut down is still doing the work of capturing and storing (sequestering) carbon. Another example is reusing broken-up concrete slabs for landscape, riprap, or even just backfill, which eliminates the *(continued on page 38)*

Builders for Climate Action

CARBON AND THE CARBON CYCLE

The atomic element carbon is the main component of the earth's biological compounds and many of its minerals, including limestone. Limestone is significant because it's the raw material for most cement. To put that in perspective, global CO_2 emissions from cement production add up to approximately 829 million metric tons, accounting for about 3.4% of global CO_2 emissions from fossil-fuel combustion and cement production.

The carbon cycle is the sequence of events describing the movement of carbon as it is continually cycled throughout earth's biosphere and includes the process of carbon storing (sequestration) in "carbon sinks" and the subsequent release of that carbon as the cycle repeats.

Here's how carbon cycles, in the form of CO_2, when first captured in a tree, then turned into lumber, and finally back to CO_2 in the atmosphere: Once a tree seed germinates, it begins to capture and process the CO_2 in our atmosphere. Using the energy of the sun, along with water and other minerals and elements, the plant assembles various proteins into the parts of a tree—roots, bark, leaves, branches, trunk, and so forth. Through the years, the tree captures and stores (sequesters) significant amounts of CO_2 from the air. According to the U.S. Energy Information Administration, one silver maple tree will sequester about 400 pounds of CO_2 in 25 years.

If the tree is burned, perhaps as pellets to heat a house, the CO_2 is returned to the atmosphere immediately—or its stored CO_2 could be returned over time if the tree dies and rots. Alternatively, if we process the tree into lumber and account for the energy expended in cutting, hauling, and milling (its embodied energy), much of the CO_2 remains captured in the lumber (scientists are still trying to quantify the CO_2 left behind in roots and slash). That CO_2 is released only when the building is burned, demolished, put in a landfill, or simply left to deteriorate. You probably notice that stored CO_2 in the lumber (or hemp, bamboo, rice stalks, cellulose, and the like) is only for the life of the structure; ultimately, the carbon is released and the cycle repeats—as it has for millions of years.

So why do we care about stored carbon? For years, buildings were leaky and energy was dirty, resulting in massive amounts of CO_2 being released into the atmosphere to heat, cool, and operate them. As we tighten up and insulate the building envelope, and heat, cool, and run buildings with clean, renewable energy (decarbonized energy), the amount of operational energy gets much smaller relative to the upfront, or embodied, energy, which becomes significantly more important (see chart, below).

Our goal is to put embodied carbon into storage, not into the atmosphere, even if only for the life of a building (or longer if we can reuse, recycle, or otherwise extend the building life). This helps to lower the CO_2 going into the atmosphere and to keep the resulting heat from CO_2's greenhouse effect within survivable human limits, hopefully until other mitigating efforts can come into play. —*C.S.*

Changing Energy Use in Buildings

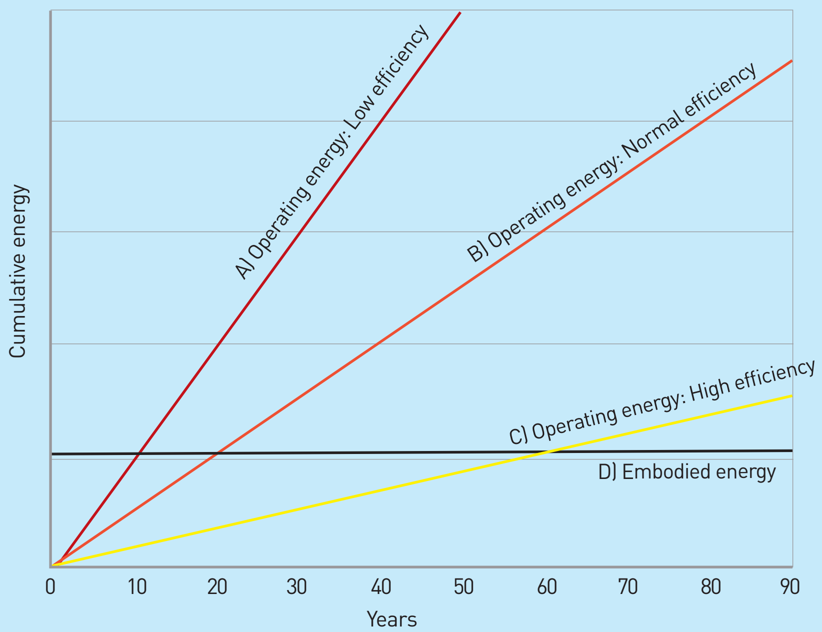
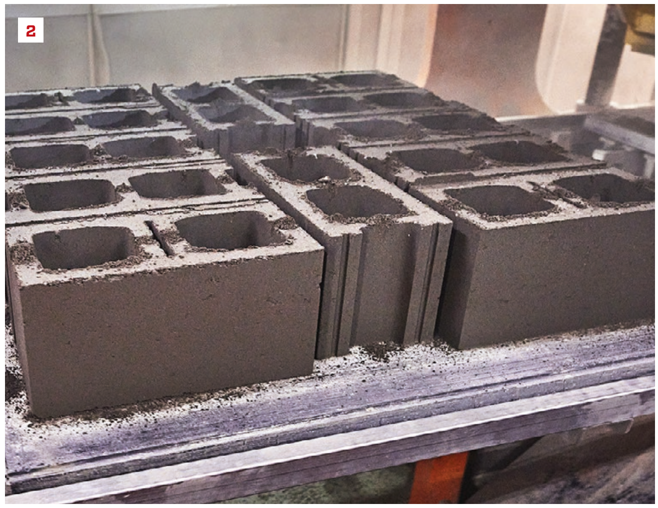


Chart data by John Ochsendorf/MIT

As buildings become more efficient, the amount of energy needed to operate them falls. The more efficient buildings become, the more operational energy approaches the energy embodied in the manufacturing of the building materials. Energy is often seen as a proxy for carbon emissions—a comparison that is fairly accurate when the majority of energy comes from fossil fuels. As more energy is decarbonized (generated from non-fossil-fuel sources) the reduction of operational carbon will accelerate, and embodied carbon will become the dominant source of carbon emissions from buildings. This is what Canadian architect and educator Lloyd Alter calls "the ironclad rule of carbon."



If a house is built on a structural slab, consider finishing the slab surface **(1)** to avoid introducing yet more materials into the home. Montreal-based Carbicrete has developed a process for producing structural concrete products with steel slag instead of with carbon-intensive cement **(2)**.

(continued from page 36) carbon that would have been emitted hauling and dumping the waste, as well as saving money on fees.

Lower embodied carbon by design. From the start, building designs should aim for low-carbon, carbon-neutral, or even negative-carbon outcomes. Stated simply, your design should incorporate materials with the least embodied carbon, and a significant reduction in upfront carbon can be made by reducing the amounts and changing the makeup of three materials: concrete, insulation, and cladding/interior surfaces—in that order.

Since most of the embodied carbon is in the structural components, the design should strive to achieve maximum structural efficiency. One example is to use optimum value engineered ("advanced") wood framing, which saves wood, money, and embodied carbon.

In addition, designs should strive to minimize waste. Perhaps your residential designs already incorporate 2-foot modular layout using common materials like 4x8 plywood, 12-foot drywall, and precut structural members. Sam Rashkin, architect for the Department of Energy Building America program, cleverly suggests adjusting the roof pitch so that roof rafters can be sized to use standard lumber lengths to eliminate waste. A centralized subpanel might reduce copper runs. Kitchens and baths can be grouped near each other and water heaters placed nearby to reduce piping and heat loss through plumbing runs (see "Architectural Compactness and Hot-Water Delivery" by Gary Klein, Jan/20). Split HVAC systems can replace steel ducting with a much smaller volume of copper and reduce the heat losses associated with ducts.

Designing a building so it can easily be remodeled—future-proofing—can lower the carbon footprint of a building over time. For instance, designers can incorporate clear spans in their plans so spaces can later be reconfigured by moving nonbearing walls without significant demolition, effort, and waste. And using structural components such as modular wood interior wall panels that are screwed in place and can easily be taken apart and used again can guarantee a longer building life and fewer future emissions.

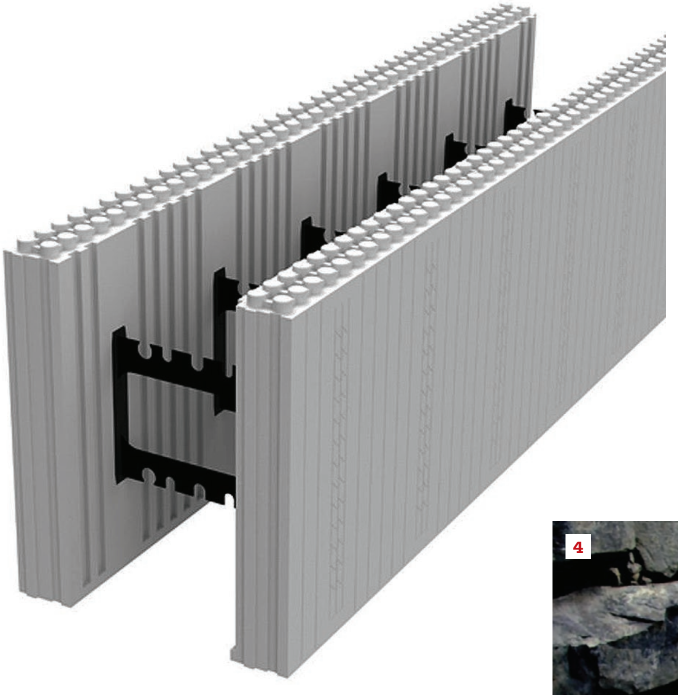
While the building envelope is critical for the energy performance of the building, the façade and roof are more expendable. These building elements are under constant assault from rain, snow, ice, and sun, and necessarily need repeated maintenance and repairs. The use of durable, local materials not only reduces the cost and frequency of repair but also reduces the use of material replacement and its associated carbon footprint.

Select low- or negative-carbon materials. Four material categories contribute substantially to a typical residential building's carbon footprint: concrete (35.5%), insulation (15.3%), cladding (12.5%), and interior surfaces including flooring, wall and ceiling materials (12.2%). When deciding on materials, you want to choose low-carbon or even negative-carbon alternatives. Replacing steel or concrete in the structure with wood or using wood cladding instead of cement or vinyl can reduce the embodied carbon in your project.

When choosing materials with low embodied carbon, you'll often encounter conflicting claims, because the science continues to evolve and because some manufacturers "greenwash" their product's carbon footprint. To understand a product's impact from a life-cycle perspective, we now have Environmental Product Declarations (EPDs)—documents that transparently report objective, comparable, third-party-verified data about products and services.

However, EPDs for an entire project can be hard to find and overwhelming to a designer or builder who wants to build with a low carbon footprint but also wants to get on with the job. Fortunately, there is an increasingly wide range of software tools and strategies

Photos: 1, Hard Rock Concrete Coatings; 2, Carbicrete



Insulated concrete form (ICF) blocks inherently make efficient use of concrete. The ICFs from Logix **(3)** are made with a low-carbon foam developed by BASF. Those from Nexcem **(4)** are made with cement-bonded wood waste. Instead of carbon-intensive steel rebar, consider fiberglass reinforcing, such as Owens Corning's Pinkbar Fiberglass rebar **(5)**.

Photos: 3, Logix Brands; 4, Nexcem; 5, Owens Corning

available to help in design and material decisions. BEAM, EC3, One Click LCA Planetary, and EC Calculator are a few. In writing this article, I chose BEAM and will discuss it below.

Also, try to use materials with high recycled content, especially metals. The carbon footprint of virgin steel, for example, is five times greater than that of high-recycled-content steel. Again, this is because the impact from raw material extraction is accounted for only the first time that material is processed. Subsequently, the recycled material includes only the reprocessing impacts.

You can also use fewer finish materials. One way is to showcase structural materials as finish. Using polished concrete slabs as a finished floor saves the embodied carbon from carpet, tile, or vinyl flooring, not to mention noxious and toxic adhesives and coatings. Finishes may help with the acoustics and thermal conditions inside living spaces. Yet, they have short lifespans due to wear and trends in fashion. The additive consequence of replacing these elements numerous times over the life of a building can have a measurable impact. So, finishes should include low-carbon materials and allow for the easy recovery of those materials for recycling or reuse.

Negative carbon. In some cases, it's possible to select materials that not only have a low carbon footprint but that also remove and store carbon from the atmosphere, a process known as carbon sequestering. For instance, some concrete mixes actually absorb and store small amounts of carbon. Others add CO_2 captured in other industrial processes (such as capturing CO_2 in coal-fired power plants) into the mix.

Our buildings can also be designed to remove and store embodied carbon, becoming carbon "sinks" that can help reverse the accumulation of the CO_2 catastrophically warming the planet. In their book, *Build Beyond Zero: New Ideas for Carbon-Smart Architecture* (Island Press, 2022), from which I borrowed many of the ideas presented here, Bruce King and Chris Magwood re-envision buildings as one of our most practical and affordable climate solutions.

Using materials made from what today is considered "agricultural

A range of low-carbon building materials: structural straw panels made by New Frameworks of Burlington, Vt. **(6)**; Neopor low-carbon rigid foam panels from BASF **(7)**; EcoCocon straw wall system from Build With Nature **(8)**; hemp insulation from Nature Fibres **(9)**.

Photos: 6, New Frameworks; 7, BASF; 8, Build With Nature; 9, Nature Fibres

waste"—products such as wheat or rice stalks that are commonly burned—can make a big impact on a project's carbon footprint because they sequester carbon that would otherwise go into the atmosphere as methane when they're allowed to rot, or as CO_2 when burned to make electricity. Wood may be the first material to come to mind, but other options include straw or hemp-based materials, say for insulation, which—unlike wood—not only store carbon but are annually renewable. And cellulose insulation, which has been successfully used for decades, is a no-brainer choice, with its negative carbon footprint.

SPECIFIC MATERIALS OVERVIEW

In this next section, we'll take a brief look at concrete, steel, and insulation materials from an embodied-carbon viewpoint.

Concrete. For all the benefits of concrete, the "moldable rock" used since it was invented by the Romans, it must be the primary target in our efforts to lower embodied CO_2. Worldwide, the cement sector represents about 7% of CO_2 emissions. In most cases, concrete is the biggest source of embodied carbon in virtually any new building project—representing 20% to 50% of the total material carbon emissions (MCE) for a low-rise building. The good news is that there are a growing number of ways, both in design and material composition, to lower concrete's impact on a project's total upfront carbon.

For one: Use less. Engineers love safety margins when designing, so if you make them aware of the impact concrete has on a project's carbon footprint, they may, for example, be able to specify smaller footings, or recommend alternative foundation systems, such as concrete piers, steel helical piers, treated posts, or just thinner stem walls. Also, the strength of concrete is largely a factor of the amount of cement in the mix. A 6-sack mix may be needed for a foundation spread footing, but is it needed for a 4-inch-thick

SPRAY POLYURETHANE FOAM – CLOSED CELL					
	Spray polyurethane foam - Closed Cell (HFC gas) / R 6.6/inch / SPFA [Industry Avg | US & CA]	100.0 ft²	100%	FALSE	409
	Spray polyurethane foam - Closed Cell (HFO gas) / Huntsman / Heatlok Soya HFO & Heatlok HFO / R 6.5/inch	100.0 ft²	100%	FALSE	78
SPRAY POLYURETHANE FOAM – OPEN CELL					
	Spray polyurethane foam - Open Cell / R 4.1/inch / SPFA [Industry Avg | US & CA]	100.0 ft²	100%	FALSE	44
SHEEP WOOL INSULATION					
	Wool / Havelock Wool / Loose-fill / R 4.4/inch	100.0 ft²	100%	FALSE	24
	Wool / Havelock Wool / Batts / R 3.6/inch	100.0 ft²	100%	FALSE	31
MINERAL WOOL BATT INSULATION					
	Mineral wool batt / [BEAM Avg]	100.0 ft²	100%	FALSE	53
MINERAL WOOL LOOSE FILL INSULATION					
	Mineral wool loose fill / NAIMA / R 3/inch [Industry Avg | N.America]	100.0 ft²	100%	FALSE	48
FIBERGLASS LOOSE FILL INSULATION					
	Fiberglass loose fill / ~R2.6/inch [BEAM Avg]	100.0 ft²	100%	FALSE	31
FIBERGLASS BATT INSULATION					
	Fiberglass batt / R 3.6/inch [BEAM Avg]	100.0 ft²	100%	FALSE	21
HEMP FIBER WOOL INSULATION					
	Hemp fiber batt / NaturFibre / Hemp Wool / R 3.7/inch	100.0 ft²	100%	FALSE	-17
CELLULOSE INSULATION					
	Cellulose / loose fill / R 3.7/inch / CIMA [Industry Avg | US & CA]	100.0 ft²	100%	FALSE	-33
	Cellulose / dense pack / R 3.7/inch / CIMA [Industry Avg | US & CA]	100.0 ft²	100%	FALSE	-66
WOOD FIBER INSULATION					
	Wood fiber batt / [BEAM Avg | EU]	100.0 ft²	100%	FALSE	-76
	Wood fiber batt / Pavatex / Pavaflex / R 3.8/inch [EU]	100.0 ft²	100%	FALSE	-87
HEMPCRETE INSULATION					
	Hempcrete / Cast in-situ / USA / R 2.1/inch, Avg. mix using NHL & PHL	100.0 ft²	100%	FALSE	-93
	Hempcrete / Cast in-situ / IsoHemp / Europe / R 2.1/inch	100.0 ft²	100%	FALSE	-187
STRAW BALE INSULATION					
	Straw Bale / Wheat & barley straw / SNaB (UK) / R 2.8/inch	100.0 ft²	100%	FALSE	-167
	Straw Bale / Wheat & rye straw / (Germany) / R 2.8/inch	100.0 ft²	100%	FALSE	-238

A BEAM calculation of the embodied carbon in insulation materials reveals a wide range of variability, from a high of +409 with carbon-intensive closed-cell spray foam to a low of -238 with carbon-sequestering straw bales.

sidewalk? For that matter, will 3 inches work instead of 4 inches?

Try using the knowledge of your concrete supplier; it often can specify low-carbon mixes that use additives such as fly ash, slag, calcined clays, or polymer fibers. The cement industry realizes the impact its product has on the environment and is making an effort to come up with lower embodied-carbon solutions. And newer substitutes such as hempcrete and carbon-neutral CMU block can work in many applications. Carbicrete of Montreal, with funding from the Quebec government, has developed a method of making concrete without cement by replacing it with a by-product of steel production, steel slag.

Steel. The steel used to reinforce concrete is also a huge contributor to a building's carbon footprint. Of course, concrete needs something to give it tensile strength. One alternative is to use rebar made from recycled steel. An even better alternative is to use fiberglass rebar, which has been around for several years but is only now getting attention as a sustainable choice. As a steel replacement, fiberglass rebar weighs less, costs less to ship, and even allows the use of unwashed sand and salt water in the mix because corrosion and subsequent spalling is no longer a problem. And there are many fiber additives that strengthen concrete. Again, your ready-mix supplier probably can provide low-carbon mixes—just ask.

Insulated concrete forms (ICFs). For those builders who do not want to abandon the many positive benefits of ICFs, fiberglass rebar and fly-ash-enhanced cement can reduce the carbon content in what is a relatively high-embodied-carbon building-envelope system. ICFs such as Logix Platinum Series, which uses BASF Neopor low-carbon-content foam, can also reduce a project's carbon footprint. And concrete form blocks, such as Nexcem, made with wood chips or other natural fibrous materials, eliminate high-carbon foam while offering a comparable resilient, energy-efficient building system.

Structural insulated panels. If you are a committed SIP builder, and I'm one of them, you have a growing number of options to reduce the amount of embodied carbon in the structural insulated panel. A SIP is a composite sandwich composed of two skins laminated to an insulative "spacer," typically 4 to 6 inches of expanded polystyrene (EPS) or extruded polystyrene (XPS).

OSB is the most common skin material, but there are lower-embodied-carbon substitutes for OSB including "boards" made of compressed straw stalks of wheat or rice or other agricultural carbon-sequestering "waste" material. Cementitious materials such as magnesium oxide (MgO) boards are being used as skins, and although they may have comparable carbon footprints to OSB, their moisture, fire, mold, and insect resistance can allow wall assemblies to eliminate additional layers—such as WRB, cladding, and gypsum drywall—and thereby lower the overall carbon footprint. Neopor with lower carbon can be substituted for EPS or XPS, which unfortunately have high carbon footprints. Other panels are available, such as Straw Bale SIP Walls by NatureBuilt, which have 1-inch-thick cement- and lime-plaster skins and straw filler between.

Wood framing. If you traditionally frame using 2x4, 2x6, or larger stud- or timber-framed walls, you are already on a path to a lower-carbon-footprint building. "Wood is good" because the material takes significantly less processing energy to extract, transport, and process (mill and kiln dry). And the carbon in the lumber, cladding, flooring, and so on is stored (sequestered) until the wood burns or decays—which returns the carbon to the atmosphere. However, the complete carbon cycle isn't as clear cut and dried (pun intended) as it looks, since there are consequences to removing trees that could still be capturing carbon if left in the forest, and it's not clear how the roots

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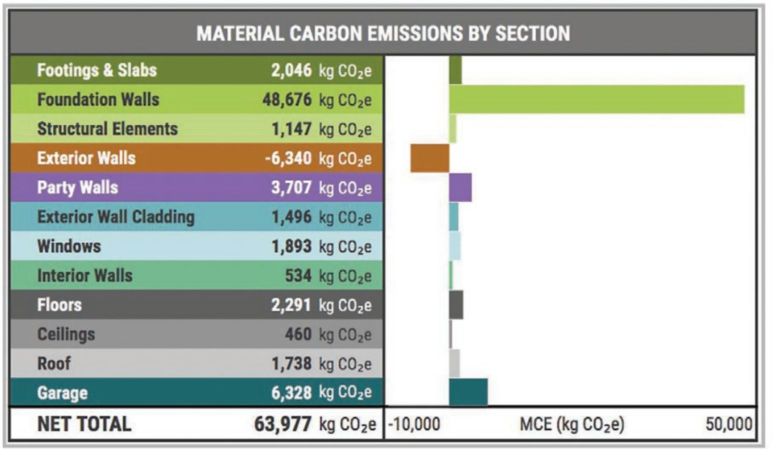

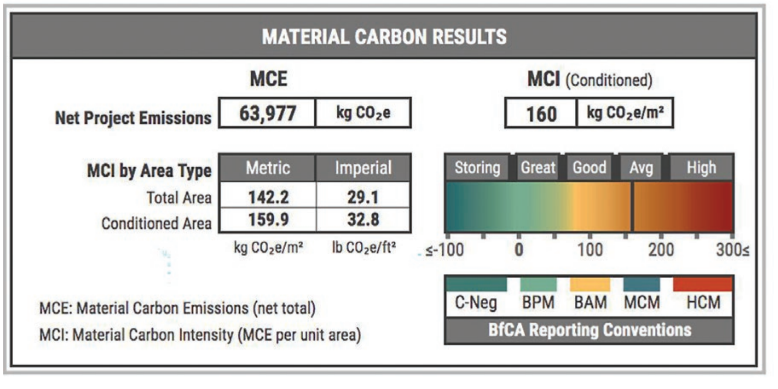

With BEAM, you can compare the material carbon embodied in different building assemblies for a project (top) and see the results for the whole building (above).

of cut trees and branches and slash contribute to atmospheric carbon.

Of course, you can simply use less wood by using advanced "optimum value engineering" (OVE, also commonly called "advanced framing"): 24-inch-on-center stud spacing, single top plates, box headers, and other wood- (read: carbon- and money-) saving tactics.

Insulation. There is a marked difference between glass-fiber materials or petrochemical-based materials, such as closed-cell spray polyurethane foam at 409 kg CO_2 net emissions, and bio-based products that store carbon. Some bio-based materials can contain more atmospheric carbon in the physical substance (that gets stored and therefore not emitted to the atmosphere) than was emitted in producing the material. For instance, cellulose is carbon negative at -66 kg CO_2; hempcrete at -187 kg CO_2; and straw bale with a whopping -238 kg CO_2 net emissions.

BEAM CARBON CALCULATOR

As mentioned earlier, there are several software tools available to help designers and builders calculate the amount of embodied carbon in the materials, assemblies, and buildings they build. But as a builder who wants to spend time building, I want a tool that I can use out of the box without a large learning curve. BEAM, which stands for Building Emissions Accounting for Materials, is a user-friendly, climate-science- and methodology-based software tool, built by a team at Builders for Climate Action.

You can get a free copy or make a donation to the Builders for Climate Action website (buildersforclimateaction.org/beam-estimator) and log in to use the BEAM Estimator. The tool is a sophisticated Google Docs online spreadsheet that is, relative to other calculating tools, simple to use, especially for builders because it's based on 12 construction categories: footings and slabs, foundation walls, structural elements, and so on up to the roof.

With BEAM, you can compare embodied carbon in materials, such as different types of insulation (see screenshot of chart on page 41); you can build assemblies and compare them (see sample at left, top); and you can compare whole buildings built with different materials (see sample of results for one building at left, bottom).

BEAM has a concise user guide to help you get started and comes preloaded with all the residential EPD data the creators could locate, and they continue to add more as it becomes available, which is a good reason to donate. You can toggle between metric and imperial measurements, a huge relief for U.S. builders unfamiliar with metric measurements like kilogram per square meter.

You will need to have a good understanding of building design and construction to navigate the assembly sections and make appropriate selections. Within each assembly section are categories of materials that will be appropriate for your project and likely many that will not be. It is up to you to build assemblies that are feasible and meet all the energy-performance and legal requirements for your project. BEAM doesn't provide any warnings or suggestions about appropriate selections.

It's worth noting that BEAM Estimator is a work in progress; nevertheless, the results are the best results possible given the current state of Life Cycle Analysis. Data in EPDs and the resulting outcomes are not 100% accurate numbers, so users should view them as guides to their selections of low-carbon materials. But as the authors make clear, especially for the three largest carbon-footprint categories of materials, reducing material amounts or making lower upfront carbon substitutions is more important than a few percentage points of error. Saving carbon now is much more critical than saving carbon over the next 30 years.

Craig Savage, a former senior editor and publisher of JLC, is currently in charge of building technology and innovation at Cypress Community Development Corp., a not-for-profit housing corporation specializing in innovative housing solutions for disaster rebuilding and workforce housing.