BuildingGreen

SPOTLIGHT REPORT

The Missing Embodied Carbon Link: Construction

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Lendlease uses solar panels to provide power during building construction.

Photo: Jason Etheridge, Lendlease

About BuildingGreen

BuildingGreen is an independent consulting and publishing company committed to providing accurate and timely information to help building industry professionals and policymakers improve the environmental performance and reduce the adverse impacts of buildings. Our purpose is to foster a thriving and equitable world through a regenerative and resilient built environment. To this end, BuildingGreen facilitates collaboration, learning, and trust to accelerate the transformation of the building industry into a force for positive change.

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The Missing Embodied Carbon Link: Construction

Some researchers say construction emissions could account for as much as 30% of a project's embodied carbon. What can be done about it?

by Candace Pearson and Elizabeth Waters

Nadav Malin contributed reporting.

Photo: Sunbelt Rentals

Turner charges its fleet of electric trucks. Prioritizing the use of efficient, preferably electric vehicles and equipment, is crucial to decarbonizing the jobsite.

Practitioners interested in reducing the embodied carbon of buildings are likely familiar with weighing the impact of different materials, like mass timber or low-carbon concrete. Low-carbon construction, however, has not been on many people's radar.

"I don't think people up until now even thought about fossil fuels being burned" on the jobsite, Oliver Atkinson, sustainability engineer at Sellen, told BuildingGreen. The few existing estimates, based on a handful of case studies and simplified assumptions, suggest the impact is relatively small—1% to 5% of the total lifetime carbon, or around 7% of the upfront embodied carbon of a building.

But once you start looking, said Atkinson, "Fossil fuels are being burned everywhere." Mark Chen, sustainability manager at Skanska, agreed: "Anything that involves big, yellow, iron pieces of equipment" will account for significant emissions, he contends.

Recent findings from construction companies that are tracking these data on projects indicate that construction emissions account for 10% to 20% of upfront embodied carbon. And an economy-wide input-output analysis suggests they could be as much as 30% of upfront embodied carbon. These figures point to the possibility that the construction process emits more than we thought, representing a bigger piece of the embodied carbon pie—and, more importantly, growing the size of the pie altogether.

In this report, we dive into the origins of current estimates, explore why they might be low, and compare them with findings from actual project-level tracking. Though we will focus on greenhouse gas emissions (using the term "carbon emissions" as shorthand for CO_2 equivalent), it's important to remember that construction emissions also contain many other criteria pollutants, which pose risks to human and ecosystem health.

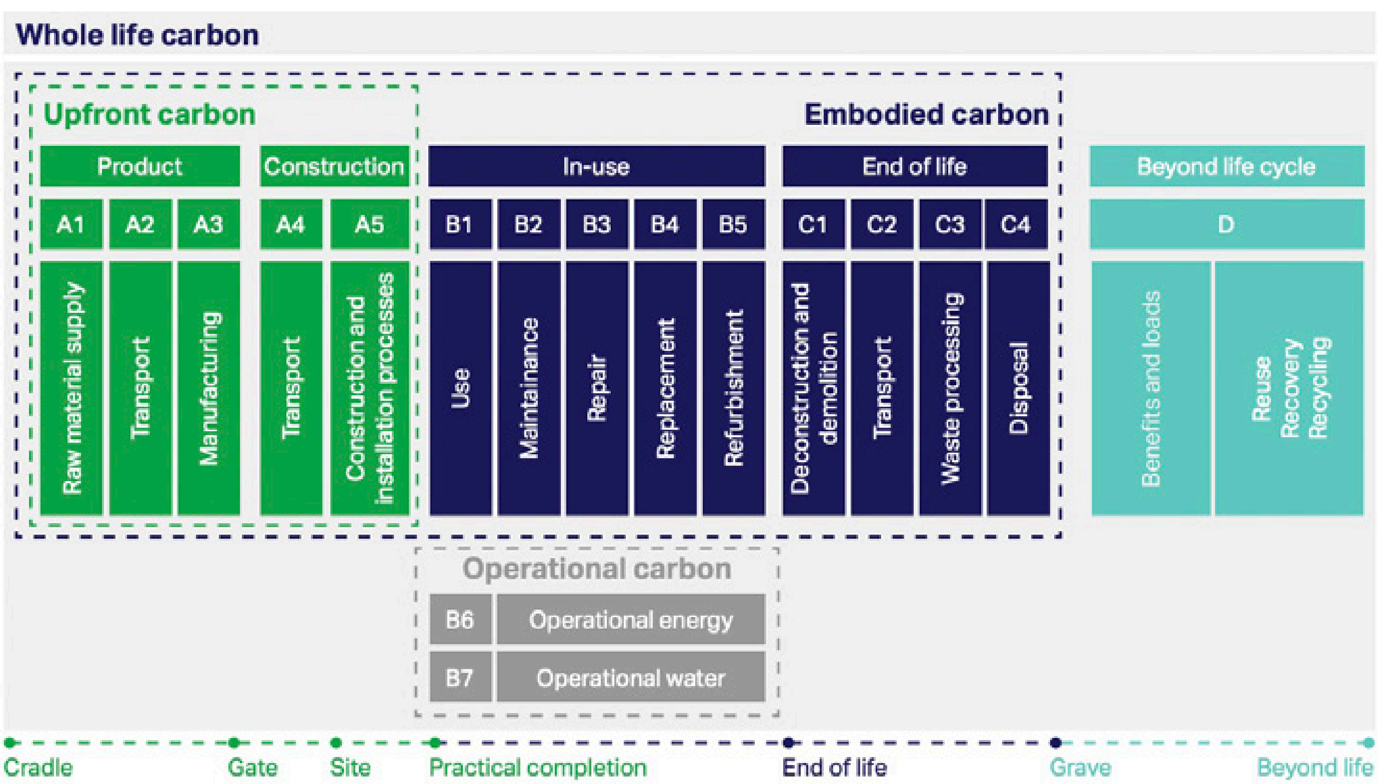
What Are Construction Emissions?

To estimate the carbon footprint of a building, a practitioner might perform a whole-building life-cycle assessment (whole-building LCA). (See the webcast LEED and Life-Cycle Assessment in Buildings, for how to complete a LEED-compliant LCA). You might be familiar with environmental product declarations (EPDs), which are based on LCAs for products. A whole-building LCA should combine the impacts of all the products and assemblies that comprise the building with lifetime operational energy projections and end-of-life impacts. (Although, in practice, whole-building LCAs are more often used to analyze embodied carbon, while operational energy use and end-of-life impacts are ignored).

The construction process is one phase that might be analyzed in a whole-building LCA. It is required by BS EN 15978, which according to this report from the University of Washington, is "increasingly becoming the common method for describing the system boundary of whole-building LCA." But it isn't a required phase for ISO 14044, referenced by LEED. Considered part of the building's upfront embodied carbon, the construction phase is divided into modules A4 (transportation of materials to the job site) and A5 (construction of the building). (See the sidebar titled "A Primer on Life-cycle Stages" for further details about the phases of a life-cycle assessment.)

Unfortunately, BS EN 15978 does little to set firm boundaries on what should be included and excluded. For example, it states that A5 includes fuel consumed for "construction activities." But what about the fuel used by a concrete mixer truck on the jobsite? Should that fall into construction emissions (A5) or emissions associated with building materials (A1–A3)?

Some entities and frameworks have tried to develop tracking boundaries that make sense for contractors and provide a more accurate picture of con-



"Net-Zero Buildings: Where do we stand?"; authors: World Business Council for Sustainable Development and Arup; July 2021

Whole-building life-cycle assessments (LCAs) attempt to quantify the potential environmental impacts of a building from "cradle" to "grave." Carbon emissions show up in multiple life phases, which British Standard EN 15978:2011 breaks down into modules A through D.

struction emissions.

For example, in a 2021 white paper (available for download from the Carbon Leadership Forum), Microsoft outlined the requirements for subcontractors, suppliers, and general contractors to track A4 and A5 emissions. They include:

- Off-road vehicles, equipment, and tools used within the jobsite
- Delivery vehicles for building materials
- Crew transport provided by the general contractor

The real estate company Hines published a report in 2022 with a comprehensive list of what to track for A4 and A5. Hines had input from Sellen, Skanska, Turner, and Webcor:

- Onsite transportation
- Temporary electrical power consumption
- Site demolition and clearing
- Excavation
- Temporary works construction (shoring systems, crane footings, etc.)
- Material handling
- Material waste

The Contractor's Commitment to Sustainable Building Practices, created by BuildingGreen's Sustainable Construction Leaders Network, offers a third framework. At the "better" tier, companies track "jobsite" carbon, which consists of:

- Fuel purchases for owned, leased, or rented equipment or vehicles
- Electric, steam, or heat utilities for contractor operations only

As is evident from these lists, the guidance varies on which construction-related activities are most important to track, presenting a challenge. As we explain below, differences in some LCA estimates seem to come down to the inclusion or exclusion of emissions associated with demolition, excavation, and employee commuting—or even a project's share of emissions from the contractor's corporate operations.

However, the bigger problem is the lack of data for each of these potential emission sources and, therefore, the lack of reliable ways to estimate them based on project-specific factors like building size, location, or materials. So even if the boundaries are well defined for a whole-building LCA, there isn't enough generalized data to determine the significance of construction practices within the context of a building's lifetime carbon footprint.

Nevertheless, contractors have ideas about which construction activities are the highest emitters and can recommend strategies to mitigate them—even if there aren't yet enough data to create generalized baselines.

Why Are Construction Emission Estimates So Low?

If we don't have construction emissions data, why do we assume this phase is relatively insignificant? It might be a case of mistaking a known-unknown for a known.

BuildingGreen spoke to the developers of the three most commonly used whole-building LCA tools: Tally, Athena, and One Click LCA. Everyone interviewed admitted that the tools' results don't represent the full scope of A5—either because they rely on limited, default assumptions or because they allow users to omit A5 data altogether.

"A5 is likely much higher than people think," explained Jennifer O'Connor, president at Athena Sustainable Materials Institute. "The argument becomes circular: tools don't have data on A5, hence the low percentage results, hence people think A5 doesn't matter."

A Primer on Life-cycle Stages

Whole-building life-cycle assessments (LCAs) attempt to quantify the potential environmental impacts of a building from "cradle" (tree harvesting, mineral mining, etc.) to "grave" (the landfill). Carbon emissions show up in multiple life phases, which are broken down into modules A through D, based on guidance from British Standard BS EN 15978:201, as explained by the Royal Institute of Chartered Surveyors (RICS).

Module A accounts for upfront embodied impacts, including carbon:

- Building materials (A1–A3): raw material extraction and supply, transport, and manufacturing
- Transport (A4): transportation of the materials and components from the factory gate to the project site
- Construction of the building (A5):
  - Pre-construction demolition (A5.1): demolition works associated with refurbishment or redevelopment of an existing built asset to a new project (same as the C1 module for the existing built asset as its own project)
  - Construction activities (A5.2): site investigations; temporary works; worker "accommodation;" onsite electricity, water, and fuel consumption
  - Waste and waste management (A5.3): impacts associated with waste generated through the construction process, including its treatment and disposal
  - Worker transport (A5.4)—optional: transport of people and employee commuting

continued

In short, users might assume that whole-building LCA tools operate with more information about construction emissions than they actually do. So when construction emissions show up as a small percentage, users imagine construction must be an insignificant driver of emissions rather than blaming the low numbers on a lack of data within the tool.

Some key industry reports, such as those published by the World Business Council for Sustainable Development (WBCSD) and LETI (originally the London Energy Transformation Initiative), reiterate this assumption, which we'll discuss later. Here, we'll break down how each major LCA tool accounts for construction emissions.

Tally and EC3: Optional fields

The Tally whole-building LCA tool and the EC3 EPD database both calculate A5 emissions from optional input fields. If users don't input any data, A5 emissions are not included in the results.

Tally, owned and operated by Building Transparency, contains optional input fields for energy and water consumed on a jobsite. Vaclav Hasik, data manager at Building Transparency, explained that Tally approaches A5 in this way because there is not enough industry research or data to create a baseline. Hasik went on, "You can do bottom-up estimates of energy used to build steel or concrete structures, but it's very difficult to do a generic estimate. [It's] going to be project specific." He noted that conducting a bottom-up analysis is also difficult because specific processes, like steel erection, are "not necessarily sub-metered on the project site," so users "might not necessarily know how much energy is spent per process." Contractors simply aren't collecting this information, he said. So whatever estimates are out there "tend not to be robust."

EC3, another tool operated by Building Transparency, is known for its database of EPDs and its features enabling comparisons between specific product choices. However, EC3 also offers visualization tools to compare the embodied carbon of a project against baselines. For this project-level summary, EC3 recently added a tab for A5, which allows users to input diesel consumption, total electricity used onsite, and grid information to account for the emission profile of the region's grid. The approach is the same as Tally's in that users can—but don't have to—enter the cumulative quantities of those fuels used on the construction site if they have the information.

Athena Impact Estimator: limited default assumptions

Athena's whole-building LCA tool, the Athena Impact Estimator for Buildings, does include some automatic default assumptions, but not for the whole scope of A5. The tool applies a "construction waste factor" by material type, according to the User Manual and Transparency Document. And for jobsite equipment energy use, it calculates the energy it takes to lift materials by crane an average distance of half of the height of the building.

These two impacts usually add about 5% to 10% more carbon to the total whole-building LCA, according to O'Connor. It is worth remembering that most users are focused on embodied carbon, so that's not necessarily the percentage range for construction's share of the project's lifetime carbon. Furthermore, O'Connor admits that this is probably an underestimate as Athena excludes any emissions associated with transporting workers or equipment, purchased capital equipment, water use, site preparation work, and utility hook-ups.

Regarding the last two activities, the user guide explains that "every site will be different, with different soil condi-

Module B accounts for embodied and operational impacts during building occupation over time:

- In-use emissions (B1): non-energy emissions
- Maintenance emissions (B2)
- Repair emissions (B3)
- Replacement emissions (B4)
- Refurbishment emissions (B5)—optional
- Operational energy use emissions (B6)
- Operational water use (B7)
- User activities (B8)

Module C accounts for a building's end-of-life impacts:

- Deconstruction and demolition (C1)
- Transport of waste to disposal facility (C2)
- Waste processing (C3)
- Waste disposal (C4)

Module D, which is optional, accounts for building benefits and impacts beyond the system boundary:

- Potential benefits from reuse, recycling, and energy recovery from the flows of materials exiting the system boundary (D1)
- Potential benefits and loads from exported utilities exiting the system boundary (D2)

tions, and it is impossible to generalize the effects based solely on the building footprint." It continues by saying that the Impact Estimator is a "comparative tool for different building materials and systems," and the site prep work and utility hook-up would likely be the same or similar for any comparative designs.

Ideally, "every consumption of fuel on the jobsite should be included," said O'Connor, but "the primary reason [more inputs are] not included is that there are no data." She doesn't think these data can be based on the material type (as Hasik envisioned when referencing bottom-up estimates comparing steel and concrete structures), but rather on the scale and type of construction. "I think it is a matter of gathering survey data based on region and distilling it down to some kind of use factor," she said.

O'Connor noted that Athena plans to launch a web version of the tool later in 2023 in which users can override the default waste and jobsite energy factors with more precise information.

One Click: Using select case studies

One Click LCA makes more comprehensive default assumptions about A5 in its tool, but as Vasilis Kalfountzos of One Click noted, "The A5 scope is big, so we can't make assumptions about everything." Still, the company updates its defaults whenever it comes across new sources of emission data it considers more reliable. Just recently, it changed the way it accounts for construction activities and site waste. Kalfountzos explained that One Click dropped "old scenarios that combine both site waste and site operations." Now, it separates these values. The tool makes default assumptions about site waste based on the quantity and type of materials modeled. And it uses a new default assumption about site operation emissions—20.22 $kgCO_2/m^2$— which One Click calculated "based on a range of references regarding fuel consumption in construction sites."

Kalfountzos shared these references with BuildingGreen, which consist of five reports from around the world. Three of the reports, from 2014, 2015, and 2016, share results from a combined total of six case studies of building energy and emission assessments and LCAs in Australia, Korea, Sweden, Italy, Turkey, and Belgium. The other two reports include analyses of construction emissions on projects in Norway and electricity use only for projects in the Czech Republic.

These reports might contain reliable data, but they comprise a small dataset, and it doesn't appear that any projects with significant A5 emissions are represented in that dataset.

Kalfountzos also clarified that users can override the defaults for both site operations and waste with more detailed, project-specific information.

Referencing RICS for default inputs

While not a whole-building LCA tool, it is worth mentioning that there is one set of generalized estimate values for A5 that could be used as inputs into any whole-building LCA tool. The Britain's Royal Institution of Chartered Surveyors (RICS) publishes one of the most comprehensive interpretations of BS EN 15978. In the second edition of its Whole Life Carbon Assessment for the Built Environment Guide, for which consultation closed in April, RICS assigns default assumptions for $kgCO_2e/m^2$ for each recommended sub-module (as outlined above in the sidebar titled "A Primer on Life-cycle Stages"):

- Pre-construction activities (A5.1): 50kg CO_2e/m^2
- Construction activities (A5.2): 25kg CO_2e/m^2

Photo: Matthew T Rader

Heavy equipment, like excavators and bulldozers, causes jobsite emissions to spike, according to Roberts.

- Waste and waste management (A5.3): RICS uses a 90% diversion-from-landfill assumption and offers a baseline building-specific emissions assumption of 5kg CO_2e/m^2.

RICS also includes a sub-module for worker transport (A5.4), defined as the "transport of people and commute of employees." But it recommends this scope as optional "unless [the workers] are bringing materials with them, as the emissions associated with these activities are not attributable to the project but to the individual employees."

In its first edition, RICS based it estimates for A5 on data gathered by the BRE SMARTWaste tool used by project teams in the U.K. According to Jane Anderson, owner of ConstructionLCA Limited, these data "would mostly have been [from] large contractors and projects, and ones with a sustainability focus." This could skew the data toward projects already performing more efficiently than average, which might contribute to default assumptions of low impact. The dataset is not publicly accessible, and BuildingGreen could not verify anything more about it within SMARTWaste. So it is hard to say how applicable these default assumptions are for typical U.S. projects.

Notably, the RICS guide recommends deconstruction and demolition of the existing asset (submodule A5.1) be included in A5 "to inform decision-making when comparing designs for retrofit or new-build options during the concept design phase." None of the reports and LCAs studied for this article—even those that cited RICS—followed this guidance. Based on the RICS default assumptions, the inclusion of submodule A5.1 would more than double total A5 estimates.

The RICS default values align closely with previous versions of One Click defaults if you excluded demolition. One Click has since updated its default for site operations, but it still excludes demolition, Kalfountzos told BuildingGreen. "We set the system boundary at the building—what happens at the moment you start constructing. Emissions from the demolition phase would usually be allocated to the previous owner," he explained. Kalfountzos indicated that the forthcoming RICS update might reallocate these impacts to A0, a pre-construction phase designated for activities considered negligible and not typically included in the project scope.

On the whole, the RICS default values could be more widely assumed by LCA tools or referenced by users. But the dataset they are based on isn't especially transparent, so it is difficult to tell if these values might also underestimate construction emissions.

Low results lead to low interest

Even though their approaches vary, each major whole-building LCA tool is likely to show very low numbers for A4 and A5—if it shows any numbers for construction emissions at all. The inherent limitations of estimating A5 might be evident at an individual project level, but the systematic undercounting of construction, in aggregate, may be misdirecting the industry.

Because some tools leave the A5 fields optional, BuildingGreen reached out to Green Business Certification Inc. (GBCI), which reviews LEED documentation, to see if the organization could estimate how many projects include A5 data in their models for LEED's whole-building LCA credit. Even though standard EN 15978 recommends the inclusion of A5 in a whole-building LCA, it seems most users pursuing the LCA option are leaving those fields blank—probably because the LEED Reference Guide does not require LCAs to include these data even though the LEED credit language references EN and ISO standards that include them.

A5 "is an optional life-cycle stage for a compliant LEED WBLCA," Jessica Gracie-Griffin, senior certification reviewer at GBCI, explained in an email to BuildingGreen, "so we haven't given A5

BUILDING LAYERS	BUILDING STAGES: PRODUCTS	CONSTRUCTION	USE		END OF LIFE	EMISSIONS	BEYOND LIFE
	A1-A3	A4-A5	B1-B5	B6-B7	C	$kgCO_2e/m^2$	D
Structure Substructure and superstructure	240	9	6		4.1	258	-53
Skin Façade	100	1	94		0.2	195	111
Space plan Partitions and internal finishes	39	0	39		0.2	78	-2
Services Building services, energy and water use	120	1	240	1512	1.4	1873	-56
Stuff Fittings, furnishings and equipment (FF&E)	5		10			15	-5
Site emissions Waste, electricity and fuel		30				30	
Building carbon emissions Embodied and operational	**503**	**40**	**388**	**1,512**	**6**	**2,449**	**-227**

Net-Zero Buildings: Where do we stand?"; authors: World Business Council for Sustainable Development and Arup; July 2021.

Whole-building LCA of an office building in London: one of six case studies completed by WBCSD and Arup on six buildings across Europe. On average, combined A4 and A5 emissions made up 7% of total embodied carbon.

(construction installation process) much attention at GBCI. Anecdotally, most WBLCA submissions in LEED don't include these impacts in their analyses."

Similarly, the treatment of construction emissions by LCA tools impacts the way this phase is reflected in industry-leading reports.

WBCSD, in its report "Net-zero buildings: Where do we stand?" published in partnership with Arup, used One Click to estimate A4 and A5 impacts for a series of case studies and found relatively small impacts.

In the report, the organizations share findings from six whole-building LCAs conducted for building projects in London, Copenhagen, and Amsterdam. Four projects were office buildings, one was mixed use, and one was a residential timber tower. On average, combined A4 and A5 emissions made up 2% of the lifetime carbon emissions of the buildings and 7% of total embodied carbon. The case studies cited the One Click assumptions of 25 kg CO_2e/m^2 for construction activities and 5 kg CO_2e/m^2 for waste. (As mentioned, according to BuildingGreen's conversation with Kalfountzos, these assumptions are no longer current, and One Click's new defaults are even lower.)

The LETI Embodied Carbon Primer doesn't specify which LCA tool it draws from, but its assumptions seem to align with the RICS default values. In its report, it breaks down the relative significance of each life-cycle phase across four U.K. building archetypes and two energy scenarios. For one such archetype, commercial office buildings, A5 makes up 1% of a building's lifetime carbon footprint under the current regulation scenario. In the second scenario, in which the same office is designed to be ultra-low energy—increasing the proportional share of embodied carbon—A5 is just 2% of lifetime carbon. In both scenarios, A5 accounts for 5% of all embodied carbon.

The low numbers published in these reports have likely reinforced the common practice of ignoring A5 construction emissions as a significant driver of carbon emissions.

How Big Could Construction Emissions Be?

Given the minimal impacts for A5 assumed by LCA tools and the lack of data entered, what is indicating construction emissions might be a more significant source of a project's embodied carbon?

Economy-wide LCA estimates 30%

BuildingGreen spoke with Greg Norris, Ph.D, chief science officer at Earthster, who analyzed the impacts of construction activities using an economy-wide input-output analysis. For details about how this analysis is conducted, and how it differs from a typical whole-building LCA, see the sidebar titled "What Is an Input-Output LCA?"

The short version is that the U.S. Environmental Protection Agency (EPA) produces an open-source resource called the US Environmentally Extended Input-Output (USEEIO) model, based on economy-wide surveys asking businesses how they spend their money. It breaks down businesses by sector and business group, separating out commercial structures and contractors. An input-output LCA can, therefore, tell us about all the carbon emissions that go into construction activities and "the business of being a contractor," explained Norris. It is more inclusive than a typical process LCA; for example, it assigns a portion of the contractor's corporate office emissions to projects. It is a valuable counterpoint to a process LCA, which, as we have seen, might exclude significant emission sources due to a lack of data.

What is an Input-Output LCA?

The US Environmentally Extended Input-Output (USEEIO) model takes a macro scale approach to estimating environmental impacts. Unlike the more conventional "process LCA" used to produce environmental product declarations (EPDs) and analyze ingredient or process changes in industry, USEEIO maps the entire U.S. economy and allocates carbon emissions by sector. The Department of Commerce's Bureau of Economic Analysis, fittingly enough, maps the economy. The EPA assigns resource and pollution flows to each sector.

This macro view is comprehensive because it includes all transactions in the U.S. economy. Nothing is left out. As Greg Norris, Ph.D, chief science officer at Earthster noted, it "finds data that you wouldn't have looked for," usually providing a higher accounting of a sector's carbon footprint. Because it takes the same comprehensive approach to all sectors, the results it provides for comparing one sector to another are still valid. But it's not very granular, and its usefulness is limited by how the sectors are defined and tracked. The data behind it are also not very current. Even USEEIO v2, released in 2022, draws from data sources that date back to 2012.

Process LCA, on the other hand, omits any resource flows below a certain threshold. Norris explained, "Process-based [analysis] doesn't necessarily account for everything. It just asks for the 'important' things." Meaning it measures what people already think is important. Process-based LCA is precise, but it's based on the practitioner's view of activities across the life cycle. Data are gathered using questionnaires

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Top 20 Economic Sectors by Greenhouse Gas Emissions for Commercial Construction

Whole-Building Life Cycle Assessment (WBLCA) phase A4 → 2 truck transport

direct emissions from construction activities & construction company operations → 1 construction

emissions from generating electricity supplied to commercial construction → 3 electricity

emissions from fossil fuel supply chain to commercial construction → 4 gasoline, fuels, & by-products of petroleum refining

emissions from architecture & engineering (project "soft costs") → 20 architectural, engineering, & related services

#	Economic Sector	kg CO2e/m2	% of total
1	*construction*	411	20%
2	truck transport	128	6%
3	electricity	123	6%
4	gasoline, fuels, & by-products of petroleum refining	120	6%
5	air conditioning, refrigeration, & warm air heating equipment	77	4%
6	metal structural products	74	4%
7	metal windows, doors, & architectural products	72	3%
8	ready-mix concrete	68	3%
9	other concrete products	50	2%
10	other plastic products	46	2%
11	other real estate	41	2%
12	fertilizers	39	2%
13	glass & glass products	39	2%
14	other durable goods merchant wholesalers	34	2%
15	asphalt shingles	33	2%
16	plywood & veneer	33	2%
17	plastic pipe & fittings	29	1%
18	cement	29	1%
19	wood windows, doors, & flooring	28	1%
20	architectural, engineering, & related services	25	1%

source: Data from USEEIO v2, assuming a typical mid-rise office construction cost of $600/ft2.
Total embodied carbon from all sectors using this method is 2,067 kg CO2e/m2.
Adapted from data provided by Dr. Greg Norris, MIT and Perkins & Will

Adapted from data provided by Dr. Greg Norris, MIT and Perkins & Will

Results from an input-output LCA estimate construction accounts for 20% of commercial buildings' embodied carbon. Adding emissions from the electricity and fossil fuel sector brings this figure to 32%.

According to USEEIO, about 20% of greenhouse gas emissions that come from making a building are emitted directly by construction companies—the general contractors and subcontractors doing the actual work. This includes corporate operations, corporate overhead, and corporate-funded employee commuting, activities that aren't typically included in whole-building process LCAs. The remaining 80% is from the supply chain. But that supply chain isn't limited to building materials; it includes two emission sources that would normally be factored into the construction phase of a whole-building LCA as emission factor multipliers—namely, the upstream emissions associated with construction energy use.

The first of these emission sources is electricity use on the jobsite, representing 6% of overall embodied carbon emissions. The second is extraction and refinement of fossil fuels used for jobsite processes. (Emissions from burning those fuels are assigned to construction activities, while emissions from extracting and refining those fuels are in the supply chain.) Extraction and refining of fossil fuels burned in power plants or on the jobsite (or used directly as a construction material, like bitumen for asphalt) account for another 4%–6% of the total embodied carbon of a project.

If you reallocate to the construction phase the emissions from jobsite electricity use and the refining of the fossil fuels burned during construction, these numbers suggest that construction represents over 30% of the total embodied carbon in a building. Even after deducting a few percentage points for emissions from corporate overhead activities, that's a far cry from the 7% average estimated in the WBCSD guide.

Though initially surprised by this finding, Norris came to believe that there must be some jobsite emission sources that traditional LCA models underestimate. His hypothesis is that the biggest of these are "trucks driving all over the place, and fuel and electricity use onsite."

Based on BuildingGreen's own analysis, refrigerants also appear to be a large driver of the CO_2e impact, but because of the nature of the input-output analysis, it is difficult to tell what those refrigerants are used for (perhaps to cool jobsites in hot climates, or as blowing agents used to install spray-foam). Regardless, the input-output analysis seems to be catching impacts that aren't currently reflected in more common, process-based whole-building LCAs.

Norris mused that the way the boundaries are currently drawn in whole-building LCA tools might be a result of convention, desire for simplicity, or a belief that a certain activity is negligible. But, he implied, the boundaries can always be redrawn. "LCA can [mistakenly] be seen as accounting analysis rather than empirical analysis …. The true rule should be that if it matters, you should include it."

Contractors say 15%–20%

It is rare for contractors to track A5 emissions, but some have started doing it for select projects.

Sellen and Skanska Balfour Beatty are tracking A1–A5 for the Microsoft Puget Sound campus modernization project in Redmond, Washington, which consists of the construction of 17 new buildings. In the white paper mentioned above, Microsoft shared findings from a comprehensive whole-building LCA it had performed for the project. Microsoft writes, "There is little data or established methodology for creating a baseline [for the construction process], making it difficult for design teams to know if their emissions are better or worse than a typical construction project. Almost no projects have tracked construction activity emissions to a high level of detail on a typical construction project."

Microsoft worked with its general contractors to develop a Construction Activity Carbon Reduction Plan (CACRP) for this project that outlined the requirements for subcontractors, suppliers, and general contractors to track A4 and A5 emissions. It included:

- Off-road vehicles, equipment, and tools used within the jobsite
- Delivery vehicles for building materials
- Crew transport provided by the general contractor

Their results showed that A4 and A5 emissions comprised about 10% to 20% of the project's total embodied carbon emissions, which was twice what Microsoft had expected. Emissions from the site work and excavation of the underground parking structure outweighed those from individual building jobsites. Once Microsoft completes these projects,

that ask for information with a preconceived idea of what is significant. Other than the fact that both LCA approaches aim to quantify impacts over the entire life cycle of a product or service, input-output LCA and process LCA are very different, and they're useful in different ways.

There is a common misconception that input-output LCA is just using dollars as a proxy for carbon emissions or other environmental impacts. In fact, it's quite the opposite. Because input-output LCA is based on EPA data on emissions by economic sector, it can show just how the carbon intensity (emissions of greenhouse gases per dollar spent) of each sector varies. USEEIO's results show, for example, that the ready-mix concrete industry emits 1.79 kg CO_2e per dollar, cement 8.82 kg, and plywood and veneer 0.64. These are national averages, however. For emissions from specific products or factories, one must use process LCA.

It works similarly for buildings: input-output LCA provides a macro view, reflecting how emissions from construction-sector activities compare with emissions from the construction material supply chain. This macro view may be useful, but it does not serve the exact same purpose as a whole-building LCA.

"The economic input-output approach is great for all of the United States, but it's not a useful approach for individual projects," noted Vaclav Hasik, data manager at Building Transparency. "For that you need process LCA."

As Jennifer O'Connor, president at Athena Sustainable Materials Institute stated, from a client's or designer's perspective, "I want to know about this building. We have to keep our perspective at the level of the building." She added, "I would tend to agree that the corporate operations

continued

it plans to normalize demolition and excavation data into $kgCO_2e$/cubic yard for excavated soil and $kgCO_2e$/square meter for demolished buildings. This will allow for comparison with the RICS (and other) data.

Chen thinks these findings apply beyond this one project: "A4 and A5 are a little more significant than we'd thought," he told BuildingGreen. "We've seen, for a few different projects, A4 and A5 have been closer to 15% or even 20% in the total A1 to A5 pie."

Bailey Zak, senior sustainability engineer at Skanska, expounded: "Five percent was consistently too low," adding that A5 "was always trending higher" than that. But Chen also noted that the definition of these phases is a little unclear.

"A5 gets murky because buildings aren't just built in space," Chen said. "A lot of earthwork is involved to construct the building foundation: moving dirt, trucking offsite, getting formwork onsite and back offsite." Those activities are sometimes more involved than even the contractors expect. He identified the three most significant inputs often excluded from whole-building LCAs: the demolition of the existing building, earthwork, and drilling and shoring. "When you're including [these sources], it drives the numbers a lot higher than what you'd probably typically see in modeling software," he said.

Chen thinks all contractors should focus on these top three drivers of construction emissions, adding that employee commuting should also be a part of the conversation. He doesn't believe it will outweigh earthwork emissions, but contends it is not an insignificant input. "Doing just those three is not too heavy of a lift," he says.

"Tracking [all A5] data is really labor intensive," Oliver Atkinson from Sellen told BuildingGreen. Much of the tracking depends upon collecting accurate data from subcontractors, which requires excellent organization and communication.

"Early on, one of my biggest projects was creating the lists of subcontractors that are onsite every month. It is a huge workload," Atkinson said, explaining

Photo: Turner

It takes dedicated staff time to collect all the information needed to calculate jobsite emissions. So far, Turner has done so on 50 completed projects with more than 100 more in progress.

should not be included. Ultimately, I want to know how much A5 diesel was consumed for the construction of the building."

But how can we more accurately estimate A5 if projects are not pursuing this bottom-up accounting? Or are relying on tools with faulty assumptions? When asked if she could point to any good data, Stacy Smedley, executive director at Building Transparency, advised, "Rely on contractors that are actually doing it," like Sellen, Skanska, and Turner. "The scopes of a project and type of project have huge impacts on the percentage of A5 emissions."

that they collect data on any work done within the construction fence and sometimes beyond: fuel consumed by equipment, tools, and off-road vehicles used onsite; the last leg driven by delivery vehicles; subcontractor commuting in company cars; and Sellen jobsite utility usage. “Every month, I go through natural gas, electricity, and put it in the data,” Atkinson said. He noted the next step would be to install sub-meters onsite to see how much energy and fuel individual processes, like cranes, use.

Chen echoed Atkinson as he explained why these data are not often tracked: “The reason why you don’t usually have projects going to this level of detail [is], you can’t truly calculate it. This data is from actuals, tracking month-to-month activities with the subs.” This new level of granularity represents “another service for construction firms,” Chen said. “I don’t think the majority of GCs have a system built out to track this on the jobsite. It’s the state of the industry.”

And this absence of “historical data can be a cause of the gap between projections and actuals,” he continued. Accurate, initial assumptions depend on subcontractor feedback. “I feel like we [at Skanska] can make projections, but is it going to be as accurate as if we went to every sub and got their estimates? Probably not. A lot of the work is dictated by subcontractors.”

BuildingGreen asked Abigail Roberts, sustainability program manager at Turner Construction Company, for her general impression of the relative significance of jobsite emissions. “Estimates are nowhere near what we’re tracking,” she began. “There are huge variations in the emissions on a jobsite.”

In 2019, Turner launched an effort to track project-level emissions in different sectors across the country, collecting its fuel consumption and utility (electricity, fossil gas, and water) use data and asking all its trade partners to send in their fuel consumption data. Currently, Turner has data from around 50 different completed projects. Roberts explained that, given the significant variability between projects, she hasn’t been able to determine an applicable standard metric. She has noticed, though, that the A5 emissions of most projects follow an M-curve. Emissions are high in the beginning of construction when heavy equipment, like excavators and bulldozers, is used. Emissions dip down in the middle of the process when, despite there being a lot of tradespeople onsite, lighter equipment is more prevalent. And emissions spike back up at the end as building systems start up and run without controls. Once commissioning is complete, emissions decrease once again during the building’s occupancy phase.

Roberts identified two main inputs that tend to throw off emission estimates: temporary power and temporary heat. “When you are running your jobsite on a generator, it’s going to be exponentially higher in emissions,” Roberts expanded. The problem is that temporary power connections are challenging to accurately schedule, and the scheduling of utility hook-ups often slips.

“Maybe you can estimate [emissions from] power generation, but most jobs underestimate how long they’ll need temporary generators onsite, “Roberts explained. “Sometimes we’re at the mercy of the utility company’s availability to bring temporary power to the site.” Roberts lives in Massachusetts, where a new stretch code is widely expected to encourage electrification. She worries about the utility’s ability to provide the site with sufficient electricity: “I don’t think the utility supply is there yet …. Building operations will always get priority [over construction] for power.”

Regarding temporary heat, Roberts recalled a project in Boston, saying she was “blown away by the emissions” associated with temporary heating during

Photo: Sunbelt Rentals

Lendlease uses solar panels to power temporary lighting on a jobsite. Temporary power (for lighting, heating, and cooling) can be a significant source of A5 emissions.

a particularly cold winter. She said Turner "got the utility bill for the heating, and that became 70% of the overall A5 emissions of the construction project." Roberts explained that there aren't a lot of temporary controls for heating, and project scheduling and urgency often force contractors to work during the winter, which requires a lot of heat to meet installation specifications.

"You can do the best calculations for your whole-building LCA and put in your A5, and it's [still] going to be skewed," according to Roberts. "I don't think you can properly estimate temporary heating, given unpredictable variations in temperature in any given year."

She also said that companies are only now starting to ramp up jobsite emissions tracking; there's a learning curve, and data collection can be cumbersome. Turner is in the process of developing its own tracking software, with plans to do deeper data mining. "With a better dataset," Roberts said, "we could all improve."

Strategies for Reducing Construction Emissions

Tracking emissions and establishing a baseline are important. But we also need to reduce emissions now and, in tandem, protect the lives and health of jobsite workers and residents of surrounding neighborhoods. In many ways, the strategies and structures used for reducing construction emissions are more established than the methods for tracking and estimating those emissions. Recommendations from developers, owners, and contractors align across the following categories.

Policies

Both Hines and Microsoft include an anti-idling policy in their requirements. Hines recommends that contractors use automated electronic anti-idling devices. And Microsoft emphasizes the importance of reducing the time that concrete delivery trucks wait onsite and encourages them to consolidate deliveries.

Though employee commuting was a lower priority for many of the contractors we interviewed, some try to influence employee behavior by offering subsidized public transportation cards, carpooling services, or even incentives for buying electric cars.

Equipment

Prioritizing the use of efficient, preferably electric, equipment is crucial. Roberts emphasized that contractors should electrify their equipment as much as possible but acknowledged that because most high-emitting equipment likely won't be made electric for years to come, this is a challenge.

Amanda Kaminsky, director of sustainable construction at Lendlease, shared with BuildingGreen that the company has started a pilot project with an electric, battery-powered equipment provider that has offered its products to Lendlease subcontractors for a few months to try so they can compare the emissions to their standard estimates from burning diesel. "We will monitor the carbon reduction of using the electric equipment," says Kaminsky. But they are also asking their subs to provide feedback about other safety and well-being upsides on the ground, including less noise, improved air quality, fewer cords, and better ergonomics with less vibration, she said.

When electric options are unavailable, ensuring that non-electric equipment is as efficient as possible is the next best thing. Microsoft requests that, when possible, tier 4 equipment (an EPA designation for non-road diesel engines) should be used for earthwork and paving, and that older, heavy equipment should be retrofitted with the best available technology. It writes that for tier 3 equipment (motor vehicles) or lower, retrofits like diesel oxidation catalysts or diesel particulate filters should be investigated.

Biofuel is another potential way to reduce jobsite emissions before electric equipment is the norm. Microsoft recommends the use of a "B20 biofuel blend (20% biofuel and 80% diesel) or renewable diesel fuel." It should be noted, though, that the environmental benefits of biofuels are debated. According to the EPA, biofuels could cause air and water pollution, increase food costs, put pressure on water resources, and result in greenhouse gas emissions through changing land-use patterns. Certain biofuels, on an energy-equivalent basis, may even emit more greenhouse gases than fossil fuel.

Power

Electric equipment is great, but it doesn't do much good without access to electric power. Kaminsky explained that Lendlease has a corporate requirement to use electric cranes. "But when we can't get sufficient temporary power from the utility in time, we end up with an electric crane with a diesel generator next to it," counteracting the intended benefits, she said. "We are collaborating with the local utility to make temporary power increasingly dependable while also working to get renewable diesel infrastructure and supply to more locations and large batteries to obtain necessary UL certifications for jobsite use."

Microsoft recommends that jobsites "connect to temporary electric power instead of generators where possible." Both Microsoft and Hines write that temporary power sources should be

Photo: Jason Etheridge, Lendlease General Superintendent

Lendlease uses solar panels to power a conference room field office at a construction site in Chicago.

programmed to shut off automatically shortly after the workday ends.

Considering that temporary electric power is not always available to jobsites, Microsoft recommends that contractors should be prepared to use generators with a tier 4 engine or, as Roberts noted, hybrid generators. The latter, Roberts explained, allows the generator to operate at its most efficient. The generator charges an energy storage system (EES), which is basically a battery with controls, instead of powering equipment directly. This can drastically reduce fuel consumption.

Temporary heating should also be electrified as much as possible, though Roberts points out that electric heat requires a higher utility supply. She advised that contractors "need to be talking very early with the utility companies. It depends on the site. It's not always possible to get the power to totally electrify," she said, adding that hydronic heating is another option. But the envelope of the site must be very tight for this method to work most efficiently. And an airtight building envelope is exceedingly difficult to achieve on a jobsite.

Organization and communication

Possibly the most essential strategies to reducing jobsite emissions involve organization and communication. There are so many different companies, people, and processes at work during the construction of a building that the articulation of clear goals and collaboration are crucial to success. Hines suggests that "general contractors should provide subcontractors with a common reporting template that is submitted each month."

Atkinson also emphasized the importance of verbally communicating written goals to make sure everyone is on the same page: "Everyone is doing their best. It's a matter of making information accessible and as clear as possible," he said. "Understand where other people are coming from. Use language that others understand."

Microsoft shared a list of lessons learned from the Puget Sound project, stressing the importance of project-wide education and discussion of requirements, using technology to track data, allowing for flexibility, and budgeting for the extra time it will take to coordinate and plan the tracking process.

With Better Data Will Come Better Baselines

Our current understanding of construction-phase impacts is limited. Whole-building LCAs currently underreport A5 because there are not enough data to generalize about U.S. construction. Input-output data include factors that many consider to be outside of a project's scope. Actual, comprehensive bottom-up data is the ideal, but most projects do not have the capacity or structure for this sort of tracking. And yet gathering this information is crucial.

Contractors need this information to benchmark current practice and measure improvements. Those who have begun tracking it often attribute their ability to do so to their company's ESG commitment. Zak noted that collecting accurate data often depends on the "the client, the project scale, [and] scope," but that contractors need to prioritize this across their business. "The construction company needs to have the people, the time, the interest. It is about making this a priority," she said. Kaminsky of Lendlease echoed this sentiment. "We [at Lendlease] just see [tracking] as our responsibility. This is under our control."

Accurate A5 estimates could also influence the decisions that owners and designers make before construction even starts. Kaminsky pointed out to BuildingGreen that full acknowledgement of, and responsibility for, the emissions associated with demolition or deconstruction of a building might encourage owners and construction managers to pursue more reuse—or at least discuss reclamation options. "Everyone needs more drivers to be thoughtful about this early phase," she said. "Too often, design documents specifying reuse and recycling are not completed when this work

Photo: Jason Etheridge, Lendlease General Superintendent

Lendlease team members collaborate in a field-office conference room powered by solar panels. The electrical conduit is coded green to emphasize the renewable power supply.

is executed. Clearer responsibility for the impacts will drive the industry to be more intentional about managing these existing resources."

O'Connor stated that fully accounting for construction emissions will help make the case for designing and procuring more prefabricated materials. "Prefabricated materials will have really high A1–A3 emissions because more work is being done at the factory," she explained. "I think it is a real issue. If you don't have proper A5 estimates, you are going to disadvantage prefabricated materials."

At the highest level, we need this information to monitor progress towards building-sector goals worldwide. In its report, WBCSD writes that we must improve our understanding of the total life-cycle emissions of buildings to create a more robust baseline against which to measure progress toward the sector's carbon reduction goals. It calls on "companies from across the built environment and around the globe to conduct whole-life carbon assessments of their projects as a matter of course, openly publishing the results so we can create and build a body of evidence and shared learning."

For whole-building LCAs to be meaningful, more accurate and widespread accounting of construction emissions will be necessary. If we continue to underestimate jobsite impacts, we will continue underestimating the overall emissions of buildings and undermining project-level and sector-wide efforts to reduce them.

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Instructors: Elizabeth Waters and Candace Pearson
Course Level: Advanced
Non Member Price: $39

Description

People interested in reducing the embodied carbon of buildings are familiar with weighing the impact of different materials, like mass timber or low-carbon concrete. Low-carbon construction has not been on many people's radar—but it probably should be.

Findings from construction companies that are tracking greenhouse gas emission data on projects indicate that construction emissions account for 10% to 20% of upfront embodied carbon. And an economy-wide input-output analysis suggests they could be as much as 30%. In short, it's possible the construction process emits more than we thought, representing a bigger piece of the embodied carbon pie. More alarmingly, new accounting could grow the size of that pie.

In this course, we dive into current estimates of construction emissions, explore why they might be deceptively low, and compare them with findings from actual project-level tracking. Though the course focuses on greenhouse gas emissions, the health of jobsite employees and local residents is also at stake: fossil fuel burning during construction emits many other criteria pollutants, which pose risks to human and ecosystem health.

Learning Objectives

Upon completion of this course, participants will be able to:

1. Understand why construction emissions are probably being undercounted, bringing new concerns to the building industry about the true scale of its environmental and health impacts.
2. Define the key stages of and processes associated with a whole-building life-cycle assessment, which estimates the upstream and downstream environmental impacts of a building project's materials, construction, operation, and demolition.
3. Describe the tools and strategies being used within the building industry to understand and document the true environmental impact, and especially the carbon footprint, of the construction process.
4. List four types of positive action building industry professionals can take to reduce the environmental and health impacts of construction.

QUIZ QUESTIONS

1. Which module of a whole-building life-cycle assessment is not required by standard EN 15978?

- ☐ a. Module A (upfront impacts)
- ☐ b. Module B (impacts during operation)
- ☐ c. Module C (impacts at end of life)
- ☐ d. Module D (impacts and benefits beyond the system boundary)

2. An environmental product declaration (EPD) estimates the environmental impacts of a ______ while a whole-building life-cycle assessment estimates the environmental impacts of a ______.

- ☐ a. product or material; building project
- ☐ b. life-cycle assessment; life-cycle impact assessment
- ☐ c. mining operation; construction site
- ☐ d. embodied carbon model; energy model

3. Which best characterizes the building industry's overall attitude toward construction-phase (A5) emissions?

- ☐ a. Most people in the industry take construction emissions seriously, agree on what to measure, and account for these emissions in life-cycle assessments.
- ☐ b. Many industry experts agree that construction emissions are a major unknown and are probably underestimated.
- ☐ c. Thought leaders in the industry have aligned around which emission sources should be tracked, but most practitioners have not yet started tracking them.
- ☐ d. General contractors have discovered that construction emissions are negligible and argue they should never be accounted for in life-cycle assessments.

4. What factors have led to a widespread belief that construction emissions are relatively small? Choose all that apply.

- ☐ a. One Click and the Athena Impact Estimator provide default assumptions that appear low compared with other emission sources.
- ☐ b. General contractors have argued that their emissions are negligible.
- ☐ c. Tally and EC3 make construction emissions an optional field and provide no defaults.
- ☐ d. LEED does not require construction emissions to be accounted for in its life-cycle-assessment credit option.
- ☐ e. The Royal Institution of Chartered Surveyors (RICS) emission estimates are based on a dataset of sustainability-focused projects.
- ☐ f. The refrigerants used in construction are known to have very low global warming potential (GWP).

5. Which one is a limitation of a "process" life-cycle assessment?

- ☐ a. It doesn't account for the upstream impacts of building materials.
- ☐ b. It's too granular to be useful for estimating true environmental impacts.
- ☐ c. It might miss important emissions because of long-established assumptions that have not been questioned.
- ☐ d. It looks at entire industry sectors, not at specific building projects.

6. Which one is a limitation of an "input-output" life-cycle assessment?

- ☐ a. It gives a directional sense of where the biggest impacts of a sector might come from.
- ☐ b. It's too granular to be useful for estimating true environmental impacts.
- ☐ c. It doesn't include impacts from transportation, corporate operations, or refrigerants.
- ☐ d. It looks at entire industry sectors, not at specific building projects.

7. How should a whole-building life-cycle assessment account for demolition of a building before new construction begins?

- ☐ a. There is no clear consensus on whether the demolition impacts should be attributed to the existing building and its prior owner or to the new building and its owner.

continued on the next page

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QUIZ QUESTIONS

- ☐ b. Demolition impacts should be attributed exclusively to the new building and its owner.
- ☐ c. Demolition impacts should be attributed exclusively to the existing building and its prior owner.
- ☐ d. Demolition impacts are negligible and don't need to be accounted for in a life-cycle assessment.

8. Which are strategies described in this course for reducing the emissions associated with construction? Choose all that apply.

- ☐ a. Avoiding life-cycle assessments
- ☐ b. Creating an anti-idling policy
- ☐ c. Encouraging use of public transit
- ☐ d. Providing personal protective equipment to jobsite employees
- ☐ e. Buying or leasing electric construction equipment
- ☐ f. Working with electric utilities to supply temporary power for jobsites
- ☐ g. Avoiding the use of concrete in the project
- ☐ h. Clearly communicating requirements to subcontractors
- ☐ i. Requiring jobsite workers to wear warm hats and gloves so heating is not needed

9. Which materials are at a disadvantage when construction emissions are undercounted?

- ☐ a. Concrete and metals
- ☐ b. Prefabricated materials
- ☐ c. Interior products
- ☐ d. Insulation with high global warming potential
- ☐ e. Any products with environmental product declarations (EPDs)

10. Which most accurately characterizes the course's position on construction emissions?

- ☐ a. The construction industry should not try to reduce its emissions until there is a reliable baseline to compare against.
- ☐ b. Specifying low-carbon materials is the only way to reduce upfront carbon emissions.
- ☐ c. The whole building industry needs to work together to better track and reduce construction emissions.
- ☐ d. Input-output life-cycle assessment offers a more granular and accurate estimate of construction emissions than process life-cycle assessment.
- ☐ e. LEED certification should require whole-building life-cycle assessment.

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