Embodied Carbon Analysis

11038 Stanford Embodied Carbon
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Glossary

Carbon Emissions All emissions of greenhouse gases. Their global warming potential (GWP) is quantified in units of carbon dioxide equivalence. A kilogram of carbon dioxide therefore has a GWP of 1 kgCO2e.

Cradle-to-Gate An assessment of a partial product life cycle from resource extraction (cradle) to the factory gate (i.e., before it is transported to the consumer) - life cycle stages A1-A3

Cradle-to-Grave An assessment of a full product life cycle from resource extraction (cradle) to the end of useful life (grave). Life cycle stages A1-C4.

Operational Carbon The emissions associated with energy used (B6) to operate the building.

Embodied Carbon Carbon emissions associated with materials and construction processes throughout the whole life cycle of a building. Embodied carbon includes: material extraction (module A1), transport to manufacturer (A2), manufacturing (A3), transport to site (A4), construction (A5), use phase (B1, excluding operational carbon), maintenance (B2), repair (B3), replacement (B4), refurbishment (B5), deconstruction (C1), transport to end of life facilities (C2), processing (C3), disposal (C4).

Environmental Product Declaration (EPD) An independently verified and registered document that communicates transparent and comparable information about the life cycle environmental impact of products.

Global Warming Potential (GWP) A metric that was developed to allow comparisons of the global warming impacts of different greenhouse gases. Specifically, it is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO2).

Life Cycle Assessment (LCA) A systematic set of procedures for compiling and examining the inputs and outputs of materials and energy, and the associated environmental impacts directly attributable to a building, infrastructure, product or material throughout its life cycle (ISO 14040: 2006).

Sequestration The process of capturing and storing atmospheric carbon dioxide (CO2).

Upfront Carbon The emissions caused in the materials production and construction phases (A1-A5) of the life cycle before the building or infrastructure begins to be used.

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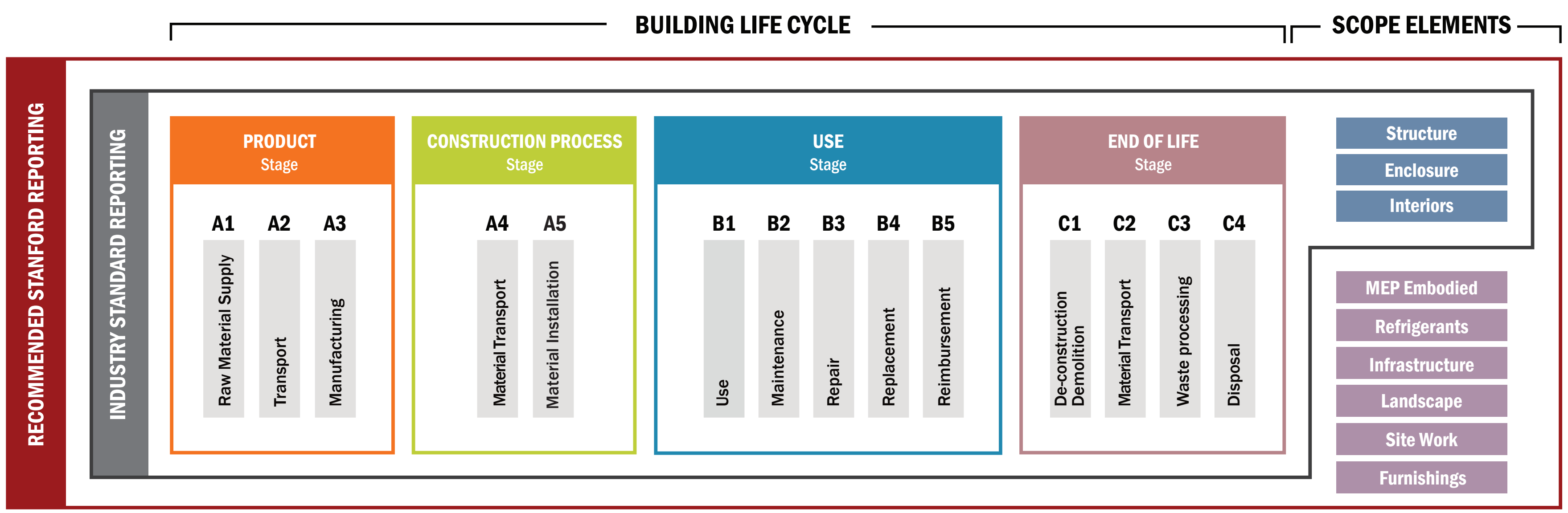

FIGURE 1.LIFE CYCLE STAGES, MODULES, AND RECOMMENDED SCOPE

Executive Summary

Atelier Ten has been engaged to develop and deliver a set of design guidelines that will help Stanford University build future building developments with lower embodied carbon.

The purpose of this work is to:

1. Identify embodied carbon characterization of typical buildings at Stanford University.
2. Analyze embodied carbon optimizations to inform reduction targets for new construction projects at Stanford University.
3. Establish opportunities and embodied carbon related scope definitions for Stanford University to become leading edge on its mission to achieve Net Zero Carbon for Scope 3 emissions.

Three representative Stanford projects were assessed to help quantity embodied carbon drivers and derive recommendations for future projects:

- The Biomedical Innovation Building (BMI), completed in 2020
- The Data Science and Computation Complex (Bridge Building), currently under construction
- The Meier and Norcliffe Residence Halls (Lagunita), completed in 2016

Findings from the life cycle analysis indicate these projects have the ability to significantly reduce embodied carbon through a combination of material (such as concrete mix design optimization or steel procurement) and design optimizations (i.e. mass timber or building reuse).

Results from the LCA studies were benchmarked against a set of industry targets and reference projects. Carbon intensities for these buildings were found to meet or exceed nearly all benchmarks after applying a combination of embodied carbon optimizations.

Scope definition consistency is an issue in the embodied carbon field, with various reporting institutions using different life cycle stages or elements boundaries. Most often, scope elements beyond structure, enclosure, and interiors are entirely omitted. An expanded Scope 3 study was completed to estimate the full, building-related Scope 3 impacts of Stanford projects. This included MEP embodied carbon, refrigerants, infrastructure, landscape, and site work. The results indicate these often overlooked scopes could add as much as 38% to traditionally reported scopes (structure, enclosure, and interiors).

A set of embodied carbon recommendations were developed based on the findings of the analysis. These include:

- Requiring life cycle assessments for all major projects
- Setting a 20% reduction target from baseline
- Tracking and reporting full Scope 3 elements, including MEP embodied carbon, refrigerants, infrastructure, landscape, and site work
- Implementing best practices to reduce Scope 3 emissions

Implementing these recommendations will make Stanford a leader in the embodied carbon field while dramatically lowering the climate change impact of the campus.

Introduction

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3. Establish opportunities and embodied carbon related scope definitions for Stanford University to become leading edge on it's mission to achieve Net Zero Carbon for Scope 3 emissions.

Towards this goal, Atelier Ten has analyzed three recently designed & built buildings on campus to establish a baseline.

Those results were then analyzed to pinpoint potential material and design optimizations that could be applied campus wide.

A research exercise took place to identify comparable design targets for similar projects, cities and universities and understand how Stanford projects are performing against those. In this report, the most relevant embodied carbon-reduction strategies have been identified to further discuss with the team.

Those strategies and additional bolder design optimizations have been proposed. Two-tier optimizations identify an "achievable" threshold and an "aggressive" one, which consider cutting edge technology and carbon-negative materials.

Significance of Embodied Carbon

According to Architecture 2030, the building industry's impact on the environment accounts for 40% of natural resources consumption, 40% of total primary energy consumption, 15% of the world's fresh water resources, 25% of all waste generation, and 40-50% of greenhouse gas emissions. Numerous scientific studies and governmental reports have established the importance of reducing carbon emissions within the next decade to avoid irreversible climate change. Most notably, the Intergovernmental Panel on Climate Change (IPCC) recently released a special report outlining the impacts of global warming above 1.5ºC which confirms that irreversible impacts from climate change are occurring faster than expected. The report also outlines a few pathways to stabilize global warming all of which require us to cut emissions in half within the next 15 years.

As operational building energy efficiency increases, the proportion of the total emissions associated with the extraction, manufacturing and transportation of construction materials constitutes a larger share of a project's carbon footprint. When buildings are net zero energy or, better yet, achieve net zero operational carbon, the embodied carbon is the entirety of the carbon footprint of the project. It is estimated that embodied emissions will account for half of all building related emissions for new construction projects between 2020 and 2050, as most embodied emissions occur upfront, rather than distributed over the lifespan of a project. Reducing embodied carbon is therefore key in order to avoid surpassing climate tipping points in the coming decades.

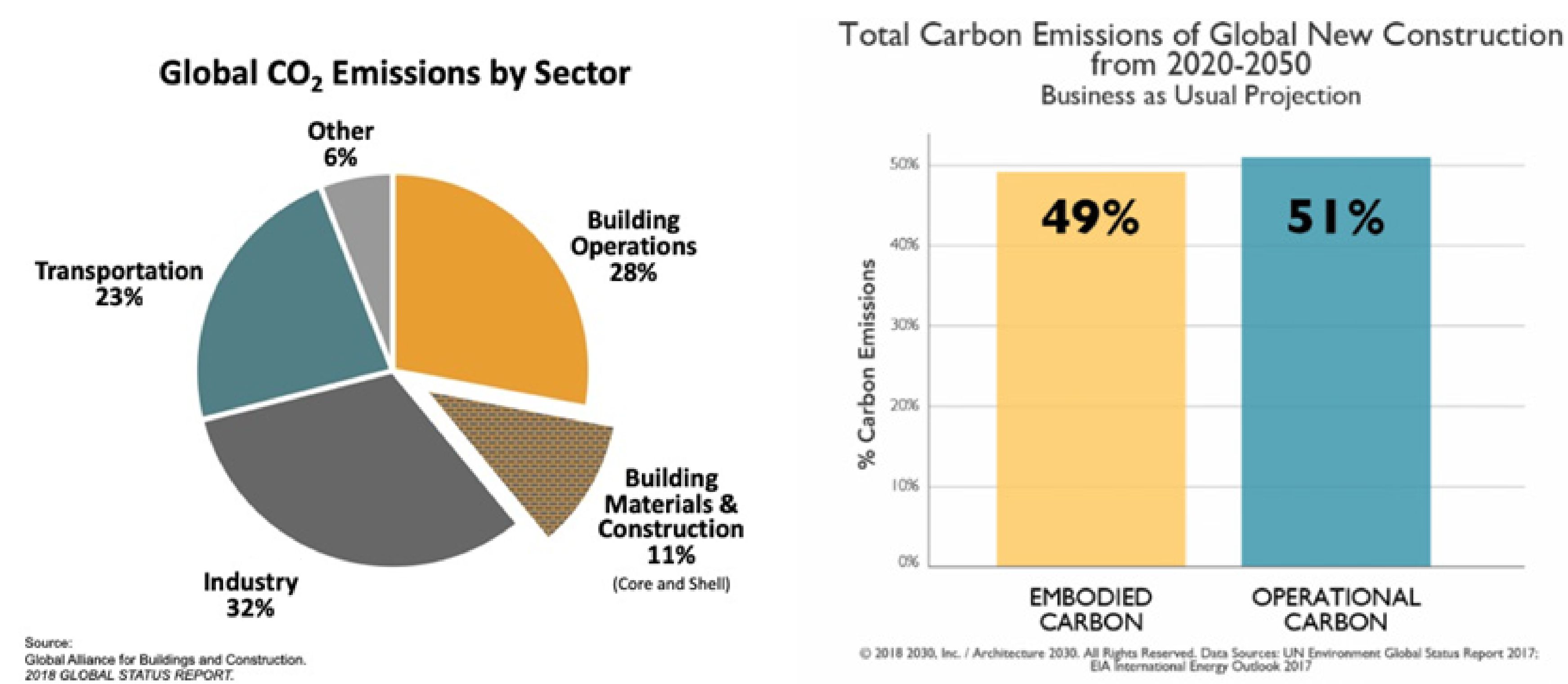
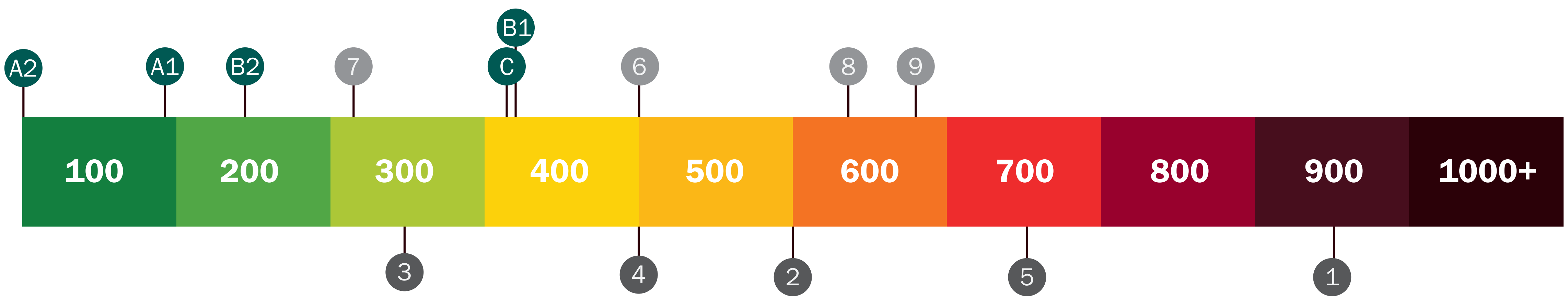


FIGURE 2: GLOBAL CARBON DIOXIDE EMISSIONS BY SECTOR AND CARBON EMISSIONS OF NEW CONSTRUCTION PROJECTS



Industry Targets
1. LETI Average Building 2020 - 950 kgCO2e/m2
2. LETI Design Target 2020 – 600 kgCO2e/m2
3. LETI Design Target 2030 – 350 kgCO2e/m2
4. ILFI Zero Carbon – 500 kgCO2e/m2
5. RIBA Built Target 2030 – 750 kgCO2e/m2

Reference Projects
A1. UBC (Canada) First Nations Longhouse – 192 kgCO2e/m2 (w/o sequestration)
A2. UBC (Canada) First Nations Longhouse – 44 kgCO2e/m2 (w/ sequestration)
B1. UBC (Canada) Campus Energy Centre – 411 kgCO2e/m2 (w/o sequestration)
B2. UBC (Canada) Campus Energy Centre – 265 kgCO2e/m2 (w/ sequestration)
C. UBC (Canada) Bioenergy Research and Demonstration Facility – 410 kgCO2e/m2

A10 Project Averages (Industry-Standard Baselines, By Structure)
6. A10 Mass Timber – 500 kgCO2e/m2 (w/o sequestration)
7. A10 Mass Timber – 315 kgCO2e/m2 (w/ sequestration)
8. A10 Concrete Building – 640 kgCO2e/m2
9. A10 Steel Building – 675 kgCO2e/m2

FIGURE 3. CARBON INTENSITY TARGETS & BENCHMARKS

Industry Benchmarks

To understand how Stanford's current buildings perform relative to other buildings, Atelier Ten collected a list of industry benchmarks and reference projects. Embodied carbon intensity was the metric used for comparability, with the units of global warming potential (GWP, expressed in kilograms of carbon dioxide equivalent emissions) per square meter. These benchmarks were generally separated in three groups: industry targets, public reference projects, and averages from Atelier Ten's internal LCA database.

Industry Targets

Internationally recognized institutions and organizations have proposed different carbon intensity targets:

1. **LETI Average Building 2020 (950 kgCO2e/m2):** The carbon intensity target the London Energy Transformation Initiative (LETI) considers to be "average" for commercial buildings. It is important to note that LETI looks only at stages A1-A5, but includes MEP and refrigerants which is not currently standard in the United States.
2. **LETI Design Target 2020 (600 kgCO2e/m2):** The carbon intensity target LETI identified as "good" for buildings designed in 2020. It is important to note that LETI looks only at stages A1-A5, but includes MEP and refrigerants which is not currently standard in the United States.
3. **LETI Design Target 2030 (350 kgCO2e/m2):** The carbon intensity target LETI identified as "good" for buildings designed in 2030. It is important to note that LETI looks only at stages A1-A5, but includes MEP and refrigerants which is not currently standard in the United States.
4. **ILFI Zero Carbon (500 kgCO2e/m2):** The carbon intensity target set by the International Living Future Institute (ILFI) in order to be eligible for the Zero Carbon Certification. It is important to note that ILFI looks only at stages A1-A5, and

excludes refrigerants and MEP equipment.

5. RIBA Built Target 2030 (750 kgCO2e/m2): The carbon intensity target the Royal Institute of British Architects (RIBA) identified as "good" for buildings completed in 2030. RIBA includes full life cycle (A1-C4) emissions, as well as MEP and refrigerant impacts.

Reference Projects

Atelier Ten searched for publicly available life cycle assessments, in particular for university or Bay Area projects. Unfortunately, there is limited public data with the exception of the University of British Columbia, which has published three LCAs. The comparison extended to similar projects with publicly available information:

A. UBC First Nations Longhouse (192 kgCO2e/m2 before sequestration, **44 kgCO2e/m2** after sequestration): A single-story, 22,000 square foot heavy timber building, shaped like a typical Musqueam-style longhouse. The Longhouse is part of the First Nations House of Learning, and houses programs for indigenous faculty and students, as well as serving as a community center for First Nations, Metis, and Inuit faculty, students, and staff.

B. UBC Bioenergy Research and Demonstration Facility (BRDF) (411 kgCO2e/m2 before sequestration, **265 kgCO2e/m2** after sequestration): A mass timber energy generation facility that processes wood waste as biomass to generate thermal energy for the academic campus' district energy system. It also supports academic research on biomass energy. The 21,000 square foot building that houses the plant is a simple rectangular industrial-style shed. A clear span, high-head section houses the energy generation system, and a mezzanine area includes offices, labs, and a public viewing space.

C. UBC Campus Energy Centre (CEC) (410 kgCO2e/m2): A 20,000 square foot hot water boiler facility utilizing cross laminated timber (CLT) and serving as the primary energy source for the academic campus' district energy system. The CEC, like the BRDF, supports education and learning through tours, interactive signage, and displays.

These three UBC projects are fairly low in embodied carbon intensity. These projects made conscious efforts to reduce embodied carbon (primarily through the use of mass timber) and do not represent what is considered industry average.

Atelier Ten Project Averages

Atelier Ten has completed life cycle assessments for over 100 projects and maintains an internal database of LCA results. As a point of reference for what is considered industry-standard (baseline), Atelier Ten has extracted typical values for a mass timber, concrete, and steel framed building.

All values below cover full life cycle stages (A1-C4) and include substructure, structure, enclosure, and interiors scopes.

6 and 7. Atelier Ten Average Mass Timber Baseline (500 kgCO2e/m2 before sequestration, **315 kgCO2e/m2** after sequestration): The average carbon intensity value for industry-standard (baseline) mass timber projects Atelier Ten has worked on, both before and after accounting for biogenic carbon sequestration.

8. Atelier Ten Average Concrete Baseline (640 kgCO2e/m2): The average carbon intensity value for industry-standard (baseline) reinforced concrete projects Atelier Ten has worked on.

9. Atelier Ten Average Steel Baseline (675 kgCO2e/m2): The average carbon intensity value for industry-standard (baseline) steel-framed projects Atelier Ten has worked on.

FINDINGS

Although carbon intensities are reported as a standard metric in the industry, the comparison of intensities may not be apples to apples because of the differing stages and scopes included in each of them. A closer review of these targets is always needed. Full life cycle carbon (A1-C4) is general seen as standard for US projects, but some benchmarks limit reporting to upfront carbon (A1-A5) only for better comparability given the uncertainties with B and C stages.

The industry benchmarks identified below span quite a range: from a high of 950 kgCO2e/m2 to a low of 44 kgCO2e/m2. Some benchmarks are intended to serve as baselines, while others serve as targets or optimized scenarios.

Consistent embodied carbon reporting is currently lacking in the industry. The Carbon Leadership Forum (CLF) attempted to create a database with results from independent projects in 2017, but was hampered by inconsistent reporting from individual project teams which often omitted scopes or phases, leading to incomplete reporting data. The CLF is currently in the pilot phase of its Benchmark v2 Study which aims to correct these inconsistencies. The results of the v2 study are expected to be released September 2022.

Information about all stages and scopes while rapidly evolving, is not reliably available in the industry. Requirements for new projects therefore should be split into reduction & tracking requirements.

Atelier Ten recommends including all stages and an expanded scope definition of embodied carbon for Stanford University's new construction projects.

	Carbon Intensity Benchmark Comparisons				Stages Included														Scopes Included			
		Name	Carbon Intensity		A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	Core & Shell	Interiors	MEP	Refrigerants
INDUSTRY	1	LETI Average Building	950	kgCO2e/m2	Y	Y	Y	Y	Y	N	N	N	N	N	N	N	N	N	INCLUDED	INCLUDED	INCLUDED	INCLUDED
	2	LETI 2020 Design Target	600	kgCO2e/m2	Y	Y	Y	Y	Y	N	N	N	N	N	N	N	N	N	INCLUDED	INCLUDED	INCLUDED	INCLUDED
	3	LETI 2030 Design Target	350	kgCO2e/m2	Y	Y	Y	Y	Y	N	N	N	N	N	N	N	N	N	INCLUDED	INCLUDED	INCLUDED	INCLUDED
	4	RIBA 2030 Built Target	750	kgCO2e/m2	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	INCLUDED	INCLUDED	INCLUDED	INCLUDED
	5	ILFI Zero Carbon	500	kgCO2e/m2	Y	Y	Y	Y	Y	N	N	N	N	N	N	N	N	N	INCLUDED	INCLUDED	EXCLUDED	EXCLUDED
REFERENCE PROJECTS	A1	UBC (Canada) First Nation's Longhouse (w/o sequestration)	192	kgCO2e/m2	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	INCLUDED	INCLUDED	EXCLUDED	EXCLUDED
	A2	UBC (Canada) First Nation's Longhouse (w/ sequestration)	44	kgCO2e/m2	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	INCLUDED	INCLUDED	EXCLUDED	EXCLUDED
	B1	UBC (Canada) Campus Energy Centre (w/o sequestration)	411	kgCO2e/m2	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	INCLUDED	INCLUDED	EXCLUDED	EXCLUDED
	B2	UBC (Canada) Campus Energy Centre (w/ sequestration)	265	kgCO2e/m2	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	INCLUDED	INCLUDED	EXCLUDED	EXCLUDED
	C	UBC (Canada) BioEnergy Facility	410	kgCO2e/m2	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	INCLUDED	INCLUDED	EXCLUDED	EXCLUDED
	6	A10 Average Mass Timber (w/o sequestration)	500	kgCO2e/m2	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	INCLUDED	INCLUDED	EXCLUDED	EXCLUDED
	7	A10 Average Mass Timber (w/ sequestration)	315	kgCO2e/m2	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	INCLUDED	INCLUDED	EXCLUDED	EXCLUDED
	8	A10 Average Concrete Project	640	kgCO2e/m2	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	INCLUDED	INCLUDED	EXCLUDED	EXCLUDED
	9	A10 Average Steel Project	675	kgCO2e/m2	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	INCLUDED	INCLUDED	EXCLUDED	EXCLUDED

FIGURE 4. CARBON INTENSITY PER STAGES & SCOPES INCLUDED

Life Cycle Analysis

Introduction

Atelier Ten has been engaged to develop and deliver a set of design guidelines that will help Stanford University design future building developments with lower embodied carbon. Towards this goal, Atelier Ten has analyzed three recently designed & built buildings, as representative buildings on campus to establish a baseline.

- **RESEARCH LAB - Biomedical Innovations (BMI) Building:** a 4-story, 225,000-square-foot steel-framed laboratory building. It is shared by researchers from across Stanford Medicine, and accommodates nearly 1,000 faculty, staff, and students.
- **WOOD FRAMED HOUSING - Lagunita Court:** a 3-story residential wood-framed building that accommodates approximately 218 students. It also includes a library and gathering spaces at the main entrance, lounges with attached kitchenettes, outdoor gathering spaces, art/project spaces, seminar rooms, and multimedia and music rooms.
- **ACADEMIC BUILDING - Bridge Data Science & Computation Complex:** a 6-story steel-framed building with a flexible framework of permanent offices, rotating research team spaces, and collaboration areas designed to adapt and evolve.

The available documents and drawings for each project have been used to conduct a whole building life cycle assessments (WBLCA). Those results were then analyzed to pinpoint potential material and design optimizations that could be applied campus wide.

Methodology

Atelier Ten conducted a whole building life cycle assessments (WBLCA) for BMI, Bridge, and Lagunita. A baseline scenario was created first based on the final cost estimates for each project. Each building was then run through three sets of material optimization scenarios aimed at reducing the highest sources of carbon.

In all cases, the baseline and optimized buildings are designed with the same gross floor area, shape and function and achieve the same energy efficiency and thermal performance. The WBLCA assessing global warming potential (GWP) follows LCA guidelines outlined in EN 15978.

System Boundary and Scope

The system boundary of this LCA is a cradle-to-grave (life cycle stages A1-A5, B1-B5, and C1-C4) assessment of the material effects of primary building elements for the project. The operational carbon was not considered as part of this LCA. Following the LCA methodology prescribed by EN 15978, the Carbon Leadership Forum and ASTM E2921, the building service life is set at 75 years.

The scope of primary building elements included in the assessment are structure (including both sub- and super-structure), enclosure, and permanently installed interior partitions and finishes. The physical scope of the LCA excludes furnishings, fittings, mechanical, electrical, and plumbing (MEP) systems, refrigerant impacts, landscape, as well as site and infrastructure works. These excluded scopes are reported separately under the "Expanding Scope 3" chapter.

Material Quantities & Properties

Material quantities were collected from the following documents:

- Biomedical Innovations (BMI) Building: BMI Building and Site Drawing's Vol 1A - 2017.12.08 & Stanford BMI Uniformat Estimate
- Lagunita Court: Lagunita Architectural RECORD SET 10-17-16 & 100 DD Lagunita - Estimate Detail 7.22.14 McCarthy
- Bridge Data Science & Computation Complex: Stanford Bridge - LCA Results-LMN Bridge Building.xlsx & SUBB_50% DD_Drawings

Material properties were assigned based on the available documentation and preliminary assumptions. In order to reflect business as usual, industry standard Environmental Product Declarations (EPDs) were used in the baseline and only changed to product specific EPDs where the specific product has been confirmed to be used in the project. When no industry standard EPD exists for a certain material, a product specific EPD intended to represent the average conditions was used. Detailed analysis inputs and assumptions are included in Appendix B.

Tools

The life cycle assessment was completed using OneClick LCA, but additional tools were used to more accurately represent certain aspects of the assessment. Specifically, the Pathfinder tool was used to estimate the embodied carbon of the landscape scope reported in the "Expanded Scope 3" chapter.

The Embodied Carbon in Construction Calculator (EC3) database was used to identify material optimization thresholds for steel and flooring. The EC3 database contains thousands of EPDs across various material categories, and reports what are considered conservative, achievable, and aggressive products in each category.

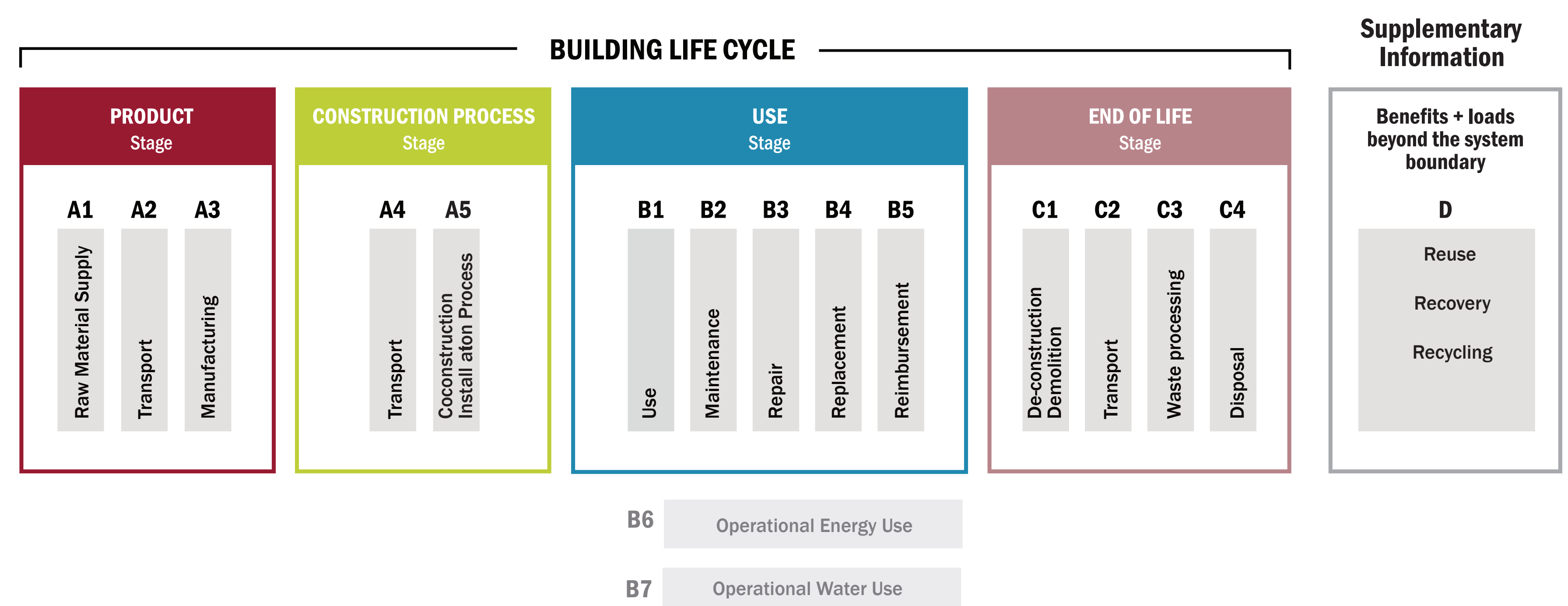


FIGURE 5. LIFE CYCLE STAGES & MODULES

Carbon Sequestration

Timber sequesters carbon prior to conversion into a building product, and that carbon is then stored within the structure of mass timber buildings. Accurately accounting for biogenic carbon and carbon storage within LCA is inherently challenging for numerous reasons. Current LCA guidelines rely on national data to represent forest management and harvest, which does not represent the wide range of practices in use today. Furthermore, the LCA industry currently applies the carbon neutrality assumption, which states that if wood is from sustainably managed forests, the emissions associated with burning biomass during the manufacturing process are addressed within the natural carbon cycle of the forest, and so do not need to be included in the GWP result of the LCA.

As there are acknowledged limitations to calculating sequestration, the potential benefit is broken out as a distinct part of this analysis, and accounts for end-of-life emissions. End of life considerations are critically important when dealing with sequestration in wood products. In line with the product category rule (PCR) guidance for structural wood, it is assumed in this LCA that 100% of wood will be sent to the landfill at the end of the project's lifespan. As wood decomposes in the landfill, it releases CO2 as well as methane (which has 25 times the global warming impact as CO2). However, this decomposition happens quite slowly, and many landfills in North America include landfill gas capture which prevents emissions from entering the atmosphere. After 100 years in a landfill, EPA WARM reduction modeling suggests only 16% of the initial sequestration credit has been lost, making land filling not a bad end-of-life option, unlike combustion which leads to an immediate release of 100% of the sequestered carbon. Sequestration values from OneClick are post-processed using the EPA Waste Reduction Model (WARM) to account for carbon dioxide and methane emissions that occur once when wood is disposed of in a landfill. All results clearly indicate whether they include sequestration or not to ensure transparency. Broadly speaking, it only makes sense to include sequestration as an offset to emissions if forests are being managed sustainably.

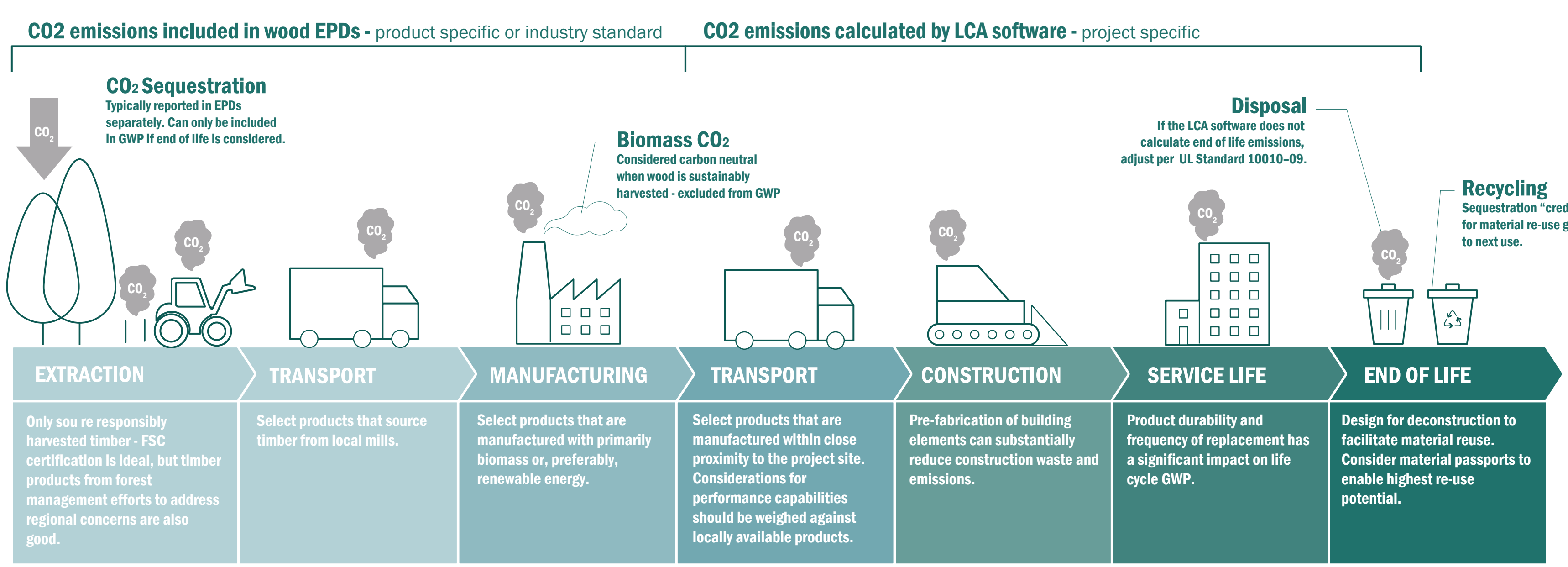


FIGURE 6. CARBON EMISSIONS THROUGH A PRODUCT'S LIFE CYCLE

Analysis and Results

The intent of this analysis was to determine where Stanford projects stand in terms of embodied carbon performance. For the three buildings selected for this analysis, an estimate of their as-built embodied carbon characterization was developed to understand the magnitude and type of carbon emission reduction these projects were able to achieve. The graphs to the right show the embodied carbon characterization of the three selected projects.

As-Built / Planned Embodied Carbon Characterization Estimates

Atelier Ten established a characterization for embodied carbon using as-built / planned materials following the Life Cycle Carbon LCA standards and OneClick WBLCA software. The analysis includes all primary foundation, structure, enclosure, and interior elements.

The characterization graphs to the right show that structural steel and concrete are consistent embodied carbon drivers in all three buildings. In BMI, steel represents 45% of total GWP, and concrete represents 25%. In Bridge, steel represents 39%, and concrete represents 36%. In Lagunita, steel (9%) is much less prominent because of the wood framing. Wood itself is a low-carbon material and therefore does not dominate the embodied carbon characterization either (5%). Concrete remains a prominent source of carbon in Lagunita (36%). Flooring is also a significant driver in Lagunita (21%) due to the large amount of carpet and frequent replacements over a 75 year analysis period. Flooring is also significant in BMI (9%) and Bridge (3%).

The pie charts below show the breakdown in embodied carbon by life cycle stage. Upfront embodied carbon emissions, which are emissions that occur prior to building occupancy (life cycle stages A1-A5), account for the majority of lifetime emissions, as illustrated in Figure 7b. This underlines the importance of building design and product selection, as most of a project's embodied carbon emissions are decided before the building is occupied. The B1-B5 Use Stage also represents a significant source of emissions, particularly in B2, due to the frequent replacement of interiors materials such as carpet.

Based on the embodied carbon drivers of the buildings identified above, Atelier Ten tested two sets of optimizations to identify opportunities for

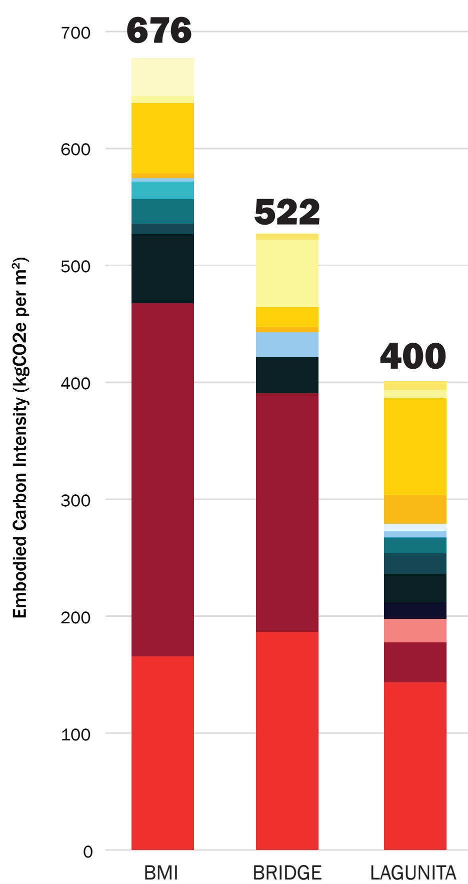


FIGURE 7A. PROJECTS' EMBODIED CARBON BY BUILDING ELEMENT, AS BUILT / PLANNED ESTIMATES

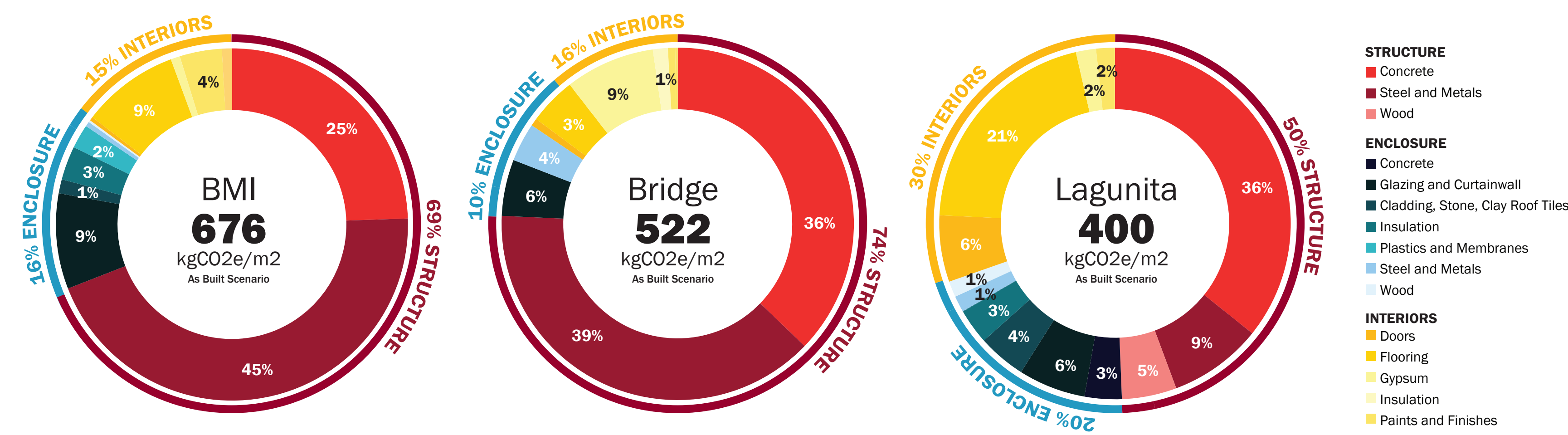


FIGURE 7B. PROJECTS' EMBODIED CARBON CHARACTERIZATION BY BUILDING ELEMENT, AS BUILT / PLANNED ESTIMATES

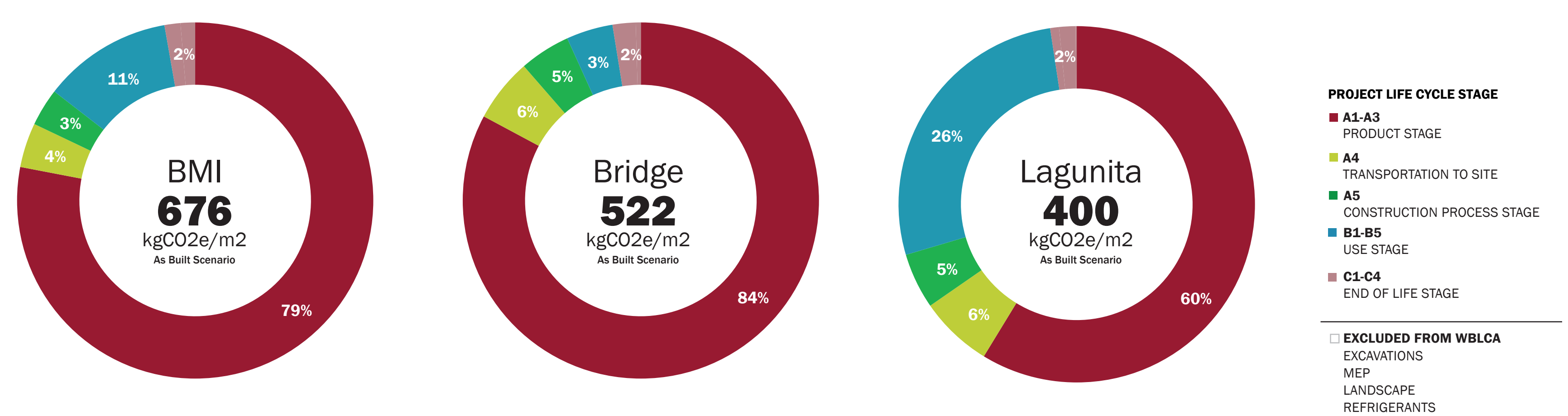


FIGURE 7C. PROJECTS' EMBODIED CARBON CHARACTERIZATION BY LIFE CYCLE STAGE, AS BUILT / PLANNED ESTIMATES further reduction.

1. Material Optimizations - To estimate how low new projects could go with low embodied carbon material choices.
2. Design Optimizations - To estimate the impact of rethinking fundamental design decisions.

Material Optimizations

As demonstrated in the baseline characterization graphs, concrete, steel, and flooring are significant embodied carbon drivers in all three buildings. To test the reduction potential in each building, a set of four optimization scenarios were run:

1. Baseline (Industry-Average)

This scenario represents what is considered as US wide average level of embodied carbon reduction. It models all materials based on national, industry-average EPDs and life cycle inventory inputs. These EPDs are often published by industry groups and reflect what is considered typical for that material in North America.

This level of optimization is predicted to align with BMI and Lagunita based on when the projects were built.

2. Bay Area Best Practice

This scenario represents what are considered leading edge practices in the SF Bay Area. This scenario represents a better performance of embodied carbon compared to national average. It models carbon optimizations to concrete, steel, and flooring based on what can commonly be achieved by projects in the Bay Area with little added effort or cost. For steel and flooring, this aligns with the Carbon Leadership Forum's "Conservative" scenario. The conservative scenario represents the upper 80th percentile of EPDs in the Embodied Carbon in Construction Calculator (EC3) database for North America. That means 80% of EPDs in the database have a carbon intensity below the conservative threshold.

For concrete, rather than use the CLF "Conservative" scenario, a 20% reduction in GWP intensity from the NRMCA Regional Benchmark for the Pacific Southwest was modeled. The decision to use GWP reduction percentage as opposed to the CLF benchmarks was made because of the wide availability of low-GWP concrete in the Bay Area.

This level of optimization is predicted to align with the Bridge project which is currently under construction, and has incorporated some best practice requirements into the specifications.

3. Achievable

This scenario represents level of embodied carbon reduction that Atelier Ten has found achievable when embodied carbon is made a priority on projects. It models the CLF "Achievable" scenario for steel and flooring, which represents the upper 20th percentile of EPDs in EC3 for a given product category. This tier is appropriate for projects making a conscious effort to reduce embodied carbon while still leaving some flexibility in product selection.

For concrete, a 30% reduction in GWP intensity from the NRMCA Regional Benchmark for the Pacific Southwest was modeled for the "Achievable" scenario. This target can be met through further mix design optimization, including increased cement replacement, aggregate selection, and inclusion of CarbonCure.

4. Aggressive

This scenario represents a high-ambition of embodied carbon reduction, that are possible with strong owner directive This represents a leading edge performance of projects. This scenario models the CLF "Low" scenario for steel and flooring, which represents the single best product in EC3 for a given product category. This tier is appropriate for projects targeting aggressive embodied carbon reductions, and limits product selection.

For concrete, the aggressive scenario assumes a 50% reduction from the NRMCA Regional Benchmark mixes. This level of reduction involves even higher amounts of cement replacement (as high as 70%) and altering mix ingredients and curing processes, such as with Type 1L cement, Blue Planet aggregate, or Solidia Concrete.

Additional details on what drives embodied carbon in these three material categories are provided in the Material Optimization Scenarios section later this report.

Material	Baseline (Industry-Average)	Bay Area Best Practice	Achievable	Aggressive
Concrete	Industry Average NRMCA 2020 Regional Benchmark	20% Better Than Baseline Cement Replacement	30% Better Than Baseline Higher Cement Replacement, High Quality Aggregates, CarbonCure	50% Better Than Baseline Highest Cement Replacement, Type 1L Cement, Specialty Suppliers
Steel	Industry Average Industry-Wide EPDs	CLF Conservative 80th Percentile of Available EPDs	CLF Achievable 20th Percentile of Available EPDs	CLF Minimum Lowest EPD Available
Flooring	Industry Average CLF 2021 Baseline	CLF Conservative 80th Percentile of Available EPDs	CLF Achievable 20th Percentile of Available EPDs	CLF Minimum Lowest EPD Available

Carbon Intensity Before and After Carbon Optimization Measures
11038 Stanford Embodied Carbon

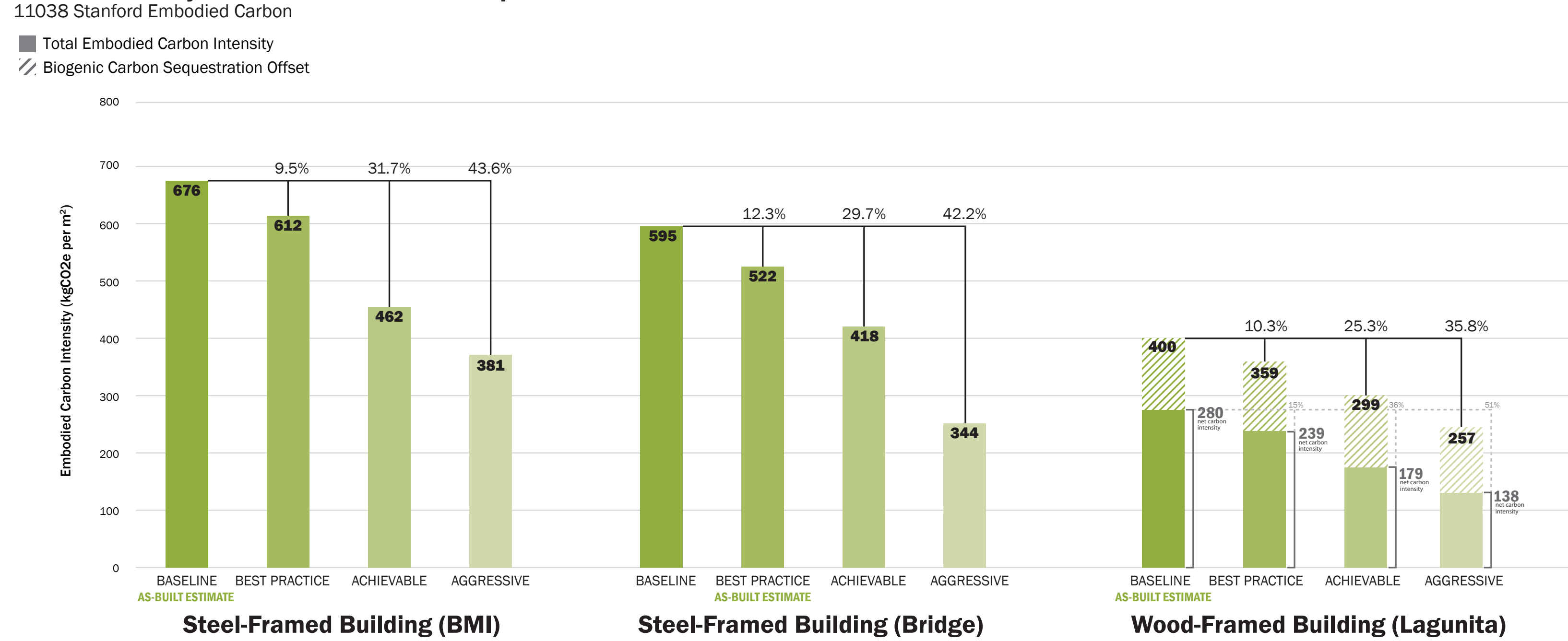


FIGURE 8. EMBODIED CARBON REDUCTIONS BY APPROACH. THE ESTIMATED AS-BUILT CONDITION IS NOTED IN GREEN.

Design Optimizations

The three cases above demonstrate the embodied carbon reduction potential associated with material optimizations. Material optimizations can be implemented at any point before procurement and offer opportunities to reduce embodied carbon while keeping the design and materiality the same. Design optimizations, on the other hand, require early coordination and fundamentally change the way the building looks.

Following are two design optimizations that are expected to be highly effective in reducing emboided carbon emissions by rethinking how new buildings are constructed / renovated at Stanford University.

1. Mass Timber as an alternative to steel structure
2. Building Reuse as an alternative to new construction

The bar charts to the right show the effectiveness of these two optimizations.

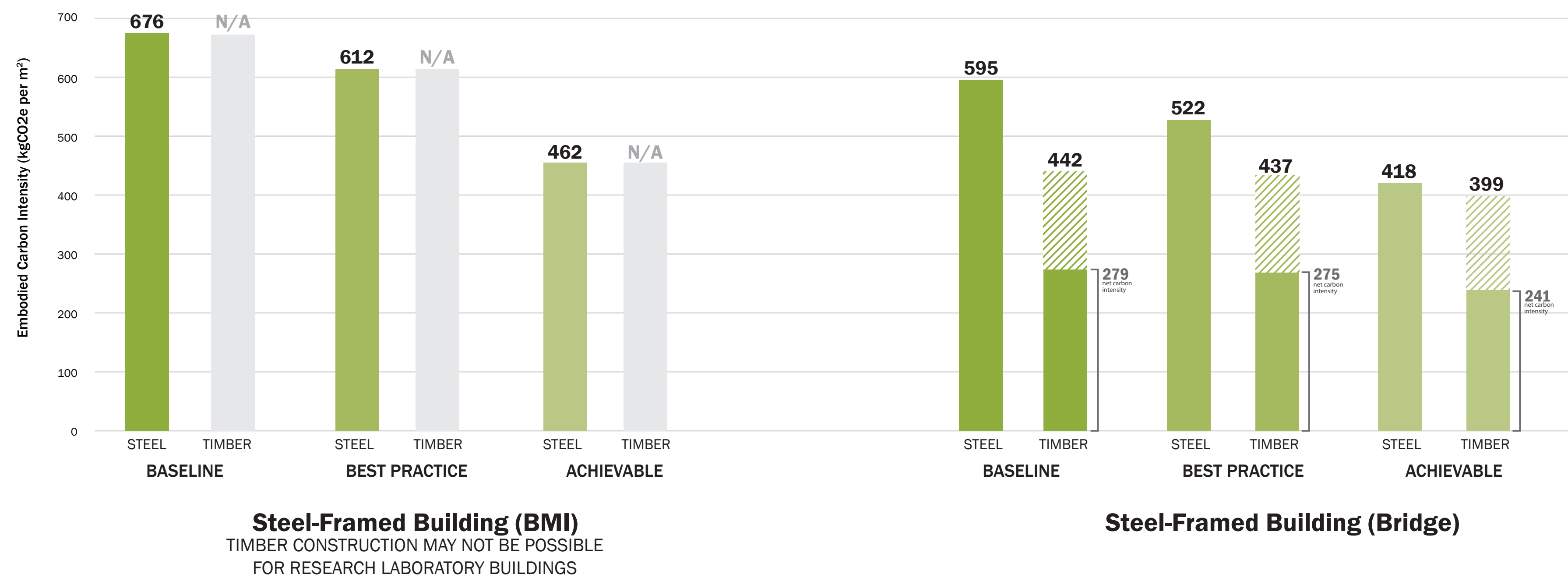


FIGURE 9A. EMBODIED CARBON REDUCTIONS ACHIEVED THROUGH A MASS TIMBER STRUCTURE

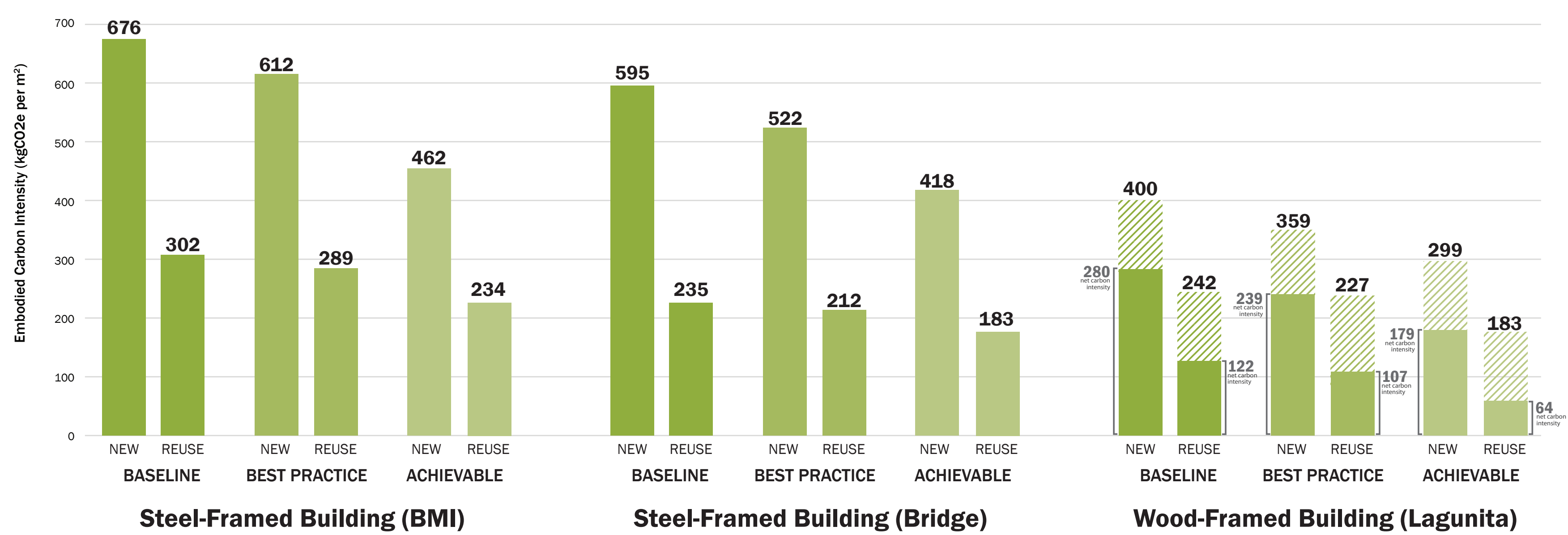


FIGURE 9B. EMBODIED CARBON REDUCTIONS ACHIEVED THROUGH BUILDING REUSE

Summary of Findings

After including optimization scenarios for concrete, steel, and flooring, we see significant reductions are possible for all three buildings.

On average, the Bay Area Best Practice scenario offers a 9%-12% reduction from baseline. The Achievable scenario offsets a 25-32% reduction from baseline, and the Aggressive scenario offers a 36%-44% reduction from baseline.

Lagunita stands out as the least carbon intensive design case because timber is a primary structural component as opposed to steel. Timber is not only a less-carbon intensive product to manufacture, but also holds sequestered carbon which further offsets the building's carbon footprint. In line with industry guidance, results are shown with and without sequestration included. In the Design Optimizations section later in this report, a hypothetical mass timber scenario is run for BMI and Bridge for comparison.

In the "Achievable" scenario, all three buildings are below 500 kgCO2e/m2, putting BMI and Bridge on par with a typical mass timber building (before sequestration). In the "Aggressive" scenario, all three cases are below 400, with Lagunita as low as 139 kgCO2e/m2 after accounting for sequestration.

For Design Optimizations, the results quantify the impact of making currently atypical design decisions at the Owner level that can reduce embodied carbon emissions of projects by a higher margin than any Material Optimizations can. Mass timber buildings with timber sequestration can reduce the embodied carbon of buildings by 50-60%. This is more than the "Aggressive" scenario under Material Optimizations, thereby making it the single most effective measure to reduce embodied carbon.

Reuse of existing building structures in lieu of new construction is an intuitive embodied carbon saving measure. The analysis captures the impact of a "realistic" reuse of existing buildings - saving the structure, but replacing enclosure and interiors for a meaningful refresh of the existing building. The reuse scenario reduces embodied carbon by about 50% across all three buildings.

Stanford vs. Industry Benchmarks

After running the BMI, Bridge, and Lagunita through the four material optimization scenarios (baseline, best practice, achievable, and aggressive), the carbon intensities of each project were plotted against the industry benchmarks established earlier in this report.

It is important to note the variation in included scopes and stages when comparing against industry baselines. The Industry Benchmarks Scope graphic in the chapter above outlines what is included in each scenario.

The findings show that all three baseline scenarios are better than or equal to Atelier Ten's average baseline projects by structural system. Additionally, all three projects have a pathway to achieve a carbon intensity of 500 kgCO2e/m2 or less when aligned with the CLF "Achievable" level, and 400 kgCO2e/m2 or less when aligned with the "Aggressive" level. These levels meet or exceed the Atelier Ten Average Baseline Mass Timber threshold, as well as 4 out of 5 industry thresholds.

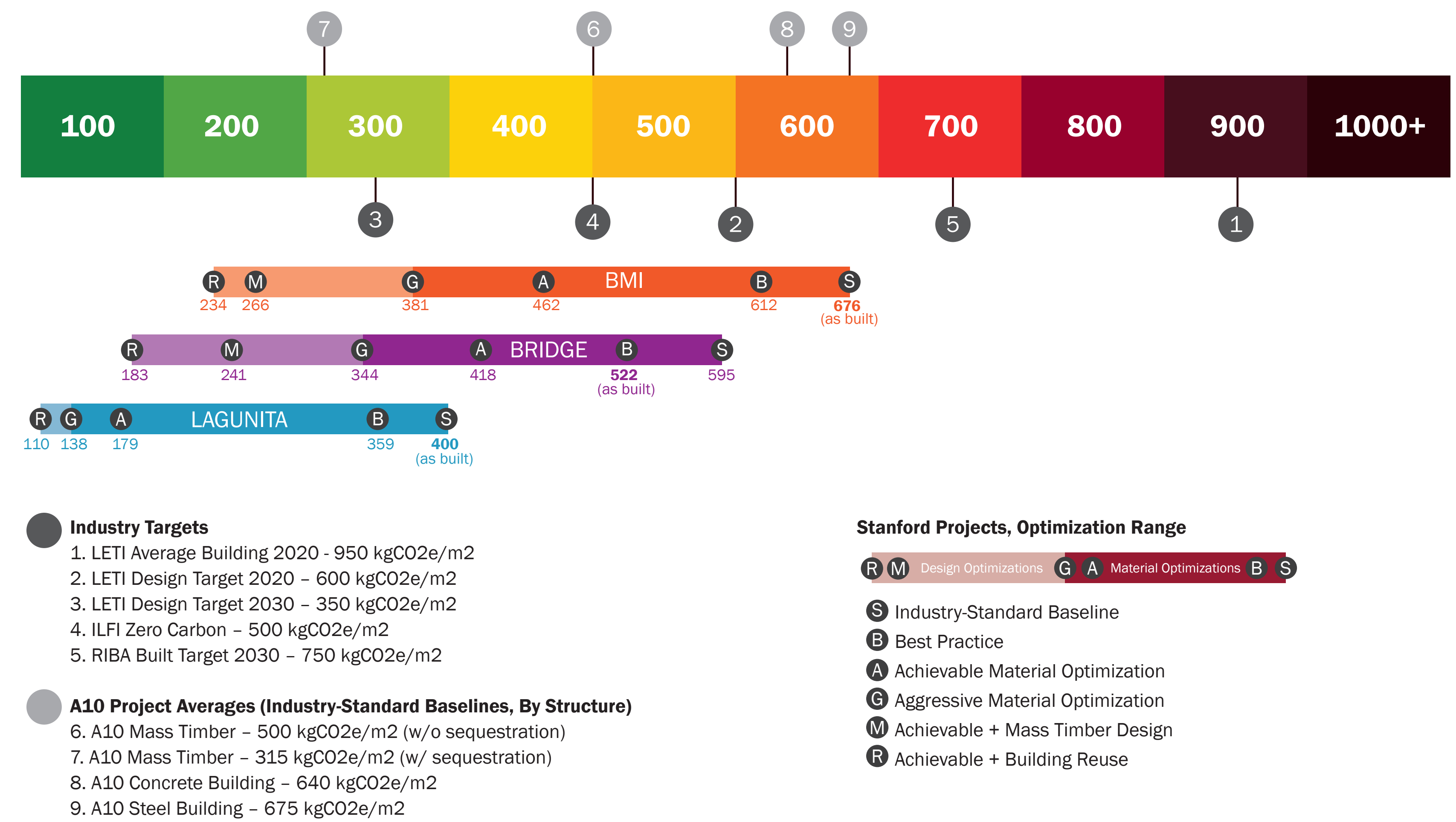


FIGURE 10. CARBON INTENSITY TARGETS, BENCHMARKS & STANFORD PERFORMANCE

	LEED	ILFI ZERO CARBON	LETI	STANFORD
Building Element				
Substructure	INCLUDED	INCLUDED	INCLUDED	INCLUDED
Superstructure	INCLUDED	INCLUDED	INCLUDED	INCLUDED
Enclosure	INCLUDED	INCLUDED	INCLUDED	INCLUDED
Interiors	EXCLUDED	INCLUDED	INCLUDED	INCLUDED
Interior Furnishings	EXCLUDED	EXCLUDED	INCLUDED	ESTIMATED
MEP Systems	EXCLUDED	EXCLUDED	INCLUDED	ESTIMATED
Refrigerants	EXCLUDED	EXCLUDED	INCLUDED	ESTIMATED
Infrastructure	EXCLUDED	EXCLUDED	EXCLUDED	ESTIMATED
Landscape	EXCLUDED	EXCLUDED	EXCLUDED	ESTIMATED
Site Work / Excavation	EXCLUDED	EXCLUDED	EXCLUDED	ESTIMATED

FIGURE 11. INCLUSIONS ON VARYING LCA FRAMEWORKS

Expanded Scope 3

Properly defining scope and stage boundaries is critical to fully understand an organizations embodied carbon emissions. Industry benchmarks in circulation today are not consistent with both the scope of included elements, or included life cycle stages.

Elements Scope

While there has been significant industry advancement over the past few years around structure embodied carbon, other potentially significant scopes have gone largely unaccounted for. The majority of LCA software today can measure foundation, structure, enclosure, and (more recently) interiors embodied carbon. However, they often overlook or under-report carbon from interior furnishings, MEP systems, refrigerants, infrastructure, landscape, and site work and excavation.

European standards such as LETI and RIBA have established embodied carbon benchmarks that cover the traditional four scopes in addition to fixed furnishings, MEP systems, and refrigerants. Atelier Ten's experience on projects in the Bay Area suggests growing interest in understanding landscape and infrastructure emissions, especially in the context of campus-scale projects which include a lot of non-building projects.

Currently, there is not a centralized software capable of tracking this expanded list of scope elements together. In order to get an idea of the full Scope 3 impacts of Stanford buildings, Atelier Ten has aggregated estimates for the following sources and added them on top of the industry-standard (baseline) LCA results for BMI, Bridge, and Lagunita (structure, enclosure, and interiors).

Furnishings

Furnishings include fixtures such as casework or furniture which are typically excluded from the interiors scope. Furnishings have short life spans and are often replaced after 10 years, which adds up significantly over the course of a project lifespan. Workstations in particular are quite carbon intensity due to the large amounts of metal they contain. Using fixture carbon intensity data from an LMN study, the impact of workstations, chairs, and tables add up to 11% of the expanded Scope 3 emissions.

MEP Systems

Mechanical, electrical, and plumbing equipment contain large amounts of metal (duct work, pipes) which can contribute significantly to a project's embodied carbon. To estimate the impact for BMI, Bridge, and Lagunita, a life cycle assessment of mechanical, electrical, and plumbing report published by the University of Washington and available through the CLF was used to approximate values. The UW Report gives MEP embodied carbon intensity for buildings based on building size and performance (standard vs. high performance). Standard was used for this study as a proxy, but a detailed MEP LCA would require material quantities that could vary based on system selection.

Atelier Ten estimates that MEP embodied carbon may account for as much as 11% of the expanded Scope 3 carbon for the three buildings analyzed.

Given the limited data on MEP embodied carbon available, it is difficult to assign reduction targets but is worth tracking as part of a projects expanded Scope 3.

Refrigerants

Refrigerants are an often overlooked contributor to global warming. Mechanical equipment leaks refrigerant over the course of the system lifespan and at the end of life when a system is decommissioned. Atelier Ten estimates that, for a typical building with on site cooling, refrigerants may account for up to 11% of full lifecycle greenhouse gas emissions over a 75 year analysis period, based on industry-standard R134a refrigerant and typical HVAC systems. Discreet systems for lab or food service may contribute even more.

The main Stanford campus has a central energy facility that supplies most of the campus' cooling. Therefore, many Stanford buildings contain relatively little refrigeration equipment. Stanford already accounts for refrigerant charge and leakage in its greenhouse gas accounting for the central energy facility, so new building projects that will connect to the central energy facility for cooling do not need to include the refrigerant impact from that cooling in the building project's lifecycle. However, there will likely will be cases where new building projects will include refrigerant containing equipment on site.

Refrigeration equipment is designed for a particular refrigerant, meaning refrigerants can't be easily swapped for a lower impact alternative. For the life of the equipment, its owner commits to topping up refrigerant charge when needed; therefore, decisions made by design teams can lock Stanford in to purchasing high-GWP refrigerants for years to come. The California Air Resources Board approved legislation in 2020 restricting some of the highest-GWP refrigerants; however, while the new legislation does cover conditioning systems, it phases in over years and doesn't directly cover some building-scale equipment.

There are a number of low-GWP refrigerants being developed. In addition to selecting mechanical, food service, and laboratory equipment that uses low-GWP refrigerants, specifying equipment with low leakage rates, and recovering 100% of refrigerants at a system's end of life can reduce refrigerant greenhouse gas impacts.

Project teams should assess the use stage impacts of permanently installed equipment with more than 0.5 lbs of refrigerant (the threshold required by the LEED Enhanced Refrigerant Management credit), looking out for the following equipment types:

Space cooling equipment:
- VRF systems
- Split system or package air conditioners or heat pumps, such as for data or telecom rooms

Food service equipment:
- Blast chillers, shock freezers
- Ice dispensers
- Refrigerated storage rooms and built-in refrigerators

Laboratory equipment:
- Laboratory-grade refrigerators and freezers

For laboratory equipment such as lab grade refrigeration, the Energy Star Product Finder can be filtered for lower impact refrigerant types.

REFRIGERANT TYPE	CARBON EMISSIONS (mTCO2e/lb)
R1233ZD	1
R1234ZE	1
R1234YF	1
R134A	1430
R410A	2088

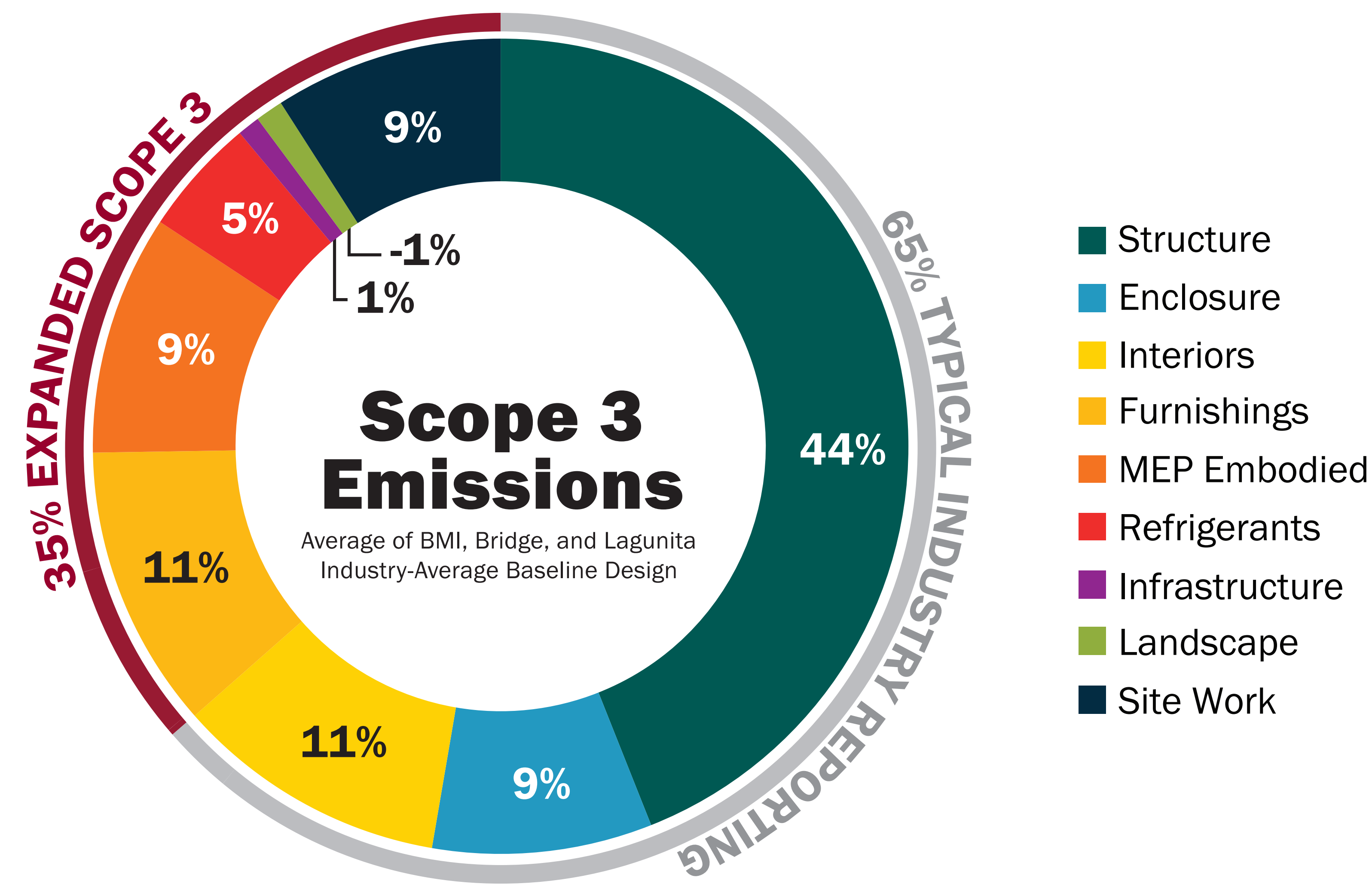


FIGURE 12. EXPANDED SCOPE 3 CARBON EMISSIONS - AVERAGE OF BMI, BRIDGE, AND LAGUNITA INDUSTRY-AVERAGE BASELINES

R452B	675
R454B	466
R466A	734
R448A	1274
R404A	3900
R513A	631
R514A	2
AMMONIA	0

GWP IMPACT BY REFRIGERANT TYPE

Infrastructure

Project infrastructure typically includes elements such as stormwater vaults, sewer and irrigation piping, parking lots, streets, curbs, and sidewalks.

Based on Atelier Ten's experience on other projects, it is estimated that site infrastructure would account for approximately 1% of Scope 3 emissions for BMI, Bridge, and Lagunita. This can vary project to project, but given that Stanford tends to consolidate parking in separate garages and low stormwater quantities, it is not a significant driver for the projects. Nevertheless, it is recommended that Stanford track infrastructure as an expanded Scope 3 element for both new construction projects as well as infrastructure-only projects (such as roadwork, parking garages, etc.).

Landscape

Landscape around new construction projects typically includes hardscape, furniture, and plants. Often times, landscape embodied carbon ends up being a negative value over a 75 year analysis period given the ongoing sequestration benefit provided by the plants. Woodier plants (trees, shrubs) offer more sequestration potential then delicate plants which often require more maintenance. Lawns, for example, emit more carbon than they sequester.

Atelier Ten estimated the carbon intensity for the BMI landscape using Pathfinder, a landscape embodied carbon calculator. The results show the landscape sequesters more carbon than it emits, offsetting approximately 1% of the overall Scope 3 emissions.

It is recommended that Stanford track landscape carbon on projects moving forward, and implement best practice design by optimizing hardscape (see concrete optimizations reported above) and selecting plant species which sequester more carbon.

Site Work (Excavation and Fill)

Site work and excavation are a potentially significant source of embodied carbon that is often ignored in whole building LCAs. While technically they should be captured in the A4 Transportation to Site / A5 Construction Installation and C1 Deconstruction / C2 Transportation Away from Site life cycle stages, the full extent is often under-reported.

LCA software such as OneClick report life cycle embodied carbon by taking EPDs (which capture A1-A3) and extrapolating out A4-C4 based on what is deemed "typical" for material types.

For example, when selecting a carpet product in OneClick, it will report the published EPD value for A1-A3, then tack on an A4 estimate based on the average distance between manufacturers and projects, and the typical transport vehicle. It will calculate A5 based on what it believes are typical emissions associated with installing that carpet. It will calculate the B stages by assuming a lifespan for that carpet (typically 15 years) and simulating the replacement multiple times over the 75-year analysis period. Lastly, it will estimate C stages based on the average distance between projects and landfills or recycling centers, using a typical transport vehicle, and finally the typical carpet waste processing emissions.

This method works well for early-stage estimation of life cycle emissions when specifics about transport vehicles and replacement frequency is unknown. However, it limits the A4, A5, C1, and C2 impacts to what it can extrapolate based on material inputs. It does not capture construction or demolition transportation and equipment emissions that are not material-tied, most significantly, earthwork. On projects with substantial amounts of below grade space (parking garages, basements), the A4/A5 and C1/C2 emissions can be significantly underrepresented by traditional LCA software.

Atelier Ten estimates that excavation and fill-related emissions could be as much as 9% in projects with below grade space based on similar projects that have tracked and reported construction emissions.

To accurately account for site work, excavation, fill, and associated transportation emissions, contractors must track equipment use and hauling-related emissions. Given the variability of site work from project to project, no reduction target is set, but it is recommended Stanford track it as part of the expanded Scope 3 emissions.

Stages Scope

Equally important to included elements is defining included stages. Various industry frameworks are currently not aligned in stage requirements. For example, LEED and RIBA require full life cycle (A1-C4) embodied carbon reporting, whereas ILFI and LETI only tackle upfront (A1-A5) carbon. The reasoning for the latter is because of the uncertainty introduced in the B and C stages and wanting to ensure more consistent comparability across projects. Best practice is to calculate full life cycle (A1-C4) impact and isolate A1-A5 for reporting where necessary.

Limitations of A4/A5 and C1/C2

As discussed under the Site Work / Excavation section above, most LCA software under-reports true A4/A5 and C1/C2 emissions because it only calculates material-tied impacts.

For consistency with industry reporting, it is recommended that Stanford track and report site work-related carbon separately from material-tied A4/A5 and C1/C2 results.

Results

Atelier Ten estimates that the "expanded" Scope 3 categories of furnishings, MEP, refrigerants, infrastructure, landscape, and site work may account for as much as 38% of Scope 3 building-related embodied carbon emissions at Stanford. In particular, furnishings are a major driver (11%), followed by MEP (11%) and site work (9%).

The results suggest that the typically-reported scopes of foundation, structure, enclosure, and interiors only represents about two-thirds of the full Scope 3 impact for projects.

RECOMMENDATION

- Report cradle-to-grave embodied carbon stages (A1-C4), with capability to break out upfront carbon (A1-A5) for comparison with all industry benchmarks
- Require LCAs and reduction target for foundation, structure, enclosure, interior scopes
- For consistency with industry reporting, it is recommended that Stanford track and report site work-related carbon separately from material-tied A4/A5 and C1/C2 results.
- Require tracking and reporting for everything else. Recommend best practices for each scope (low GWP refrigerants, minimize excavation, optimize hardscape, etc)

Recommendations

There are currently major gaps in the embodied carbon field, and Stanford has an opportunity to become a leader by committing to a combination of design best practices, reduction targets, tracking, and reporting.

Applicability

- Reduction targets and reporting required for all projects required Board of Trustees approval.

Best Practices

- Start with building reuse, which can cut embodied carbon emissions in half compared to new construction.
- If reuse not feasible, consider mass timber with sustainability sourced wood to cut emissions by up to 40%.
- After optimizing the design for low-embodied carbon, consider material optimizations.

Reduction Target

- Target a minimum 20% reduction from baseline design for A1-C4 core and shell and interiors scopes.

Methodology

- All high carbon impact products must have a product specific, third party verified EPD. For all products, where possible, request a product specific, third-party verified EPD.
- LCA scope should include foundations, structure, enclosure, and permanent interior finishes and include life cycle stages A1-C4 (cradle-to-grave).
- Approved tools: OneClick, Tally, EC3, and Pathfinder

Implementation

- Scoping/Concept: consider Best Practices and Design Optimization strategies
- SD: Identify likely carbon drivers, evaluate design alternatives, set reduction goals
- DD: LCA to establish baseline carbon characterization and test material optimization impacts
- CD: Update LCA
- CA: Update LCA with EPD data for actual procured materials.

Reporting

- Teams should track and report the expanded Scope 3 emissions for furnishings, MEP systems, refrigerants, infrastructure, landscape, and site work.
- A1-A5 emissions from as-built WBLCA reported in annual scope 3 emissions in the calendar year the project is completed.
- B1-C4 emissions reported in annual scope 3 emissions in the calendar year those activities occur.

Next steps:

- Develop Low Embodied Carbon Design Guidelines that provide a more detailed process for project teams to follow, define criteria for establishing project baseline, and methods for calculating A3 and A4 emissions specific to Stanford's campus.
- Develop methodology for estimating embodied carbon in smaller, non-BOT level projects.
- Study mass timber trade-offs and limitations.

Long Term Goals:

- Develop database of carbon intensity for different building types
- Establish carbon intensity goals for different building types, rather than % reductions from baseline.
- Life cycle analysis is still emerging within the design and construction industry. Stanford should revisit its targets in 5 years to make them a) more aggressive and b) reflect the data set of Stanford projects developed during the first 5 years.

Appendix A

Design Optimization Scenarios

Mass Timber Structure

Mass timber has ballooned as a sustainable alternative to steel or concrete structures in recent years. Mass timber take less energy to manufacture than concrete or steel, and when paired with sustainable forestry, sequesters significant amounts of carbon from the atmosphere.

Mass timber structures are typically lighter, which enables a 10-20% reduction in foundations, allowing projects to reduce the quantity of carbon-intensive concrete and rebar.

Modeling mass timber as a design alternative requires detailed design calculations from a structural engineer. For the purposes of this analysis, mass timber projects from Atelier Ten's internal database were analyzed to understand how an industry-standard mass timber project compares to an industry-standard steel project. On average, mass timber shows a 26% improvement over steel buildings before sequestration, and a 53% reduction after accounting for sequestration. When comparing optimized mass timber vs. optimized steel, the average reduction is 5% before sequestration, and 42% after sequestration.

Building Reuse

The single biggest way projects can reduce embodied carbon is to reuse existing structures. As demonstrated in the baseline characterization pie charts earlier in this report, foundations and superstructure are responsible for the majority of embodied carbon in a typical project. By reusing structures, all that embodied carbon can be avoided. It also avoids embodied carbon associated with demolition of an existing building, waste processing, and construction emissions associated with building new.

For the purposes of this analysis, the reuse scenario was modeled by assuming a full interior and enclosure replacement. A 20% allowance for structural repairs, additions, or improvements was included as well.

Enclosure replacement may not be necessary in every case, but is recommended in cases where there is poor thermal performance or daylight quality issues. An operational carbon vs. embodied carbon comparison should be completed when considering enclosure replacement. For organizations like Stanford which have 100% renewable energy, envelope replacement may not be necessary.

RECOMMENDATIONS

- Select materials that align with the CLF "Achievable" material targets. It is recommended that specific material carbon intensity limits be added to project specifications and incorporated into the bidding process.
- For concrete, it is recommended that project teams establish a minimum 30% reduction target from the NRMCA benchmark.
- This level of material optimization was sufficient to put BMI, Bridge, and Lagunita on par with Atelier Ten's average baseline mass timber project (500 kgCO2e/m2 without sequestration), which represents an ambitious, but achievable embodied carbon intensity for new construction projects today.
- Projects should explore opportunities to target "aggressive" material optimizations (best in class materials) where possible to remain cutting edge in reducing embodied carbon emissions in a rapidly evolving industry.
- Projects with significant concrete (all steel and concrete buildings) should look into partnering with low-carbon concrete companies such as Solidia and Blue Planet.
- Stanford should develop standard embodied carbon requirements around major materials such as concrete, steel, and flooring. Adding material carbon intensity language to project specifications and as part of the procurement process can lead to significant reductions.
- Evaluate opportunities for design optimizations such as mass timber, building reuse, or minimizing below grade spaces in early schematic design to achieve the largest reductions.

Appendix B

Material Optimization Scenarios

Baseline - Industry Average

This scenario models all materials based on national, industry-average EPDs and life cycle inventory inputs. These EPDs are often published by industry groups and reflect what is considered typical for that material.

For concrete, that assumption is the National Ready Mix Concrete Association's (NRMCA) 2020 Regional Benchmark report. The NRMCA report lists average global warming potential intensities for normal-weight and light-weight mixes at various strength classes based on what is typical for the region (in this case, the Pacific Southwest). In the Pacific Southwest, an average mix includes 12% cement replacement.

For rebar, the Construction Reinforcing Steel Institute (CRSI) industry average EPD is used. The EPD assumes rebar is 98% recycled content and is manufactured in an electric arc furnace.

For structural steel, the Metal Building Manufacturers Association (MBMA) industry wide EPD for primary structural steel frame components is used. The default assumption for recycled content is approximately 80%.

For carpet and resilient flooring, there is no industry-wide EPD available, so a product-specific EPD with the GWP intensity closest to the Carbon Leadership Forum (CLF) baseline was used.

Bay Area Best Practice

This scenario models carbon optimizations to concrete, steel, and flooring based on what can commonly be achieved by projects in the Bay Area with little added effort or cost. For steel and flooring, this aligns with the Carbon Leadership Forum's "Conservative" scenario. The conservative scenario represents the upper 80th percentile of EPDs in the Embodied Carbon in Construction Calculator (EC3) database for North America. That means 80% of EPDs in the database have a carbon intensity below the conservative threshold. The conservative value can be used as a proxy for best practice for projects in the Bay Area that do not have explicit embodied carbon reduction targets.

Using the Embodied Carbon in Construction Calculator (EC3), project teams can search directly for EPDs that meet the CLF "Conservative" target in a given material category.

For steel, key factors that influence GWP intensity are the recycled content of the steel, the furnace type (electric arc vs basic oxygen), and the fuel type. Electric arc furnaces are recommended because they can accommodate higher amounts of recycled content (up to 100%) and can run on renewable energy. For example, Nucor Steel's Seattle plant produces rebar in an electric arc furnace which operates on renewable hydroelectric power, achieving a 50% reduction from industry average rebar. When selecting steel suppliers, it is important to require product specific EPDs from steel mills and compare the GWP intensities to find the lowest-GWP option.

For carpet and resilient flooring, yarns and backing materials are the major contributors to embodied carbon, and compounded by the relatively short lifespan that leads to frequent replacement. Recycled polymers in both yarns and backings greatly reduce the impacts as compared to virgin petrochemically based materials used in typical carpets.

In addition to a high performing carpet tile, the backing is constructed of post-consumer carpet tiles, bio-based additives, and pre consumer recycled materials, which are net carbon negative.

For concrete, rather than use the CLF "Conservative" scenario, a 20% reduction in GWP intensity from the NRMCA Regional Benchmark for the Pacific Southwest was modeled. The decision to use GWP reduction percentage as opposed to the CLF benchmarks was made because of the wide availability of low-GWP concrete in the Bay Area. Based on Atelier Ten's Bay Area experience, the CLF benchmarks are much higher than what is considered best practice. A 20% reduction from the NRMCA benchmark is easily achieved through cement replacement.

CEMENT REPLACEMENT

Portland cement is the primary driver of embodied carbon in concrete mixes due to the energy-intensive manufacturing process (often powered by coal) and the direct release of CO2 as part of the calcination process. Reducing cement by replacing with supplementary cementitious materials (SCMs) is the easiest way to reduce GWP intensity of a concrete mix. Common SCMs include fly ash and slag, by products of carbon-intensive coal power plants and basic oxygen furnace steel production. Cleaner alternatives include glass pozzolans, silica fume, or rice husk ash, though availability is currently limited in the Bay Area.

It is important to factor in concrete cure times when looking at high-replacement concrete mixes. High-replacement mixes often cure slower which can conflict with project schedule requirements. To combat this, it is recommended that teams identify specific applications that can accommodate 56-day cure time and target high cement replacement there. For example, 50% cement replacement is often achievable in foundations where there is more schedule flexibility. In places where a standard 28-day cure time is needed (often slabs), 30% cement replacement is a more appropriate target. It is important to communicate carbon reduction targets with the structural engineer, contractor, and concrete supplier early in the project so a mix-by-mix strategic approach can be taken.

Achievable Optimization

This scenario models the CLF "Achievable" scenario for steel and flooring, which represents the upper 20th percentile of EPDs in EC3 for a given product category. This tier is appropriate for projects making a conscious effort to reduce embodied carbon while still leaving some flexibility in product selection.

For concrete, a 30% reduction in GWP intensity from the NRMCA Regional Benchmark for the Pacific Southwest was modeled for the "Achievable" scenario. This target can be met through further mix design optimization, including increased cement replacement, aggregate selection, and inclusion of CarbonCure.

HIGH QUALITY AGGREGATES

Aggregate selection can play a role in the amount of cement needed in a given concrete mix. Higher quality aggregates have better adhesion properties, which means up to 15% less cement is needed. In the Bay Area, Orca aggregate from British Columbia is common. This naturally occurring aggregate is formed by glaciers, and is stronger and has better adhesion properties than typical aggregates.

CARBON CURE

CarbonCure is a technology available in the Bay Area that injects CO2 sourced from industrial emitters into concrete during the curing process. This CO2 gets converted to calcium carbonate which strengthens concrete and enables a reduction in cement. On average, CarbonCure provides a 4-6% reduction in GWP per cubic yard of concrete.

Achieving concrete embodied carbon reductions requires early collaboration between the structural engineer, contractor, and concrete supplier. It is recommended that concrete GWP limits be written directly into the specifications and included as part of the bidding process.

Aggressive Optimizations

This scenario models the CLF "Low" scenario for steel and flooring, which represents the single best product in EC3 for a given product category. This tier is appropriate for projects targeting aggressive embodied carbon reductions, and limits product selection.

For concrete, the aggressive scenario assumes a 50% reduction from the NRMCA Regional Benchmark mixes. This level of reduction involves even higher amounts of cement replacement (as high as 70%) and altering mix ingredients and curing processes, such as with Type 1L cement, Blue Planet aggregate, or Solidia Concrete.

PORTLAND LIMESTONE (TYPE 1L CEMENT)

Concrete mixes in the Bay Area today almost exclusively use Ordinary Portland Cement (OPC), an ultra-carbon-intensive ingredient. Portland-limestone cement (also called Type 1L cement) is an OPC alternative that can reduce the GWP of cement by 10% - 30%. This carbon reduction comes from the reduction of clinker quantity within the cement. Clinker is an intermediate component of cement that's formed through the carbon-intensive process of sintering limestone, often fueled by coal. Clinker production is responsible for a significant portion of the GWP of concrete. Type 1L cement reduces the amount of clinker and replaces it with pure limestone instead.

Type 1L cement is already used in many parts of the world (Canada, Europe) as well as some parts of the United States. Its adoption in the Bay Area has been slowed by regulatory bodies such as Caltrans, which only just approved the use of Type 1L cement in California in October 2021. It will take some time for concrete suppliers to add the infrastructure needed to offer Type 1L cement at scale, but strategic partnerships with institutions such as Stanford could help speed up adoption.

There are also a number of up and coming concrete companies with proprietary technology that fundamentally alters the concrete ingredients and/or process. Two of the more developed companies are Solidia and Blue Planet:

SOLIDIA TECHNOLOGIES

Solidia is a cement and concrete technology company with two core strategies for reducing carbon in concrete:

1. A cement manufacturing process which uses less energy-intensive kilns, leading to a 30-40% reduction in greenhouse gas emissions during manufacturing compared to Ordinary Portland Cement.
2. A concrete curing technology that cures concrete with CO2 instead of water, sequestering 240 kg of CO2 per ton of concrete, and enabling significant water savings. This also shortens the cure time to less than 24 hours (compared to the traditional 28 days) which could solve the cure time issue discussed earlier.

BLUE PLANET CO2 SEQUESTERED AGGREGATE

Blue Planet has developed a technology that permanently sequesters waste CO2 from flue gas into a synthetic limestone carbonate mineral coating. This coating can be applied to regular aggregate, recycled aggregate, or form an entirely new artificial aggregate from scratch. The synthetic limestone is 44% sequestered CO2 by mass. Considering coarse and fine aggregates together make up the majority of a concrete mix by weight, this is a potentially significant amount of sequestered carbon.

Blue Planet is still in its early stages and has not yet completed an environmental product declaration, making it impossible to document in compliance with ISO standards for LCAs. There is also a potential double-counting issue with their product if industrial emitters are claiming the same credit for the carbon capture that Blue Planet is coating their aggregates in. However, Blue Planet has the potential to sequester significant amounts of carbon, enabling projects to approach net carbon neutral or even net negative.

Stanford Material Palette

In addition to high-volume products like concrete, steel, and flooring, there are specific materials that are part of the standard Stanford material palette were investigated as part of this analysis. The French Limestone at BMI and Clay Roof Tiles at Lagunita were analyzed as Stanford-specific items and found to contribute 1% and 4% respectively to the baseline designs. While this is relatively small in the baseline scenario, as other parts of the building (concrete, steel, flooring) are aggressively optimized, the proportion these Stanford-specific materials represent grows to 2% (limestone) and 7% (clay roof tiles). In low-carbon buildings, these Stanford materials could end up playing a more substantial role in a project's embodied carbon footprint. While it is understood these materials are an important part of the Stanford design aesthetic, Atelier Ten recommends looking for low-carbon alternatives for future projects, particularly for the roof tile.

Appendix C

Construction & Demolition Emissions

Introduction

Industry based frameworks for evaluating embodied carbon of projects are based on enabling material substitutions for projects in design. Demolition of existing structures on site is out of scope for these assessments. However, demolition is very much a part of Stanford University's embodied carbon footprint. This section lays out the approach for quantifying embodied carbon emissions of demolition activities at Stanford University when information becomes available.

The Seely G. Mudd Chemistry building is a three-story, 112,108 square foot project being demolished on Stanford's campus. Because WBLCA software are often limited in their ability to capture the C1 Deconstruction and C2 Transportation Away from Site life cycle stages, Atelier Ten submitted an information request to the demolition contractor to better understand the impact of the demolition.

Scope & Next Steps

The scope of the Mudd demo analysis covers demolition equipment operated on site as well as vehicles transportation to and from the site. Per discussion with Stanford, a decision was made to include personnel commuting in both company-owned and privately-owned vehicles to ensure comprehensive coverage.

Preliminary information about worker commute, demolition equipment count, trucking distance, etc. has been collected.

Atelier Ten has converted inputs on demolition equipment operating hours and vehicle miles driven into fuel consumption. Emissions factors for various fuel types is listed in the table to the right.

Diesel is the highest contributor both in absolute volume of fuel used, and in terms of CO2 emission intensity at 74.14 kg CO2 per MMBtu.

Excavation and fill in particular can be significant drivers of construction and demolition related carbon. Projects with large holes to excavate or fill require prolonged use of diesel equipment on site, then many trips in low-fuel-efficiency trucks to take dirt on or off site.

Temporary power is often a significant contributor to construction and demolition related emissions because of the reliance on diesel generators. However, Stanford projects are able to plug into existing power supplies on campus which are offset with 100% renewable energy, essentially zero-ing out that emissions source.

FUEL TYPE	CO2 EMISSIONS ($kgCO_2$ / MMBTU)
DIESEL	74.14
GASOLINE	71.26
ELECTRIC (CALIFORNIA GRID AVERAGE)	67.70
BIODIESEL (B20)	59.44
LIQUEFIED NATURAL GAS	54.45
RENEWABLE DIESEL	31.65
ETHANOL (E85)	14.79
ELECTRICITY (STANFORD RENEWABLE ENERGY)	0

EMMISSIONS FACTORS BY FUEL TYPE

Construction and demolition related emissions can vary substantially from project-to-project. It is recommended that Stanford require general contractors to track and report equipment use and fuel transportation-related consumption during the construction and demolition phases.

Based on the information gathered, the next step is to calculate the full demolition activities impact, analyze the data, and draw conclusions.

RECOMMENDATIONS

Construction and demolition related emissions reporting is not yet standardized, making it challenging to establish a reduction target. However, it is understood to be a potentially significant source of Scope 3 emissions, especially in projects with significant amounts of excavation or fill required. Therefore, it is recommended that Stanford:

- Require contractors to track and report construction (A4/A5) and demolition (C1/C2) emissions
- Recommend best practices to reduce emissions, such as:
  - Anti-idling policy
  - Use of fuel-efficient equipment
- Bigger moves that could lead to reduced A4/A5 and C1/C2 emissions could include:
  - Minimization of below grade space to cut down on excavation/fill requirements
  - Design for Deconstruction
  - Building Reuse