ARUP NRDC

Natural Resources Defense Council

Embodied carbon reduction roadmap

Strategies and policies for the state of California

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The carbon emissions associated with materials used in the built environment, referred to as "embodied carbon," are estimated to contribute to 11% of all global energy-related carbon emissions.[1] While currently this figure is less than the 28% of global carbon emissions attributed to building energy use, it is estimated that, due to the rapid growth of new construction needed to meet the demand of growing populations, nearly half of the total carbon emissions from new construction from now until 2050 will be attributable to the embodied carbon of our built environment.[2]

While there has been extensive focus on policies addressing decarbonization of industrial materials and separately on addressing energy use in buildings, these policies reduce material production emissions and operational emissions. Additional policies are needed to reduce the balance of whole building emissions affected by design and construction practices. The goal of this study was to fully synthesize the broader technology and policy landscape relevant to embodied carbon in buildings.

The study chose to focus on the state of California and local governments within the state, which allows the assessment to consider feasibility more practically and specifically. California was chosen due to its capacity, leverage, and track record for lowering barriers and risks for others in the nation and around the world.

Surely enough, legislative movement around embodied carbon in California is rapidly developing. Assembly Bill (AB) 2446, signed into law in 2022, directs the development of a framework for measuring and reducing the average carbon intensity of building materials with a target set of 40% reduction by 2035. Meanwhile, the public sector in California has shown market leadership in low carbon material procurement through the landmark bill AB 262, known as the Buy Clean California Act. Most recently, the California Building Standards Commission voted unanimously to adopt embodied carbon requirements into the state's green building code, known as CALGreen.

A wide range of strategies can be deployed to reduce embodied carbon in the built environment, encouraged by policy action. This study looked first at different types of available strategies and estimated the relative proportion of embodied carbon they could reduce. The strategies were then mapped against different types of building-sector policies.

For the first task, Arup quantified the reduction potential of various strategies through 2045, which is the net zero target date for the state of California. Embodied carbon reduction strategies in buildings were categorized as those that are implemented at the project scale, building system scale, or procurement (material) scale. Strategies to optimize the project were determined to have the most reduction potential in the short term while strategies to optimize procurement (i.e., material-level reductions) had the most reduction potential in the long term. This is because many of the technologies to decarbonize material production are slower to scale. In contrast, strategies to optimize the project that focus on building less or more efficiently can be implemented immediately.

Based on evaluating both ease of implementation and magnitude of reduction potential, policies taking both a building-focused approach and material-focused approach would lead to the highest Potential scale. Moreover, both a building-focused approach and material-focused approach can be effectively integrated into building codes. A building-focused approach uses whole building life-cycle assessment to evaluate performance. A material-focused approach uses environmental product declarations to evaluate performance. While examples of building code integration are provided within the report, mid-cycle changes to CALGreen are already underway.

In addition to statewide code update efforts, local building code authorities can adopt more stringent requirements, and local planning authorities can do more to integrate embodied carbon into planning requirements and zoning incentives. Addressing embodied carbon in city climate action plans and supporting industry-led initiatives to educate practitioners on the importance of, and methods to reduce, embodied carbon are additional levers that can help cut embodied carbon.

The report herein provides a policy roadmap and describes how the research team arrived at these specific recommendations.

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1. World Green Building Council, Bringing Embodied Carbon Upfront (World Green Building Council, September 2019).
2. Carbon Leadership Forum, Embodied Carbon Facts and Figures, accessed January 7, 2023, https://carbonleadershipforum.org/wp-content/uploads/2019/11/Embodied-Carbon-Facts-and-Figures.pdf.

Embodied carbon reduction roadmap

1 Embodied carbon reduction roadmap

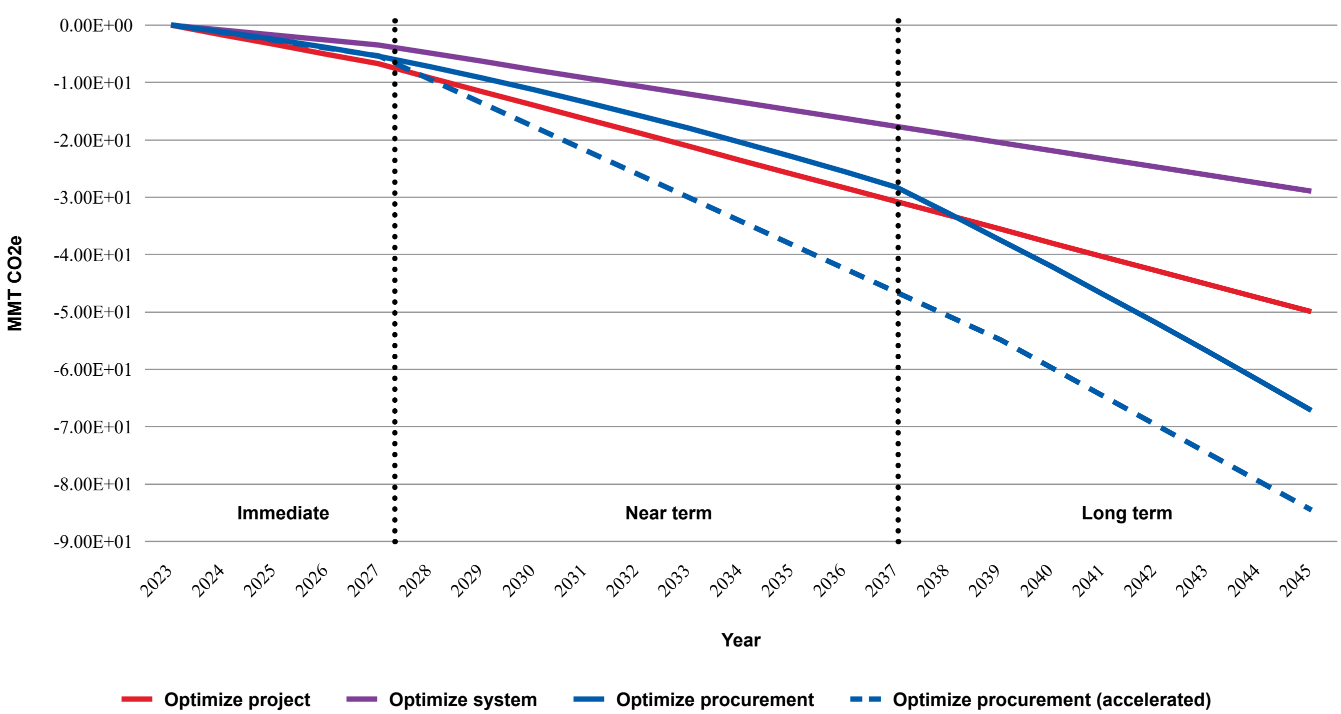
Arup quantified the reduction potential of strategies explored within this report for new residential and commercial construction in California. By quantifying reduction potentials, strategies with a more significant reduction potential can be identified. The appropriate policy lever for each strategy can then be identified to understand which policy levers are more impactful.

The methodology and background data used for this analysis can be found in Appendix B. Due to data availability, the strategies which are quantified are only those that contribute to cradle-to-gate embodied carbon emissions, i.e., emissions associated with the production of material. Note that embodied carbon data is currently limited and as such the results from this analysis should be consider a rough approximation. Nonetheless, the directional magnitude of reduction potential can be used to draw useful insights.

Building embodied carbon reduction strategies can be grouped by strategies that optimize reductions at the project, building system, or procurement (material) level. The cumulative global warming potential (GWP) reduction over time for each strategy category can then be estimated over time. This report considers a timeline through 2045, which is the target for the state of California to become net zero as established by Executive Order (EO) B-55-18, and through 2035, the target set in AB 2446.

As shown in the Figure 1, strategies which seek to optimize the project can effectively be implemented immediately and have the most cumulative reduction potential in the immediate and near term. Over time, as new material technologies become available and are adopted, optimize procurement strategies become the most impactful. If material-level reduction strategies are implemented on a more accelerated timeline through faster development and deployment, then optimize procurement strategies will more quickly have the most reduction potential and achieve greater reductions overall.

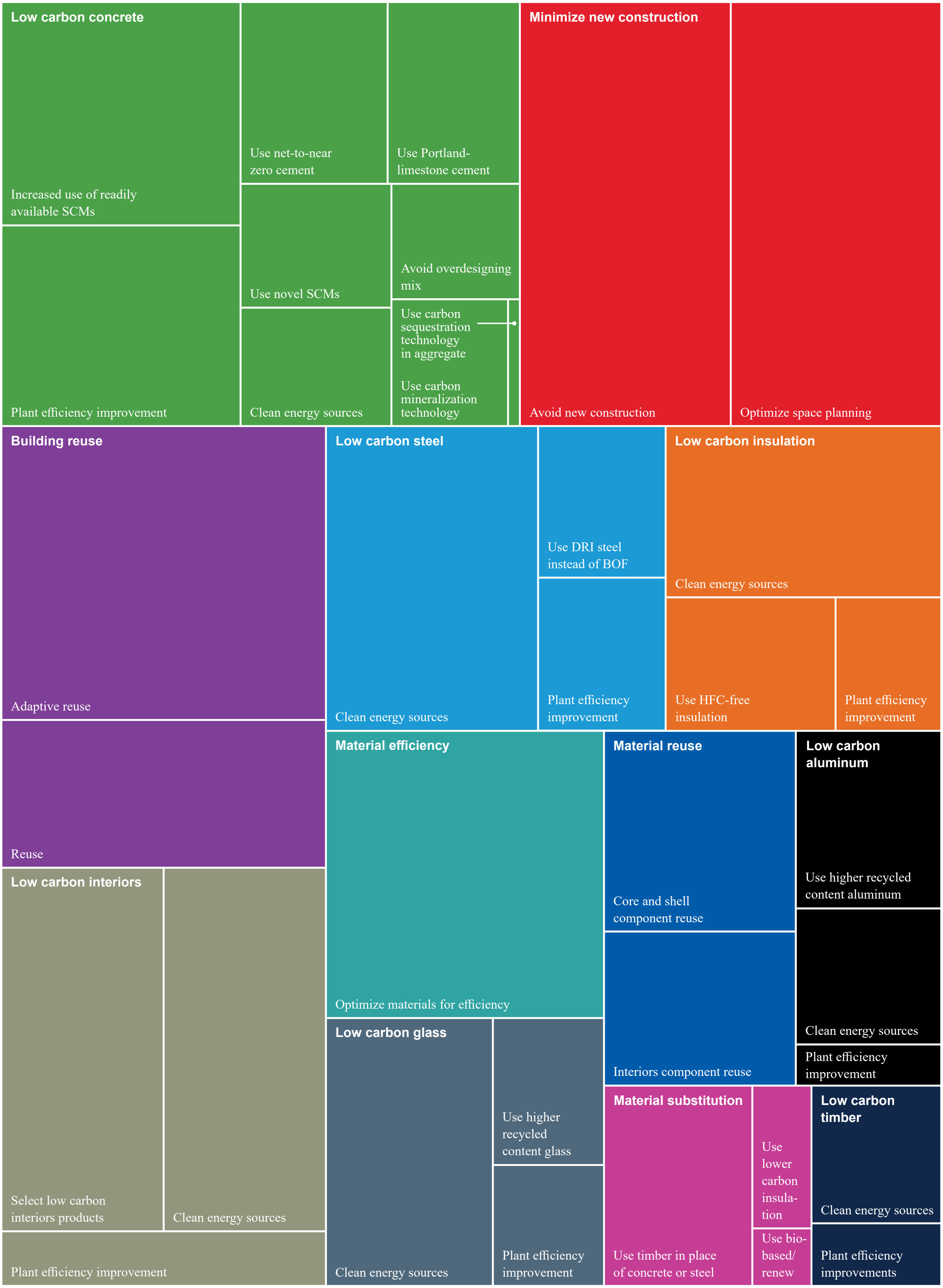
Figure 1: Cumulative GWP reduction over time by strategy



In summary, strategies oriented at optimizing the project and building systems can seek to reduce overall material use in the immediate and near term but strategies to optimize material procurement will be needed to develop decarbonized materials to fully achieve net zero embodied carbon over time.

Figure 2 presents the potential annual reduction potential of each key strategy and associated sub-strategies. The relative magnitude further reflects the importance of material-focused strategies in conjunction with building-focused strategies, with building-focused strategies optimizing both the project overall and building systems.

Figure 2: Relative annual GWP reduction of strategies



To determine appropriate policy levers, the general format of potential policy requirements is first considered. Whole building life-cycle assessment, a method of quantifying building level embodied carbon performance, can be used as a building-focused approach to evaluate strategies which optimize the project or systems. A material-focused approach can measure performance of environmental product declarations (EPDs) against set GWP thresholds.

The cumulative estimated reduction potential of each of these policy requirements is shown in Figure 3. Both have significant reduction potential and are integral in reducing embodied carbon by 2045. A more accelerated adoption of low carbon material technologies could result in a material-focused approach achieving equivalent reduction potential to a building-focused approach.

When looking at the cumulative reductions through 2035, in alignment with the target set by AB 2446 and as shown in Figure 3, a similar conclusion can be drawn. However, through 2035 it is anticipated that fewer low carbon material technologies will be available as in 2045, therefore the building-focused approach becomes more relevant in the near term.

Individual strategies are mapped against relevant policy categories to determine which policies have the most potential. The annual relative GWP reduction potential of each policy category is shown in the Figure 5. It should be noted that the figure shows the estimated maximum annual reduction potential for each policy category, so the timeline over which each policy category is implemented is not accounted for. The relative magnitude indicates a continued focus on clean procurement policies is important. Additionally, building codes present a clear opportunity for significant reduction potential.

Figure 3: Cumulative GWP reduction through 2045 by policy approach

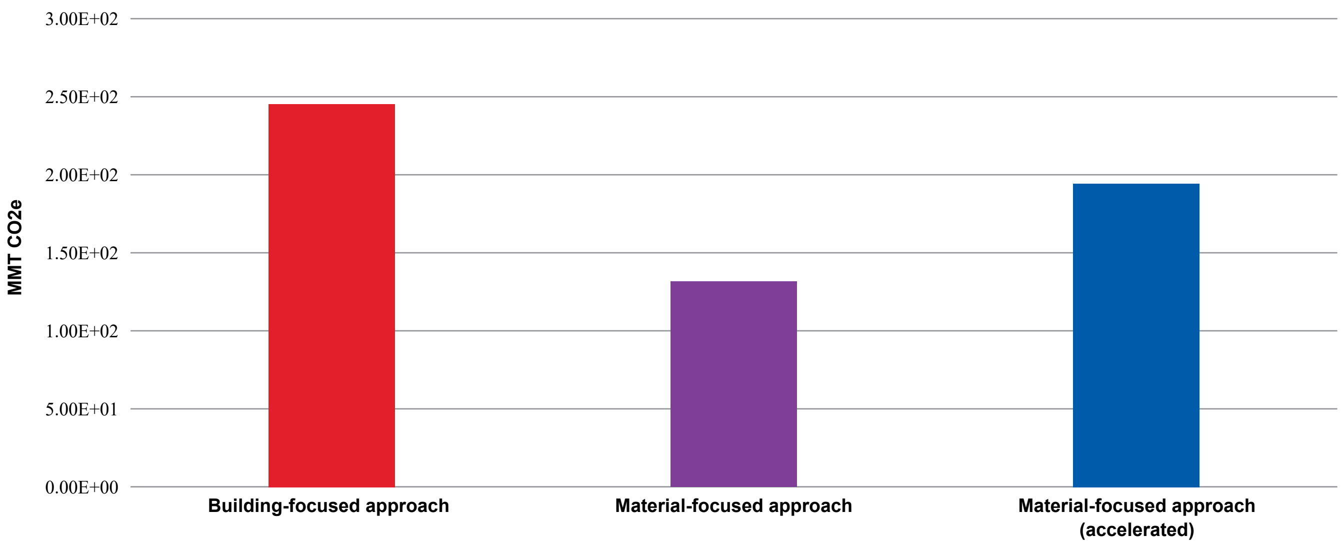


Figure 4: Cumulative GWP reduction through 2035 by policy approach

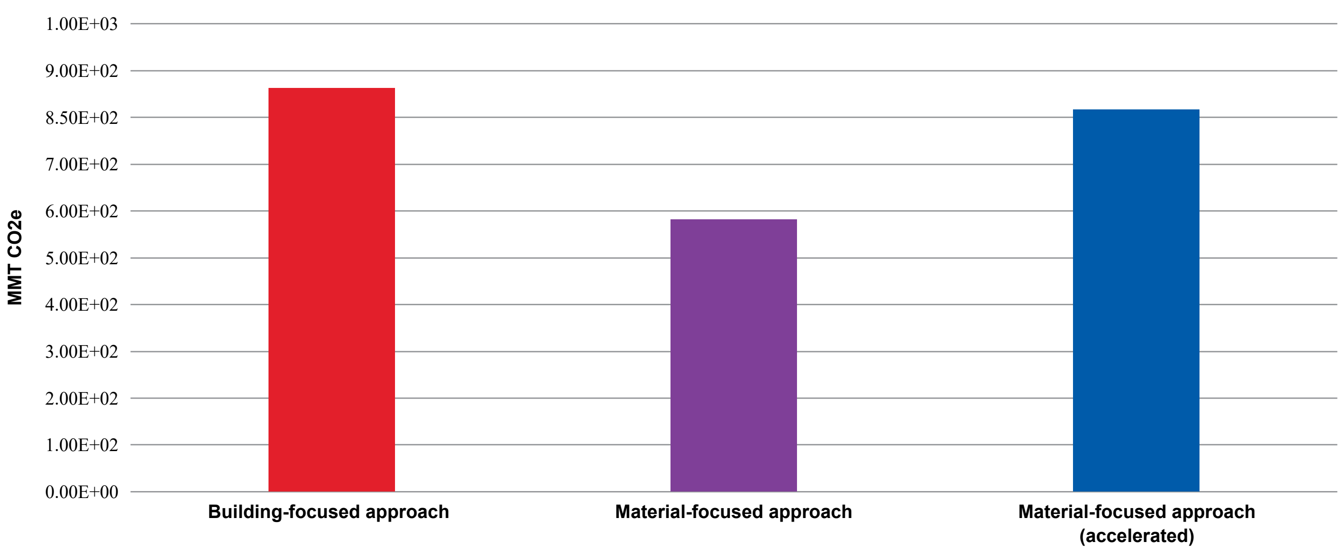


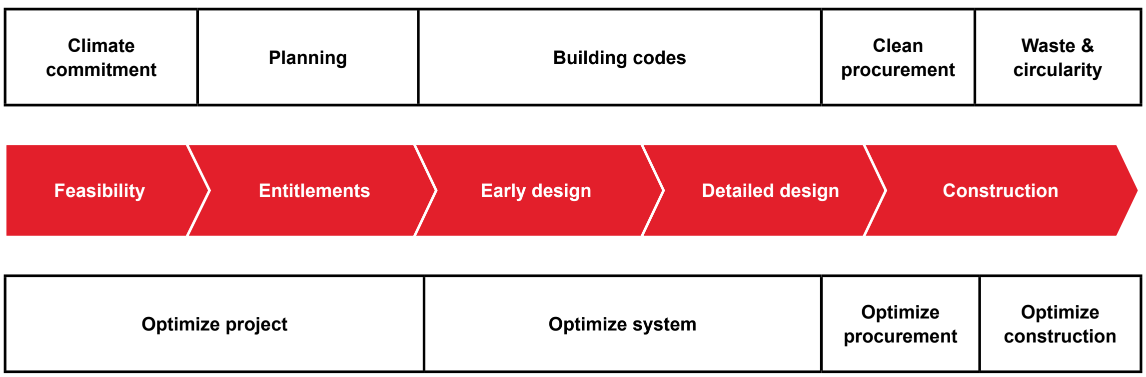
Figure 5: Relative annual GWP reduction of policy categories

Embodied carbon reduction strategies

2 Embodied carbon reduction strategies

Strategies to reduce building embodied carbon can be applied at any stage of a project. Strategies can be organized into four main categories: optimize project, optimize system, optimize procurement (materials), and optimize construction. The timeline of implementation for each category of strategies can be mapped against an individual building project timeline, as shown in the following figure, along with associated policy category. Policy categories are discussed in further detail in a later section of this report.

Figure 6: Project timeline



The following sections describe each strategy category and the sub-strategies within each category. Strategies which contribute to upfront embodied carbon reductions are included in the analysis provided in Section 1 and are provided in list form in Appendix B.

Table 1: Strategy categories

Strategy category	Key decision maker	Relevant policy categories
Optimize project	Building Owner	Planning, Climate commitment
Optimize system	Design Team (Architect, Engineer)	Building codes, Training & education
Optimize procurement	Contractor	Clean procurement, Building codes
Optimize construction	Contractor	Waste & circularity, Climate commitment, Building codes

2.1 Optimize project

Prior to initiating the design for a new construction or major renovation project, the building owner can evaluate and assess the need for the project. The building owner has significant opportunity to reduce embodied carbon at this stage because they can decide to minimize the size and scope of the project, whether to reuse existing buildings, or to avoid the need to build altogether. This can occur when the building owner initially completes a feasibility analysis. Further evaluation occurs once the entitlements phase is initiated, at which point a building owner hires consultants to seek zoning and other land use approvals.

Any policies directed at optimizing space use at the building scale should be considered alongside city-scale policies to increase density. Balancing density at the city-scale with minimizing space planning at the project-scale will lead to optimizing embodied carbon overall. Ultimately, the goal is to first maximize utilization of already produced materials, followed by minimizing the greenhouse gases emitted in the production of any new materials.

Optimize project sub-categories:

- Minimize new construction
- Building reuse

2.1.1 Minimize new construction

Some of the space planning needs of the building owner are self-directed (e.g., desired office density), while others are mandated through zoning codes (e.g., minimum vehicle parking requirements), or building codes (e.g., minimum bedroom size). Specific programmatic requirements are more impactful than others. Most notably, underground parking levels are more carbon intensive than above grade levels (regardless of use) due to the need to have concrete retaining walls. Minimizing the amount of new construction required can avoid the embodied carbon emissions associated with the production of new building materials.

Building owners can be driven by their own climate commitments to minimize the amount of new construction, by acknowledging the impact of embodied carbon on their Scope 3 emissions. LendLease is an example of a developer that has committed to net zero by 2040, including embodied carbon emissions. Zoning and building codes can be modified to avoid unnecessary space planning minimums.

Example Policy: LendLease Absolute Zero Carbon by 2040 Commitment

2.1.2 Building reuse

Once the space needs are optimized, seeking to use existing building stock can avoid the need for manufacturing of new building materials. Reuse can include purchasing or leasing an existing building with no or minimal retrofits needed, or adaptive reuse converting vacant or abandoned property into a usable building. Building reuse can be challenging for several reasons, including buildings deemed unfit for purpose, zoning requirements precluding adaptive reuse, and difficulty in upgrading older buildings to current code requirements.

Climate commitments can encourage building owners to consider building reuse to avoid the embodied carbon emissions associated with new construction. Zoning codes can be modified to allow for building reuse, specifically adaptive reuse, by accommodating multiple building use types in different areas rather than limiting to a single use type. The Los Angeles Adaptive Reuse Ordinance is one such zoning ordinance used to encourage adaptive reuse.

Example Policy: Los Angeles Adaptive Reuse Ordinance

2.2 Optimize systems

The project design phase is initiated once the overall programmatic needs of the building are optimized, and the massing is complete. The project entitlements phase often overlaps with the early design phase. The owner engages a team of design consultants at the start of the project design phase. The design process commences with concept design, followed by schematic development, design development, and lastly construction drawings. The design methodology is regulated through building codes. This includes the California state-wide building codes as well as any local amendments.

During the design phase, the systems within the building, such as the structural system, roof system, or façade system, can be optimized.

Optimize systems sub-categories:

- Whole building life-cycle assessment
- Material reuse
- Material efficiency
- Material substitution
- Low carbon specification

2.2.1 Whole building life-cycle assessment

Whole building life-cycle assessment (WBLCA) is a key strategy to reducing embodied carbon because it allows the design team to quantify and understand the carbon intensity of their building design. There are currently no established and widely adopted whole building embodied carbon benchmarks in California or the United States. However, efforts are underway to harmonize WBLCA methodology and establish benchmarks for the United States. Benchmarking efforts include the Carbon Leadership Forum (CLF) WBLCA Benchmark Study v2. The development of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)/ International Code Council (ICC) 240P – *Evaluating Greenhouse Gas (GHG) and Carbon Emissions in Building Design, Construction, and Operation* standard seeks to establish consistent methodology for the US. While the ASHRAE standard is not yet published, project teams may fall back on standards found in other countries, such as BS/EN 15978:2001, which describes calculation methods for building performance[3] or the RICS *Whole life carbon assessment for the built environment*, 2017.[4]

In lieu of available benchmarks, design teams typically perform WBLCA to identify embodied carbon "hotspots" or to target reductions against a baseline building. Typically, the baseline building is established as an early design against which designers seek to make improvements.

WBLCA is the best tool available for a performance-based analysis of embodied carbon. WBLCA gives designers the flexibility to explore multiple strategies and opportunities to achieve reductions. The other strategy sub-categories listed in this section can be evaluated and quantified using WBLCA. WBLCA is a credit option in green building rating systems, including the US Green Building Council (USGBC) Leadership in Energy and Environmental Design (LEED) and multiple standards developed by the International Living Future Institute (ILFI). These rating systems each define a general methodology and scope for the assessment to ensure alignment.

There are currently no mandated requirements for conducting a WBLCA in California building codes or otherwise, though, as of August 2023, there is an approved mid-cycle update to the California state-wide green building code, CALGreen, to include WBLCA as a mandatory requirement for large commercial buildings and schools. This is discussed in further detail in the policy section of this report.

Vancouver is the first city in North America to integrate a WBLCA requirement into their building codes. In May 2022, the Vancouver City Council approved changes to the Vancouver Building By-law to require designers to calculate, limit, and later reduce, embodied carbon in new commercial buildings over a certain size threshold. The Vancouver Building By-law includes provisions for performing a comparative WBLCA against a baseline building.

Example Policy: Vancouver Building By-law

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3. *Sustainability of Construction Works - Assessment of Environmental Performance of Buildings - Calculation Method*, BS/EN 15978:2001 (London, UK: British National Standards, 2011), https://www.thenbs.com/PublicationIndex/Documents/Details?DocId=299189.

4. *Whole Life Carbon Assessment for the Built Environment*, 1st ed. (London, UK: RICS, November 2017), https://www.rics.org/profession-standards/rics-standards-and-guidance/sector-standards/building-surveying-standards/whole-life-carbon-assessment-for-the-built-environment.

2.2.2 Material efficiency

The opportunity to select the most materially efficient systems occurs during early design stages. By using appropriate system choices, design teams can minimize overall material use. This can include laying out column grids to minimize structural spans, using more efficient shapes (e.g., open web steel joists), avoiding transfer girders and long span cantilevers, and stripping overly conservative design criteria.

While minimizing project costs by minimizing materials generally keeps overdesign in check, there are often cases where greater efficiency incurs a premium because of higher design, manufacturing, or labor costs. Adding carbon to costs as another key decision metric can give stakeholders greater awareness of climate impacts where they do not align with cost. This strategy is not yet in policy explicitly but is rewarded by green building rating systems, which do appear in policy. The most common form of this is where LEED certification allows a faster path through the entitlement process.

2.2.3 Material substitution

Material substitution refers to designing systems around alternate, lower carbon material options. Often, this is substituting the use of renewable materials for non-renewable materials. A key example of this is substituting concrete or steel with mass timber for the building structure. Another example is using bio-based insulation in place of petroleum-based products. For this strategy, the building must be designed around the material substitution and differences in performance. This may include differences in floor or wall build-ups to accommodate the substituted material.

The City of Emeryville now provides a development bonus density for projects that utilize mass timber for a portion of the structural system in place of concrete or steel.

Example Policy: Emeryville Mass Timber Development Bonus Density

2.2.4 Specify low carbon

Once the systems are optimized, in later design stages appropriate material specifications can be made. This typically occurs during the construction drawings phase prior to issuing bid documents. The design team produces specification sections for each material and component used on the project (based on the American Institute of Architect (AIA) MasterSpec®). Some of the specification sections are written using performance-based language, which provides performance requirements that the material supplier to the construction team must meet but otherwise does not prescribe a specific product. Other specification sections are prescriptive and may call out a single specific supplier and product from which the contractor is expected to not deviate or list several supplier and product options that the contractor can make a final selection from. Thus, as a design strategy, specifying low carbon products is through prescriptive specifications whereas products that are performance-specified require actions from both the design team and the construction team. Performance-based specifications can include embodied carbon as a performance metric that must be met by the supplier.

Commonly used building products and the specifier of those products is outlined in the following table. Note that some architects choose to engage a specification writer to outsource the writing of certain specification sections. Additionally, some project teams may include a façade designer responsible for the specification of façade materials, while other projects using more conventional façade systems may opt to have the specification writing be the responsibility of the architect (or their specification writer).

Marin County was the first jurisdiction in the US to adopt low carbon concrete performance

Specification section	Specification type	Specifier
Concrete	Performance-based	Structural Engineer
Structural steel	Performance-based	Structural Engineer
Cold-formed steel framing	Performance-based	Architect
Curtain walls	Prescriptive	Architect (or Façade Engineer)
Metal cladding	Prescriptive	Architect (or Façade Engineer)
Insulation	Prescriptive	Architect (or Façade Engineer)
Interior finishes (gypsum wallboard, ceiling tile, carpet)	Prescriptive	Architect

requirements into their local building code. Owner design guidelines can sometimes include material environmental performance requirement. Designers must integrate these requirements into project specifications.

Example Policy: Marin County Low Carbon Concrete Code

2.3 Optimize procurement

During the construction phase of a project, the contractor becomes responsible for purchasing building materials. It is at this point that the contractor engages material suppliers. Strategies to perform whole scale change in building systems are not possible during this phase, nor are most strategies focused on material substitution. At this stage, strategies are focused at procuring the lowest carbon option within a material category, sometimes referred to as product substitution.

If performance-based specifications are utilized, the material supplier has a wide range of strategies available to meet carbon performance targets. This can include differences in actual manufacturing processes, use of recycled or reused material, or simply improvements to plant efficiency or fuel source. The carbon performance is quantified using EPDs. Manufacturers may participate in an industry-wide EPD or carry product-specific EPDs for their product lines. While the contractor is responsible for the purchasing of materials, the design team must approve any final product selections.

In contrast to contractor-purchased building materials, owners sometimes choose to directly procure building materials which the contractor may install. When the owner chooses to purchase certain building materials, there are additional strategies they can employ to reduce whole life carbon emissions of buildings, stemming from circular economy principles of keeping products in use longer. As an alternative business model, circular purchasing is the idea of keeping products within a circular supply chain rather than the typical linear economy model of take, make, use, waste.

Strategies to minimize material-level carbon impact typically vary by material, except for broad strategies like plant efficiency improvements and fuel switching to clean energy sources. The following sections describe strategies for each of the material categories included. The analysis included earlier in this report excludes strategies relating to asphalt and services. Asphalt and services were not included in the available embodied carbon data used for the analysis.

Optimize procurement sub-categories:

- Concrete
- Steel
- Timber
- Insulation
- Glass
- Aluminum
- Interiors
- Asphalt
- Services

2.3.1 Concrete

Concrete has a large carbon footprint due to the intensity of the production process and the volume used. Concrete is present in all buildings, regardless of main structural system used, because it can be the most appropriate material for specific applications (e.g., foundations). The majority of concrete's carbon footprint is attributed to cement, and, of cement emissions, most are process emissions rather than fuel-based emissions. Therefore, strategies to minimize and/ or replace cement are most effective in reducing the carbon footprint of concrete.

To minimize cement content, concrete subcontractors and their ready-mix suppliers have a number of strategies available to them prior to considering cement replacement. First, the ready-mix supplier can optimize mixes to avoid overdesigning. Higher cement content results in higher strength concrete, so designing for the actual specified strength instead of higher strength than needed can reduce cement content. Further refinement of mixes, including better aggregate gradation, can reduce cement content while achieving the same strength performance. Some companies are experimenting with commercially available artificial intelligence to help with mix optimization.

Next, the ready-mix supplier can choose supplementary cementitious materials to replace some of the cement used in the mix. Currently, fly ash and slag are the predominant supplementary cementitious materials used, although their availability is finite and becoming limited. The cement industry is currently transitioning over to Portland-limestone cement, which has a higher limestone content than ordinary Portland cement.

Newer, promising supplementary cementitious materials are gradually gaining market acceptance in California and the U.S. Examples include ground glass pozzolan, calcined clay, and harvested fly ash. The California Department of Transportation (Caltrans) has an authorized materials list for cementitious materials used in concrete. Supplementary cementitious materials not on this list would have to seek approval from Caltrans. The California Department of Transportation (Caltrans) has an authorized materials list for cementitious materials used in concrete. Supplementary cementitious materials not on this list would have to seek approval from Caltrans. New companies, like Brimstone and Sublime, are developing novel processes for producing traditional cement from lower carbon raw materials, like calcium silicate. These technologies are in pre-commercial stages.

New companies, like Brimstone and Sublime, are developing novel processes for producing traditional cement from lower carbon raw materials, like calcium silicate. These technologies are currently in pre-commercial stages.

While cement is responsible for the majority of concrete's carbon footprint, aggregate used in concrete also has a carbon impact. Recycled aggregate can be used in place of virgin aggregate, although the applicability of mixes with recycled aggregate is typically limited to pavement due to potential quality issues.

At the ready-mix plant, carbon dioxide can be injected and stored in the concrete to allow carbon to be stored with no impact to performance. Carbon injection technology has an added benefit of reducing the amount of cement needed in the mix. Available technologies include CarbonCure and Solidia and are becoming widely adopted in the market. BluePlanet is a mineralization technology for storing carbon in aggregate.

The concrete subcontractor is responsible for the installation of the concrete provided by the ready-mix supplier. The concrete subcontractor often has their own requirements in addition to the performance requirements specified by the design team that impact the final mix design selection. Typically, this includes early strength requirements for post-tensioning concrete and stripping of formwork. If the contractor overspecifies the early strength needed for their construction process, the mix can be overdesigned. In-situ concrete maturity sensors can be used to monitor concrete strength gain in the field so that the concrete subcontractor can determine when the concrete achieves the early strength needed. However, special inspection requirements in the building code or imposed by the local authority may limit the use of maturity sensors.

The concrete subcontractor may also have finishability requirements (typically for floor slabs) that are impacted by certain mix designs containing supplementary cementitious materials. Supplementary cementitious materials like fly ash and slag are known to lengthen concrete cure times so concrete subcontractors may limit their use in mixes that have schedule impacts.

Many policies are emerging to address the carbon performance of concrete by setting thresholds that mixes must meet, typically through Buy Clean Acts aimed at public procurement. Most recently, the New Jersey Low Embodied Carbon Concrete Leadership Act was signed into law. More information on Buy Clean Acts is provided in the policy section of this report.

Example Policy: New Jersey Low Embodied Carbon Concrete Leadership Act

2.3.2 Steel

The majority of steel is manufactured using either a basic oxygen furnace (BOF) or electric arc furnace (EAF). EAF uses recycled scrap steel, while BOF is used to produce steel products from virgin iron ore. EAF is less carbon intensive because of the use of recycled product and use of electricity; however, because the demand for steel outweighs the availability of recycled steel, BOF production is necessary to keep up with current global demand.

Direct reduction iron is iron produced by removing the oxygen from iron ore to convert it to iron without having to melt it, lowering the carbon footprint of the process relative to BOF. Certain producers are exploring using hydrogen fuel for direct reduction iron.

Steel is already a very highly recovered and highly recycled material. Increasing steel recovery to 100% recovery will result in newly produced steel with higher recycled content; however, opportunities to increase the already high rates of steel recovery are limited. Instead, plant efficiency improvements and use of clean energy sources is highly critical to decarbonizing steel production.

Buy Clean Acts have included provisions for steel carbon performance. The Buy Clean California Act includes steel within the list of regulated materials.

Example Policy: AB 262: Buy Clean California Act

2.3.3 Timber

Timber is a renewable material that can be regrown but whose net emissions, when considering forest carbon, depend on whether or not forestry practices are sustainable. The carbon sequestration that occurs during the growth phase of timber results in carbon which is stored during the life of the wood building product. Structural wood building products include cross-laminated timber (CLT), glue-laminated timber, plywood, oriented strand board (OSB), laminated veneer lumber (LVL), and dimensional lumber.

The benefits of carbon storage in wood building products can only be realized if the timber is harvested in a sustainable way that does not impact mature forests or utilize clearcutting practices. In addition, the harvested timber must be regrown, otherwise the carbon release at end of life is simply delayed. The net climate benefit will be largely determined by forest management practices.

At the forest level, carbon is released through several processes, including respiration, combustion (e.g., fire), and decomposition. Certain forest management practices can better help to mitigate the amount of carbon released at the forest level in order to maximize net carbon sequestration. Currently, the Forest Stewardship Council standard is recognized as the best available forest management program in regards to maximizing forest level net carbon sequestration. It should be noted that achieving certifications for wood products can be challenging due in part to the complexity of supply chains.

While forest level carbon storage and emissions are highly significant, they are outside of the scope of wood product EPDs. Instead, carbon impacts of the wood product reported in EPDs is primarily attributed to the production of the material itself. At the mill and fabrication facilities, maximizing the use of the timber volume minimizes waste and can help to reduce carbon emissions. Waste at each of these facilities is often burned as biomass, which emits carbon.

Similar to steel, plant efficiency improvements and use of clean energy is highly critical to decarbonizing wood building products.

2.3.4 Insulation

Insulation provides thermal resistance to building exteriors. There are various types of insulation based on intended application. Common insulation types are mineral wool for exterior walls and extruded polystyrene (XPS), expanded polystyrene (EPS), or polyisocyanurate (polyiso) for roofs and below grade foundation walls. Closed cell spray foam insulation is another product type that is sometimes used in residential applications.

Rigid polyurethane spray foam, sealants, and XPS contain hydrofluorocarbons in the blowing agent. California has already phased out the use of HFC-134a in insulation products. Manufacturers have responded with new product lines using different blowing agents. Hydrofluoroolefin (HFO) is a commonly used replacement blowing agent.

The performance specification of insulation is highly dependent on building code requirements for energy performance. Impacts to operational carbon performance in selection of insulation needs to be considered, which may limit the strategies employable during the procurement process.

The Buy Clean California Act includes limits for mineral wool board insulation. Because insulation is a broad product category, regulations have typically been limited to one product type within the category.

Example Policy: AB 262: Buy Clean California Act

2.3.5 Glass

The flat glass production process incorporates cullet (waste glass) alongside virgin materials. Compared to a material like steel with high recycled content, flat glass has very low rates of cullet. The majority of cullet comes for internal waste streams followed by pre-consumer waste streams, with very little coming from post-consumer waste streams. Flat glass requires high quality cullet. Recycled content can vary significantly between suppliers.

Flat glass is a covered material under the Buy Clean California Act.

Example Policy: AB 262: Buy Clean California

2.3.6 Aluminum

Aluminum also typically includes recycled content. Post-consumer scrap collection rates vary widely at the global scale but are generally high overall. This high recovery rate is inadequate to meet global demand; however, so manufacturers must meet the shortfall with virgin aluminum. Virgin aluminum production varies widely in embodied carbon based on the source of electricity used for smelting.

While increasing aluminum recovery rates will have some benefit, the use of clean energy sources is critical to decarbonizing aluminum production.

2.3.7 Interiors

Interior elements of a building include partitions, ceiling, and floor finishes. Materials within this category include gypsum wallboard, ceiling tiles, and carpet (tiles and broadloom). Even within a given product category, there can be wide variability in embodied carbon performance amongst products, in part due to differences in performance attributes. For example, a higher density carpet will have an inherently higher carbon impact than a less dense carpet fabricated using the same constituent materials.

Similar to other product categories, strategies lessening the embodied carbon impacts of interior products include higher rates of recycled content and use of bio-based constituent materials. AB 1369 was meant to fill a gap in AB 262 by expanding the list of eligible materials under the Buy Clean California Act to include gypsum board, insulation, carpet and carpet tiles, and ceiling tiles. AB 1369 failed.

Example Policy: AB 1369: Buy Clean California Act (failed)

2.3.8 Asphalt

Asphalt is batch mixed, similar to concrete. As a result, the environmental impact of asphalt can be reduced through improvements to its constituent parts. To avoid the production of primary asphalt, asphalt pavement can be reclaimed during reconstruction or resurfacing and reused. Other waste products can be used to replace the aggregate in asphalt, including roof shingles and recycled tires. In California, AB 338, later codified as Public Resources Code 42703, requires that Caltrans use crumb rubber in their asphalt mixes.

Environmental accounting is not widespread yet within the asphalt industry. In 2022, the GSA released an Environmentally Preferable Asphalt Standard requiring product-specific EPDs for asphalt products to help bring greater environmental performance disclosure within the industry.

Example Policy: AB 338

2.3.9 Services

Service elements of a building include any mechanical, electrical, plumbing, and fire protection equipment and accessories. Specific equipment selection choices made during the design process serve as the “basis of design.” Contractors can provide alternate product selections of similar performance during the procurement process.

Generally, equipment and accessories (e.g., piping) using less material overall will have a lower embodied carbon footprint. There is currently very limited availability of information on the environmental footprint of services through EPDs or otherwise.

2.4 Optimize construction

The embodied carbon impacts of the construction phase are typically minimal compared to the embodied carbon impacts of product manufacturing but can still be impactful, particularly because the greenhouse gas emissions occur within the communities in which the projects are built. Construction phase strategies are focused on reducing carbon emissions associated with the transport and construction of building materials as well as minimizing on-site waste.

Optimize construction sub-categories:

- Low carbon transportation
- Electrified construction equipment
- Reduce waste

2.4.1 Low carbon transportation

The transportation impacts on embodied carbon can be reduced through minimize transportation distances and use of electric transportation options. Transportation impacts are most often not reported in EPDs, so should be considered alongside EPD information. WBLCA includes the transportation impacts, but typically assumes an average value that may not be reflective of the actual project.

New York City EO 23, adopted in 2022, requires capital project agencies to use low-emission vehicles.

Example Policy: New York City EO 23

2.4.2 Electrified construction equipment

Most construction equipment is gas- or diesel-powered, which contributes to emissions and harmful air quality due to on-site combustion. Electrified equipment will need to be developed to replace fossil fuel powered equipment in order to reduce on-site emissions. While adoption is limited, upcoming technologies include battery-electric vehicles and other electric and/or battery-operated equipment.

New York City EO 23 includes a provision requirement for the use of low-emission equipment with a preference for all-electric equipment.

Example Policy: New York City EO 23

2.4.3 Reduce waste

A significant amount of waste can be generated on a construction site, which often ends up in a landfill. CALGreen has a provision for projects to recycle and/ or salvage for reuse a minimum of 65% of nonhazardous construction and demolition waste. Waste diversion can help to produce supply for future projects seeking to employ material reuse.

Contractors can help to minimize waste on-site through early coordination and efforts to prefabricate as much as possible off-site.

Example Policy: CALGreen Construction and Demolition Diversion Provision

Embodied carbon policies

3 Embodied carbon policies

Policies can either directly or indirectly affect embodied carbon. Indirect policies include those that inadvertently encourage more material use and therefore more embodied carbon emissions, such as parking minimums. Embodied carbon should be a consideration made in evaluating any indirect policies; however, these policies are not the focus of this report. Instead, this report focuses on direct policy levers that regulate or incentivize lower carbon building construction.

Policies impacting building embodied carbon are vast and applied ranging from the hyper-local level to the state level. Some policy types more directly prescribe embodied carbon performance, while other policy types have indirect impacts to embodied carbon. The broad range of policies presents both a challenge and opportunity, in that multiple levers can be explored to enact change.

For the purposes of this report, policies are grouped together into the following categories with key policy authors, implementers, and policy enforcers noted:

Policy category	Key policy author	Key policy implementer	Key policy enforcer
Planning	State and local legislatures	Planning commission	Planning authority
Building codes	State and local legislatures	Building standards commission	Building department
Clean procurement	State legislature	Public sector agency	Public sector agency
Waste & circularity	State and local legislatures	Public sector agency	Public sector agency
Climate commitment	Executive	Executive	N/A
Training & education	State legislature	Professional licensing commission	Professional licensing board

Specific policy types within each policy category can be evaluated in terms of potential scale, implementation feasibility, and timeline for implementation. Ratings can be given based on the following criteria:

Legend		
Potential scale	Low	Directly affects only certain building types in a city
	Medium	Directly affects most building types only in a city or only certain building types in a state
	High	Directly affects most building types in a state
Implementation feasibility	Low	National-level process
	Medium	State-level process
	High	City- or organization-level process
Timeline	Long term	5+ years
	Near term	2-5 years
	Immediate	1-2 years

These ratings are then applied to each policy type in the following table to then identify strategic policy focus areas. Reviewing the table, zoning requirements, zoning incentives, CALGreen, local building code amendments, and local stretch codes present as clear policy focus areas. Additional policies with ease of implementation in the immediate include supporting updates to climate action plans and development of industry-led educational initiatives.

Policy category	Policy type	Potential scale	Implementation feasibility	Timeline
Planning	Zoning requirements	Medium	High	Near term
	Zoning incentives	Low	High	Immediate
Building codes	Base codes	High	Low	Long term
	Green building code (CALGreen)	High	Medium	Near term
	Local building code amendments	Medium	High	Near term
	Local stretch codes	Low	High	Immediate
	Owner design guidelines	Low	Low	Immediate
Clean procurement	Buy clean acts	Medium	Medium	Long term
	Public sector incentives	Medium	Medium	Near term
	Owner procurement guidelines	Low	High	Immediate
Waste & circularity	Construction & demolition diversion ordinance	Medium	High	Near term
	Deconstruction ordinance	Low	High	Long term
Climate commitment	Executive orders	Low	Medium	Near term
	Climate action plans	Low	High	Immediate
	Private sector commitments	Low	Low	Near term
Training & education	Professional certification	Low	Medium	Near term
	Industry-led educational initiatives	Low	High	Immediate

3.1 Planning

The planning phase of a project is critical in reducing embodied carbon. Fundamental choices in building location, size, and design allow for the largest reduction potential to be achieved. Therefore, planning policies to encourage low carbon construction at the start of the development play a vital role in early adoption of embodied carbon reductions. These policies are typically legislated through a local legislative body (e.g., city council), executed by the local planning commission, and enforced by the local planning authority. Planning policies include zoning and other land use regulations.

Planning sub-categories:

- Zoning requirements
- Zoning incentives

3.1.1 Zoning requirements

Zoning and land use regulations typically dictate the appropriate use of the building and general size, shape, and height. For the purposes of embodied carbon, size, height, and appropriate use requirements are most impactful. Reducing building size and height can reduce material quantities and therefore embodied carbon; however, limiting size and height may have adverse impacts on encouraging less dense growth at the regional scale. Appropriate uses determine what purposes land can be used for, which is important in considering building reuse. Other zoning requirements can indirectly affect embodied carbon. For example, zoning requirements for what materials can be used for a building exterior may preclude the selection of lower carbon enclosure options.

In some cases, more stringent zoning or land use requirements can minimize new construction and promote creative use of existing parcels or buildings. In other cases, reducing zoning requirements and expanding incentives can encourage more intentional space use, lower carbon designs, and building reuse.

Zoning and land use laws depend on each municipality, but rezoning efforts involve the local planning commission consulting a city's master plan, holding public hearings, and determining if changes would benefit the community. However, legislative bills related to zoning, such as Senate Bill (SB) 9 (which ends single family zoning in California), have passed without complete oversight of the local Planning Commission. The vast scope of zoning laws and stakeholders presents challenges to politically feasible and widely adopted policies. As a result, zoning laws are seldom updated comprehensively (often on the magnitude of decades, rather than years). Ordinances to amend zoning codes are common instruments for more immediate implementation.

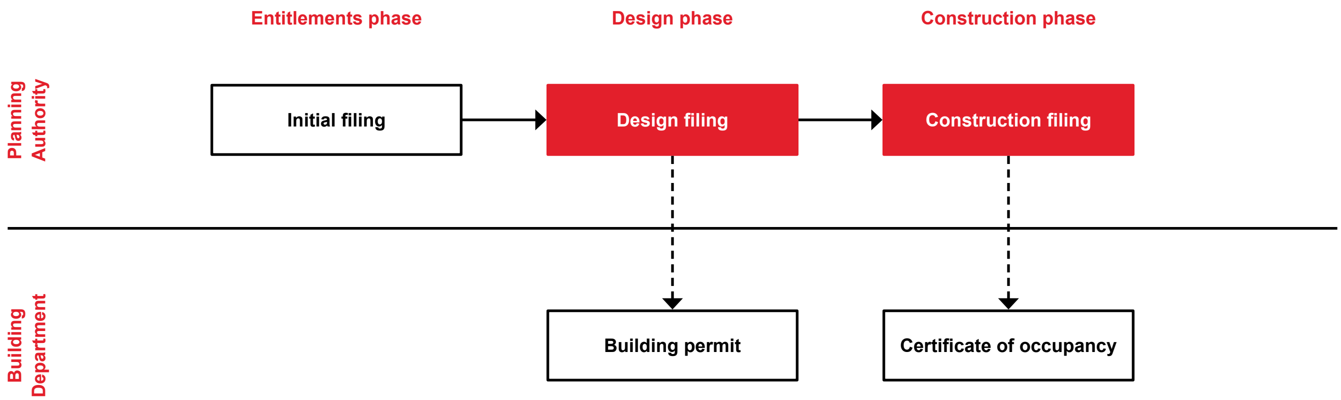
Attention is being given to zoning codes as an opportunity to integrate embodied carbon requirements, in part because updates can be passed at the local level. The London Plan issued by the Greater London Authority now includes whole life-cycle carbon assessments, which includes operational and embodied carbon, for projects of strategic importance to London as of 2021. Typically, these are larger, taller developments. Benchmarks by project type are provided but projects are not required to meet the benchmark. Instead, projects are compared to the relevant benchmark during the planning approvals process. If a project has an above average carbon footprint, the planning approval may be harder to receive.

Article 37 of Boston's zoning code requires all projects to be LEED certified and meet other sustainability and resilience requirements since 2007. The Boston Planning Commission is currently considering integrating an embodied carbon reporting requirement into Article 37. For Article 37 compliance, a submission to the planning authority is required at the beginning and end of a project's design phase.

Based on these prior precedents, an available policy lever would be to integrate a WBLCA provision into local zoning codes. Because local zoning codes typically require zoning submissions only during the entitlements phase, introducing WBLCA requirements into the zoning code would require additional zoning submissions, as shown in the following figure. This figure is based on the process used for Boston's Article 37 submissions, with the filings noted in red being additional to the typical initial filing for zoning approvals. The Article 37 process is integrated between the planning authority and building department to ease the administrative burden on project teams.

Integrating WBLCA into zoning codes would also allow for project embodied carbon data to be collected in order to eventually have sufficient data for establishing local embodied carbon benchmarking, similar to what has been done for building energy performance standards.

Figure 7: Example coordinated planning and building approvals process



3.1.2 Zoning incentives

Zoning incentives are the use of bonuses in the form of increased project density or other benefits offered to a building owner in return for the owner providing certain features or design elements desired by the city, region, or state. Incentives are typically offered through local zoning ordinances but can also be provided at the state level. An example of a policy at the state level is the California Density Bonus Law, originally initially enacted in 1979 and updated with more recent legislation in many years since. The law generally allows developers to exceed normal density restrictions if certain criteria are met.

An example of a local incentive is the Los Angeles Adaptive Reuse Ordinance, passed in 1999, for the downtown area. The Adaptive Reuse Ordinance was expanded to other neighborhoods in 2003. The incentive allows the adaptive reuse of older buildings to meet less stringent zoning and code requirements while streamlining the approval process for developers. It has allowed dozens of structures to be repurposed, largely as housing.

The City of Emeryville has implemented a development density bonus incentive for the use of mass timber construction. The incentive rewards projects that substitute mass timber construction for traditional structural materials like steel and concrete. Projects are awarded development density points based on the percentage of mass timber construction utilized.

Incentives also encompass tax breaks and funding assistance. These types of incentives can again be offered at the local or state level. An example of a monetary incentive for low carbon construction is Boston's Mass Timber Accelerator Program, which provides funding for development teams to explore the benefits and assess the feasibility of incorporating mass timber into building projects. Funding assistance programs often receive support from federal partners and non-governmental organizations (NGOs). In the case of the Boston Mass Timber Accelerator Program, support was provided by the United States Department of Agriculture Forest Service, the Softwood Lumber Board, ClimateWorks, and the Boston Society for Architecture.

Incentives could serve as an opportunity to reward low embodied carbon performance. Projects could be awarded zoning incentives if it can be demonstrated through a WBLCA that the project has a lower embodied carbon footprint. In this way, WBLCA is used as an incentive, rather than requirement.

3.2 Building codes

Building codes provide site-level building, material, and safety requirements. This includes base codes directed at regulating life safety and energy conservation as well as green building codes, local amendments to base and/or green building codes, and local stretch codes. While not mandated from a regulatory perspective, building owners often have design guidelines that projects must adhere to as well.

Building codes sub-categories:

- Base codes
- Green building code (CALGreen)
- Local building code amendments
- Local stretch codes
- Owner design guidelines

3.2.1 Base codes

Base codes refer to the set of building codes adopted by jurisdictions that apply to all building projects. California adopts the International Code Council (ICC) series of codes, including the International Building Code (IBC), as the base code. The other codes issued by ICC include the International Residential Code, International Existing Building Code, International Fire Code, International Plumbing Code, International Mechanical Code, and International Energy Conservation Code. The scope of base codes has traditionally been limited to life safety and energy conservation and does not include consideration of greenhouse gas emissions. As such, embodied carbon is not considered directly within base codes. Requirements in the base codes may indirectly affect embodied carbon, such as minimum room sizes that would result in a larger building than perhaps would otherwise be designed.

ICC issues code updates every three years. The code development process occurs over several years and includes code change proposals submitted by the public and numerous public hearings and comment periods. NBI is a prominent NGO involved in submitting embodied carbon code change proposals through the code development process.

Once ICC issues its updated series of codes, the California Building Standards Commission (CBSC) must then adopt it. The most recent California Building Code was published July 1, 2022, adopting the 2021 ICC series of codes, with amendments. The California Building Code is updated every three years, although mid-cycle updates are considered. Once the statewide base codes are published, the local jurisdictions then adopt the statewide codes with the option to amend them (refer to the Local Building Code Amendments section).

Most every jurisdiction in the United States adopts ICC's series of codes as their base codes. Because base codes include mandatory requirements that all projects must meet, the impact of changes to base codes is widespread. However, implementation is incredibly difficult due to the process for updating ICC's series of codes. Further, at this time the ICC has not indicated a desire to incorporate consideration of greenhouse gas emissions in the base codes, except within the consideration of energy conservation.

AB 2446 (Carbon Intensity of Construction and Building Materials Act), adopted in 2022, directs CBSC to develop a framework for measuring and reducing the carbon intensity of construction and materials to achieve an 40% net reduction below a certain baseline by 2035, with interim goals of 20% reduction by 2030. It is uncertain at this time if one of the outcomes of AB 2446 will be integration of new requirements into either the base codes or CALGreen mandatory measures. It is unknown if CBSC is developing working groups at this time, although it is likely that the same participants in the Carbon Reduction Collaborative (see next section) will also be supporting work in response to AB 2446.

3.2.2 Green building code (CALGreen)

Beyond its suite of base codes, ICC also publishes the International Green Construction Code (IgCC) as a mandatory code that local jurisdictions can optionally choose to adopt. IgCC is based on ASHRAE 189.1 *Standard for the Design of High-Performance, Green Buildings Except Low-Rise Residential*. The IgCC has been gaining adoption in jurisdictions across the United States since its original publication in 2012. ASHRAE 189.1 has a proposed Addendum currently in consideration which would establish GWP limits for a flexible set of products (the jurisdiction would decide scope).[5] ASHRAE 189.1 is considering integrating a mandatory WBLCA provision in future versions.

California set precedent for mandatory green building code adoption with the publication of the California Building Standards Code Title 24, Part 11, referred to as the California Green Building Code or CALGreen. CALGreen precedes the IgCC with its adoption in 2009 as the first-in-the-nation mandatory green building code. The code was originally developed in response to AB 32 with SB 1473 granting CBSC the authority to develop a green building code. CALGreen encompasses planning and design, energy efficiency, water efficiency and conservation, material conservation and resource efficiency, and environmental quality. CALGreen is also unique when compared to IgCC in that it is applicable to new construction and major renovation building types, including low-rise residential.

CALGreen has a base set of mandatory requirements that apply to all projects. CALGreen also includes voluntary tier 1 and tier 2 compliance levels that local jurisdictions can adopt as mandatory requirements. A list of jurisdictions adopting tier 1 or tier 2 as mandatory measures in not publicly available but known to be widespread. Santa Rosa, Petaluma, and Davis are cities that have adopted tier 1 as mandatory; Palo Alto has adopted a range of tier 1 and tier 2 compliance for certain requirements.

5. "Public Review Draft Standards," ASHRAE, accessed February 1, 2023, https://osr.ashrae.org/default.aspx.

The CALGreen mandatory requirements do not currently include embodied carbon provisions; however, as of August 2023, there are approved mid-cycle code change updates to incorporate embodied carbon provisions that are anticipated to go into effect in 2024. To date, CALGreen tier 1 and tier 2 have included requirements for recycled content and construction waste reduction. Additional voluntary embodied carbon provisions have been provided, including WBLCA. Because these provisions have been voluntary in nature, they have not often been pursued.

CALGreen is updated every three years on the same cycle as the base codes. There is the ability to introduce mid-cycle code change proposals outside of the standard cycle. During the mid-cycle code change process initiated in 2022, the Carbon Reduction Collective introduced an embodied carbon code change proposal. Rocky Mountain Institute (RMI), New Buildings Institute (NBI), Architecture 2030, CLF, ClimateWorks, AIA, and USGBC are all NGOs which participated in the collaborative. Arup was also a participant.

The code change proposal, which has since been approved but as of this report's writing is not yet in effect, applies only to non-residential buildings 100,000 ft^2 and larger, and schools 50,000 ft^2 and larger. Tier 1 and tier 2 provisions are elective unless made mandatory through local code amendments. The proposed compliance pathways are as follows:

With the mid-cycle code change proposal accepted, CALGreen is currently a very effective policy lever for introducing embodied carbon requirements and will continue to be over time as requirements can be made more stringent in future code updates. Because CALGreen covers all new construction and major renovation projects in California, the applicability of the embodied carbon provisions can be broadened to capture more building types.

3.2.3 Local building code amendments

Local jurisdictions can amend the statewide building codes if they choose to. This includes amending the base codes and/ or CALGreen. As mentioned previously, CALGreen has requirements for tiers 1 and 2 that local jurisdictions can adopt as mandatory requirements, which many do.

Local jurisdictions do frequently amend statewide base codes for various reasons, often for life-safety considerations specific to the jurisdiction's objectives, such as seismic or fire performance requirements. Local building authorities are responsible for the enforcement of all codes.

	Proposed mandatory	**Proposed tier 1**	**Proposed tier 2**
Prescriptive (building reuse)	45% of structure and enclosure to be reused	75% of structure and enclosure to be reused	75% of structure and enclosure to be reused and 30% of interior non-structural elements to be reused
Performance (WBLCA)	10% reduction from baseline	15% reduction from baseline	20% reduction from baseline
Prescriptive (material limits)	175% of Buy Clean California Act GWP values; concrete 175% of National Ready Mix Concrete Association v3 Pacific Southwest regional benchmark GWP values	150% of Buy Clean California Act GWP values; concrete 150% of National Ready Mix Concrete Association v3 Pacific Southwest regional benchmark GWP values	100% of Buy Clean California Act GWP values; concrete 100% of National Ready Mix Concrete Association v3 Pacific Southwest regional benchmark GWP values

Marin County in California was the first local jurisdiction to integrate embodied carbon requirements into their base building code amendments in 2019. The Marin County amendments include provisions for low carbon concrete. It requires projects to meet limits in either cement content or embodied carbon (i.e., GWP) in all concrete mixes used on the project. By incorporating the low carbon concrete requirements into the building code, the limits are applied to all projects, public and private.

Local building code amendments are typically made on the same three-year cycle when the local jurisdiction goes through the statewide base code adoption process. There is typically a code change proposal process at the local level, organized by the local building commission. The local legislature also can impose amendments to the building code. An example is the recently passed Los Angeles Ordinance 18774 which directs the Los Angeles Green Building Code to be amended to require all-electric newly constructed buildings. The code change proposal process and legislative process are parallel to one another and reach different audiences and stakeholders. While either process can be used to achieve local code amendments, it is often effective in pursuing both processes to achieve successful outcomes. A similar dual-front approach can be taken to statewide code changes as well.

Jurisdictions with progressive climate goals can be receptive to code change proposals and bill proposals at the local level to amend base codes. However, because the local amendments apply only to the local jurisdiction, the impacts are limited. The most directed policy implementation for a local building code amendment to include embodied carbon would be working with jurisdictions to adopt tier 1 or tier 2 CALGreen requirements as mandatory once the CALGreen mid-cycle code change process is complete.

3.2.4 Local stretch codes

Local stretch codes (also referred to as reach codes) are locally mandated alternative compliance pathways that are more aggressive than base codes and/ or CALGreen. Because stretch codes provide an alternative compliance pathway, they are not mandatory. Building owners and design teams may consider electing to use stretch codes in order to avoid meeting requirements of the base compliance pathway or the desire to meet higher performance goals.

Note mandatory codes, like local amendments to CALGreen, can be considered by some as stretch codes. For the purposes of this report, we refer to stretch codes only as those codes which offer alternative compliance pathways. An example of a stretch code is the Santa Monica's Energy Reach Code, which offers an all-electric alternative compliance pathway for new construction.

Stretch codes can also be used as part of incentives offered by the jurisdiction. In order to receive the incentive, buildings can be required to meet the local stretch code. Tier 1 or tier 2 CALGreen adoption can serve as a local stretch code.

Similar to local building code amendments, local stretch codes are limited in reach. They are further limited in application in that they are not mandatory for all projects.

3.2.5 Owner design guidelines

Owners with large building portfolios often have their own internally developed design standards that projects must conform to. These design guidelines contain requirements in addition to the applicable building codes. Owners with sustainability goals are beginning to integrate embodied carbon requirements into their design standards.

An example is the General Service Administration (GSA) P100 *Facilities Standards for the Public Buildings Service*, October 2021 version with 2022 addendum. The design standard now includes a requirement for all new construction and major modernization projects to target a 20% embodied carbon reduction by performing a WBLCA. Additionally, projects using at least 10 cubic yards of concrete or asphalt must meet GSA's Low Embodied Carbon Concrete and Environmentally Preferable Asphalt standards.[6]

Owner design guidelines are not regulated. Owners can be motivated to develop low embodied carbon design standards through their climate commitments (refer to private sector commitments section). Because not all owners have design guidelines and the approach to updating or implementing them is piecemeal, this policy lever is difficult to implement and limited in reach.

6. U.S. General Services Administration, P100: *Facilities Standard for the Public Buildings Service* (U.S. General Services Administration, October 2021 with 2022 Addendum), https://www.gsa.gov/cdnstatic/P100%202022%20Addendum%20Final_.pdf.

3.3 Clean procurement

Clean procurement covers both public and private procurement policies requiring sourcing of lower carbon materials. While designers consider these policies during the design phase, the contractor is responsible for conformance with the policies during the procurement phase.

Clean procurement sub-categories:

- Buy Clean acts
- Public sector incentives
- Owner procurement guidelines

3.3.1 Buy Clean acts

Several states and local jurisdictions have passed bills which are collectively referred to as "Buy Clean" acts in recent years, including California. These acts stipulate GWP limits for specific product categories. The acts are passed by either state legislature and are limited in reach to public sector procurement only.

Buy Clean acts can have varying levels of specificity and targets, depending on the enforcement (local, state, or federal). More localized policies can integrate regional information on material carbon intensity, whereas federal policies can provide more funding and/or influence a larger scale of projects.

California passed the first state-level Buy Clean legislation in 2017, known as the Buy Clean California Act. The bill tasked the Department of General Services (DGS) and the California Air Resources Board (CARB) to create GWP limits for the following materials: structural steel, concrete reinforcing steel, flat glass, and mineral wool board insulation. These material requirements apply to public works projects. As of January 2022, the GWP limits have been established and in July 2022, the authorities determined GWP limit compliance of eligible materials using EPDs.[7]

Buy Clean is one the most institutionalized embodied carbon policies, as various versions of the policy have been adopted at the city, state, and federal level (in certain regions). Policies can include a combination of the following: disclosures, standards, and incentives, along with clarification around scope of projects and materials. Most policies allow adoption and implementation over a two- to four-year timeframe.

One of the main challenges of Buy Clean policies is to obtain adequately granular data to account for potential regional variability of materials.

In 2021, SB 778 and AB 1369 were amendments introduced to fill in gaps in the Buy Clean California Act. AB 1369 would have introduced finish materials and shifted the requirement for EPDs to be product-specific instead of facility-specific, but it did not pass. SB 778 would have introduced concrete as an eligible material, updated the EPD requirements, and added performance-based specification requirements and performance incentives for concrete, but it also did not pass. AB 1250, under consideration by the California Senate as of August 2023, would put in place EPD collection requirements for concrete and asphalt in Caltrans projects. If adopted, it will enable the department to expand its clean materials procurement.

3.3.2 Public sector incentives

Buy Clean acts regulate the use of materials covered under the policy. Other policy initiatives have emerged recently to take a more performance-based appropriate to low carbon material selection, by offering incentives to bidders that incorporate use of low carbon materials. This could be in the form of "points" awarded for low carbon material selection alongside points provided for other performance measures, like cost. New Jersey AB 5223/ SB 3732 are examples of this type of policy. The bill proposed applying a supplemental discount rate to the price of concrete bids with lower GWP. Though AB 5223 did not pass as is, New Jersey Governor Phil Murphy signed SB 287/ AB 2234, the Low Embodied Carbon Concrete Leadership Act (LECCLA), into law on January 30, 2023. This law is an incentive program that provides an income tax credit of up to 8% to manufacturers of low-carbon concrete who supply at least 50 yards of concrete for state-funded projects.[8] The bills that make up LECCLA are a carryover of AB 5223/ SB 3732.

As a policy lever, public sector incentives are less impactful than Buy Clean acts because they incentivize the use of low carbon materials rather than mandate it.

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7. "GWP Limits – Buy Clean California Act," California Department of General Services, accessed January 3, 2023, https://www.dgs.ca.gov/PD/Resources/Page-Content/Procurement-Division-Resources-List-Folder/Buy-Clean-California-Act.
8. Chris Neidl, *New Jersey Adopts First-of-a-Kind Low Carbon Concrete*, NRDC, January 31, 2023, https://www.nrdc.org/experts/sasha-stashwick/new-jersey-adopts-first-kind-low-carbon-concrete-law.

3.3.3 Owner procurement guidelines

In addition to owner design standards, owners may have internally developed procurement guidelines, including preferred products. GSA has Low Embodied Carbon Concrete and Environmentally Preferable Asphalt standards, which are integrated into their P100 design standard. The low carbon concrete standard requires product-specific EPDs and demonstration that mixes meet specific GWP limits. The environmentally preferable asphalt standards similarly require product-specific EPDs along with integration of low carbon asphalt strategies, such as use of reclaimed asphalt pavement.

The Inflation Reduction Act provides the Environmental Protection Agency (EPA) with funding to support the development and standardization of EPDs for construction materials and to develop a low-embodied carbon labeling for construction materials. Additionally, the Inflation Reduction Act directs funding to GSA and the Federal Highway Administration (FHWA) to purchase low carbon materials. EPA was tasked with defining low carbon materials for GSA and FHWA. An interim determination from EPA was issued December 22, 2022 to allow GSA and FHWA to begin establishing criteria for product purchasing.[9] The interim determination specifies that low-GWP materials qualified for funding should be in the best performing 20% of comparable materials. GSA has responded to the interim determination with draft GWP limits for concrete, asphalt, steel, glass, and cement.

Owner procurement guidelines, specifically for large scale building owners like GSA, have the potential to encourage lower carbon material production through increased demand. The impacts to market availability of new low carbon material options can then benefit the industry overall.

3.4 Waste & circularity

After planning regulations are implemented during the feasibility stage of a project, followed by building codes during the design stage of a project, and clean procurement policies during the procurement phase of a project, the building is constructed, occupied, and eventually deconstructed or demolished. There are various policies that address waste that occurs during construction and at the building end-of-life.

Waste and circularity refer to policies, often passed by local city governments, to handle construction waste, demolition, and material reuse. The Delta Institute estimates that up to 70% of building materials can be recycled, and up to 25% can be reused for a typical single-family home.[10] The most common policy measures include construction and demolition waste diversion requirements and deconstruction ordinances, which require building assessments and/or disassembly that supports reuse of building components.

Waste & circularity sub-categories:

- Construction & demolition diversion
- Deconstruction ordinances

3.4.1 Construction & demolition diversion ordinance

CALGreen contains a mandatory requirement that 65% of construction and demolition waste is to be diverted or recycled. Some local jurisdictions have instituted additional requirements. In San Francisco, the Construction and Demolition Debris Recovery Law amends the San Francisco Environment Code and requires that construction and debris material removed from buildings in San Francisco must be recycled or reused, rather than sent to a landfill or incinerator.

While construction and demolition diversion policies can be written to apply to all projects, they are enacted locally so have limited reach. Additionally, because the impact of construction waste on whole building life-cycle carbon emissions is minimal, these policies are limited in direct impact, although they could potentially help to establish a supply of reused material for future buildings..

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9. Janet J McCabe to Mr. Andrew Wishnia and Mr. Kevin Kampschroer, December 22, 2022, U.S. Environmental Protection Agency, https://www.epa.gov/system/files/documents/2023-01/2022.12.22%20Interim%20Determination%20on%20Low%20Carbon%20Materials%20under%20IRA%2060503%20and%2060506_508.pdf.

10. Delta Institute, *Deconstruction & Building Material Reuse: A Tool for Local Governments & Economic Practitioners* (Delta Institute, May 2018).

3.4.2 Deconstruction ordinance

Some cities have banned demolition altogether in favor of deconstruction. The Palo Alto Deconstruction and Construction Materials Management Ordinance states that as of July 2020, any residential or commercial projects where structures are being completely removed are required to obtain a salvage survey as part of the building permit process. Materials are required to be separated into materials for reuse or recycling. Prior to the final inspection for the building permit, the permit holder must show that materials on the salvage survey were correctly salvaged. Outside of California, both Portland, Oregon and San Antonio, Texas, have deconstruction policies in place.

The movement towards deconstruction can result in embodied carbon savings from limiting production of new materials and raw material sourcing through material reuse. At the same time, deconstruction requires the city to have proper entities to deconstruct building components, transport and store salvaged materials, and effectively market them to builders. Salvaged materials also need a place to go; policies that incentivize or require reuse should address all steps from deconstruction to reuse on site.

3.5 Climate commitment

Climate commitment refers to broad mandates or initiatives, often through executive action, to set GHG emission limits targets that support, either directly or indirectly, embodied carbon requirements. Climate commitments are all voluntary in nature but are often the first step in setting goals that inform the development of supporting policies.

Climate commitment sub-categories:

- Executive orders
- Climate action plans
- Private sector commitments

3.5.1 Executive orders

Executive orders (EOs) are issued by the executive branch of a government. In California, EOs are issued by the Governor. EOs provide the basis upon which other bills are built upon. For example, AB 2446 references EO B-55-18, which ordered a state-wide goal to achieve carbon neutrality as soon as possible, but no later than 2045, and to achieve and maintain net negative emissions thereafter.

New York City EO 23, issued in 2022, mandates the use of low carbon concrete, low emission vehicles and equipment, EPDs, and WBLCA on all capital construction projects under capital project agencies. Because EO 23 was issued as an executive order, its applicability had to be limited in scope to public sector projects.

In California, because bills related to embodied carbon have already passed through the state legislature, which has farther reach than the executive office, policy levers focused on state and local legislatures are deemed to be more effective and impactful.

3.5.2 Climate action plans

Climate action plans generally include GHG emissions reduction targets and detail action to help meet those goals. As part of the climate action plans, GHG quantification is often included. Historically, climate action plans have included scopes 1 and 2 GHG accounting and have not included scope 3, under which most all embodied carbon emissions are accounted for.

California regions with climate action plans inclusive of embodied carbon policies and programs include Marin County, Albany, Oakland, San Francisco, and Dublin in northern California. In Southern California, Los Angeles's Green New Deal Sustainable City "pLAn" also includes embodied carbon. A more comprehensive list of climate action plans which include embodied carbon is provided in Appendix A.

3.5.3 Private sector commitments

Climate commitments also cover private corporations, especially those with environmental, social, and governance (ESG) commitments and guidelines. ESG guidelines may require GHG accounting, including scope 3 emissions. In California, SB 260, the Climate Corporate Accountability Act, requires CARB to develop and adopt regulations requiring corporations with revenues in excess of $1 billion doing business in California to disclose their greenhouse gas (GHG) emissions. This bill failed on the assembly floor. The Securities and Exchange Commission has proposed rulemaking to enhance and standardize climate-related disclosures for investors, including any claims made by publicly traded companies on their scope 3 emissions.

One climate commitment example comes from C40 Cities. The C40 Clean Construction Forum aims to reduce construction emissions, particularly related to materials and machinery. These cities are engaging the private sector and trying to push the market forward in supplying low emission materials. They are also working on coordinating tools and data to help assess construction emissions and the impact of materials, all of which influence embodied carbon. Los Angeles is a signatory to C40's Clean Construction Declaration, which promises to halve emissions from all construction activities by 2030.

Some large-scale owners voluntarily participate in initiatives harnessing their purchasing power, such as the First Movers Coalition, which is an initiative seeking to decarbonize certain industrial sectors.[11] These types of initiatives can send strong market signals to address embodied carbon. The Green Public Procurement Pledge is another voluntary commitment program, this one focused on national and local governments to reduce carbon from public construction projects.[12] The pledge can be used as a supplemental commitment that is more aggressive than Buy Clean acts.

Climate commitments can help drive policy momentum and market transformation within embodied carbon, but without the right set of incentives or enforcement mechanisms, it can also fall short of its intended goal.

3.6 Training & education

Training and education refers to policies that influence how professionals and other stakeholders are educated on embodied carbon. Training and education helps to ensure embodied carbon reduction strategies that rely on the participation of multiple stakeholders can be implemented successfully. For example, the use of performance-based specifications by design teams helps to allow for the use of low carbon concrete technology on projects by removing prescriptive requirements. However, the use of performance-based specifications is not something that can be easily regulated, so it is contingent upon proper training and education to support their use.

Strategies in this policy section themselves may not be technically feasible as policy requirements (or require nuance based on a building's use case and local context) but provide important considerations for optimizing embodied carbon. Therefore, training and education requirements on embodied carbon and high-impact strategies can be embedded into existing professional certification and training frameworks.

Training & education sub-categories:

- Professional certifications
- Industry-led educational initiatives

11. "First Movers Coalition," World Economic Forum, accessed February 17, 2023, https://www.weforum.org/first-movers-coalition.
12. *Press release: UN-led coalition to release targets to cut carbon from public construction projects*, Industry Energy Accelerator, September 21, 2022, https://www.industrialenergyaccelerator.org/general/press-release/.

3.6.1 Professional certification

Professional licensure for practicing design professionals is administered by licensing agencies using statewide requirements. Professional licensing requirements vary state by state and typically include continuing education requirements. Continuing education courses are typically developed by NGOs and are specifically designed to meet the license renewal requirements.

In California, the state legislature can regulate the state licensure requirements. AB 1010 is one example of the legislature creating such training and education requirements. Through AB 1010, which passed in 2021, all licensed architects in the state of California must go through five hours of continuing education every two years (when renewing their license) specifically on the topic of net-zero carbon design.

Other continuing education programs for license maintenance, which span professional engineering licensing to sustainability certifications (e.g., USGBC LEED Green Associate), can incorporate similar requirements or even be more specific regarding embodied carbon training to expand the capacity of design professionals to advocate for these changes at a larger scale.

3.6.2 Industry-led educational initiatives

Industry organizations and NGOs, such as NRDC, NBI, RMI, and CLF, play a large role in aggregating and disseminating information for project teams to improve embodied carbon practices in the building design process. It also involves forming task groups and working groups to collaborate on best practices, improve implementation potential, and set commitments. Examples of such groups include the Structural Engineering Institute's SE 2050 Commitment and the AIA 2030 Commitment. There is also potential to influence certification organizations, such as USGBC or ILFI, to strengthen embodied carbon requirements in their certification programs. LEED includes a number of material use and material waste credit options and ILFI's Zero Carbon certification sets embodied targets alongside operational carbon targets.

Training and education may not have the direct embodied carbon reductions other policy categories have, but they can help create major changes at the project level when top-down policies face other challenges. More knowledge within the practitioner community can also motivate designers and contractors to contribute to embodied carbon advocacy efforts.

Conclusion and recommendations

4 Conclusion and recommendations

This report focuses on policy levers at the state and local level in California that can achieve embodied carbon reduction for both public and private sector buildings projects.

Based on evaluating both ease of implementation and magnitude of reduction potential, policies taking both a building-focused approach and material-focused approach have the highest potential emissions reduction potential. Moreover, both a building-focused approach and material-focused approach can be effectively integrated into building codes. A building-focused approach uses whole building life-cycle assessment to evaluate performance. A material-focused approach uses environmental product declarations to evaluate performance.

In California, approved mid-cycle changes to incorporate mandatory embodied carbon requirements into the statewide green building code (CALGreen) are expected to go into effect in 2024. Additionally, local jurisdictions in California can accelerate their impact by adopting CALGreen tier 1 or tier 2 embodied carbon requirements, which are more stringent, as mandatory. Tier 1 or tier 2 requirements can be adopted at the local level as mandatory through local green building code amendments or can be used as alternative compliance pathways through local stretch codes.

The CALGreen whole building life-cycle provisions will require design teams to demonstrate a set reduction against a baseline defined by the design team, along with alternative prescriptive pathways for building reuse and low carbon material selection. However, standardized, regionally relevant whole building level embodied carbon benchmarks set by a jurisdiction, similar to those used in building energy performance standards, are not currently available due to lack of data and challenges with data quality. To build up the necessary data, planning policies could be used by jurisdictions to require the reporting of building embodied carbon to eventually set appropriate benchmarks. This approach is being implemented in London and considered in Boston and neighboring Cambridge. The London planning policy does not require projects to meet a set benchmark; however, a project's embodied carbon performance is considered as part of the planning approvals in a more qualitative manner.

Zoning incentives offered through planning policies pair well with the regulatory requirements to encourage embodied carbon reduction strategies. The City of Los Angeles has an Adaptive Reuse Ordinance to incentivize building reuse. The City of Emeryville has a development bonus density incentive for the use of mass timber in place of more carbon-intensive structural materials. Because zoning ordinances are issued at the local level, these incentives can also be relatively easy to implement. These zoning incentives can also help to overcome a major hurdle in implementing larger scale embodied carbon reduction strategies – cost.

Overall, while many emerging polices address material-level carbon performance, it is recommended that more focus goes into policies that encourage project- and building- scale reductions. This study has shown the gap and opportunity of policies focused on planning and design of whole buildings. Advancing building-focused policy approaches at the same time as materials-focused approaches would accelerate the buildings sector towards a zero-carbon future.

Appendix A
Policy summaries

California state level policies

Policy	Relevant to	Date	Status	Summary
Assembly Bill 338	Clean Procurement	October 7, 2005	Adopted	AB 338 requires the use of crumb rubber in asphalt procured by Caltrans. Available at http://www.leginfo.ca.gov/pub/05-06/bill/asm/ab_0301-0350/ab_338_bill_20051007_chaptered.html.
Assembly Bill 32: Global Warming Solutions Act	Climate Commitment	September 27, 2006	Adopted	AB 32 required GHG emissions reductions to 1990 levels by 2020. CARB was the lead agency to implement the law and eventually directed CBSC to develop green building standards. Available at https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=200520060AB32&search_keywords.
Senate Bill 1473: California Building Standards Law	Building Codes	September 30, 2008	Adopted	SB 1473 gave CBSC the authority to adopt, approve, codify, update, and publish green building standards for any occupancy. This in turn led to the development of CALGreen, which was the first in the nation green building code when adopted in 2009. The most recent version (2022 CALGreen) became effective January 1, 2023. CALGreen is available at https://www.dgs.ca.gov/BSC/CALGreen. SB 1473 is available at http://www.leginfo.ca.gov/pub/07-08/bill/sen/sb_1451-1500/sb_1473_bill_20080930_chaptered.html.
Assembly Bill 262: Buy Clean California Act	Clean Procurement	October 15, 2017	Adopted	AB 262 was introduced and passed by the state legislature in 2017. This was the first Buy Clean legislation to be adopted in the United States. Available at https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180AB262.
Senate Bill 260: Climate Corporate Accountability Act	Climate Commitment	January 26, 2021	Failed	SB 260 would require companies doing business in California that have greater than $1 billion in revenue to report their scope 1, 2, and 3 emissions. Available at https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202120220SB260.
Senate Bill 7: Jobs and Economic Improvement Through Environmental Leadership Act	Climate Commitment	May 20, 2021	Adopted	SB 7 re-enacts and expands the California Environmental Quality Act (CEQA) streamlining provisions for “environmental leadership development projects” that were originally adopted in the 2011 Jobs and Economic Improvement Through Environmental Leadership Act (AB 900) until 2026. It also expands the types of projects that can be certified to include certain qualifying housing development projects, and provides revised procedures for the quantification and mitigation of GHG emissions for eligible projects. Available at https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=202120220SB7.
Senate Bill 778: Buy Clean California Act	Clean Procurement	May 20, 2021	Failed (Passed Senate)	In 2021, SB 778 and AB 1369 were amendments introduced to fill in gaps in the Buy Clean California Act. SB 778 builds upon AB 262 by including concrete as a covered material. SB 778 would have introduced concrete as an eligible material, updated the EPD requirements, and added performance-based specification requirements and performance incentives for concrete. Available at https://leginfo.legislature.ca.gov/faces/billVotesClient.xhtml?bill_id=202120220SB778.
Assembly Bill 1010: Net-Zero Carbon Continuing Education Act	Training & Education	September 16, 2021	Adopted	AB 1010 requires all licensed architects in the state of California to go through five hours of net-zero carbon design continuing education every two years (when renewing a professional license). Available at https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202120220AB1010.
Assembly Bill 2446: Carbon Intensity of Construction and Building Materials Act	Building Codes	September 16, 2021	Adopted	AB 2446 requires the Energy Resources Conservation and Development Commission (in consultation with the CARB) to design a framework for measuring and reducing the carbon intensity of construction and materials to achieve an 80% net reduction in new construction by 2045, with interim goals of 20% below 2020 levels by 2030 and 40% below 2020 levels by 2035. Available at https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202120220AB2446.
Senate Bill 596	Climate Commitment	September 23, 2021	Adopted	SB 596 requires the state board to develop a comprehensive strategy for the state’s cement sector to achieve net-zero emissions of greenhouse gases of cement used within the state as soon as possible. Available at https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202120220SB596.
Assembly Bill 1369: Buy Clean California Act	Clean Procurement	January 31, 2022	Failed (Passed Assembly)	In 2021, SB 778 and AB 1369 were amendments introduced to fill in gaps in the Buy Clean California Act. AB 1369 would have introduced finish materials and shifted the requirement for EPDs to be product-specific instead of facility-specific, but it did not pass. Available at https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=202120220AB1369.
Senate Bill 1297	Clean Procurement	May 24, 2022	Failed (Passed Senate)	SB 1297 would require the Energy Resources Conservation and Development Commission to develop a plan to advance low-carbon materials and methods in building and construction projects. Available at https://legiscan.com/CA/drafts/SB1297/2021.

California local level policies

Policy	Relevant to	Effective date	Status	Summary
Los Angeles Adaptive Reuse Ordinance	Planning	December 20, 2001	Adopted	The Adaptive Reuse Ordinance helps facilitate the conversion of older, economically distressed, or historically significant buildings to apartments, live/work units, or visitor-serving facilities to reduce vacant space and preserve LA's architectural and cultural past. Available at https://www.ladbs.org/docs/default-source/publications/ordinances/adaptive-reuse-ordinance---l-a-downtown-incentive-areas.pdf.
San Francisco Green Building Code	Building Codes	2006	Adopted	Municipal buildings must achieve LEED certification (LEED Gold if above 10,000 gross square feet), divert at least 75% of construction and demolition debris, and meet other green building requirements within Chapter 7. Available at https://codelibrary.amlegal.com/codes/san_francisco/latest/sf_environment/0-0-0-577.
San Raphael Climate Action Plan	Climate Commitments	April 23, 2019	Adopted	The City of San Rafael's Climate Action Plan includes an item to use carbon-sequestering building materials. Available at https://storage.googleapis.com/proudcity/sanrafaelca/uploads/2019/06/Att-D-CCAP-2030-Final-Draft-4-23-19.pdf.
Los Angeles Green New Deal Sustainable City "pLAn"	Climate Commitments	April 29, 2019	Adopted	Los Angeles's Green New Deal Sustainable City "pLAn" incorporates embodied carbon. Available at https://plan.lamayor.org/sites/default/files/pLAn_2019_final.pdf.
San Anselmo Climate Action Plan	Climate Commitments	June 11, 2019	Adopted	The City of San Anselmo's Climate Action Plan includes an item to use carbon-sequestering building materials. Available at https://www.townofsananselmo.org/DocumentCenter/View/24823/San-Anselmo-Climate-Action-Plan-2030-pdf?bidId=.
Albany Climate Action Plan	Climate Commitments	December 2, 2019	Adopted	Albany's 2019 Climate Action and Adaptation Plan includes embodied carbon. Available at https://www.albanyca.org/home/showpublisheddocument/43215/637116692863100000.
Marin County Low Carbon Concrete Code	Building Codes	December 17, 2019	Adopted	The Marin County Low Carbon Concrete Code contains a set of requirements that reduce the greenhouse gas emissions of concrete while still maintaining the strength and durability of concrete. This plan is also referred to as the Bay Area Low Carbon Concrete Code. Available at https://www.marincounty.org/-/media/files/departments/cd/planning/sustainability/low-carbon-concrete/12172019-update/low-carbon-concrete-code.pdf?la=en.
Palo Alto Deconstruction & Construction Materials Management Ordinance	Waste & Circularity	July 1, 2020	Adopted	The Palo Alto Deconstruction & Construction Materials Management Ordinance prohibits demolition for construction projects, instead requiring deconstruction. Available at https://codelibrary.amlegal.com/codes/paloalto/latest/paloalto_ca/0-0-0-65161.
Oakland Climate Action Plan	Climate Commitments	July 24, 2020	Adopted	Oakland's 2030 Equitable Climate Action Plan (ECAP) includes embodied carbon. Available at https://cao-94612.s3.amazonaws.com/documents/Oakland-ECAP-07-24.pdf.
Dublin Climate Action Plan	Climate Commitments	September, 2020	Adopted	Dublin's Climate Action Plan 2030 and Beyond (CAP 2030) includes embodied carbon. Available at https://www.dublincapupdate.com/wp-content/uploads/2020/10/Final-CAP-edit.pdf.
San Francisco, Los Angeles C40 Clean Construction Declaration	Climate Commitments	November 24, 2020	Adopted	Los Angeles is a signatory city to C40's Clean Construction Declaration. Available at https://www.c40.org/wp-content/uploads/2021/11/CLEAN_CONSTRUCTION_CITIES_101121.pdf.
Marin Climate Action Plan	Climate Commitments	December 8, 2020	Adopted	The Marin Climate Action Plan has a section on consumption-based emissions that addresses embodied carbon by recommending policy and program development that explores low-embodied carbon or carbon-sequestering materials. Available at https://www.marincounty.org/-/media/files/departments/cd/planning/sustainability/climate-and-adaptation/cap-2030_12082020final.pdf.
Fairfax Climate Action Plan	Climate Commitments	July 7, 2021	Adopted	The Town of Fairfax's Climate Action Plan has two small pieces that address embodied carbon in Section S-4 Building Materials: Encourage use of climate-friendly building materials that store more carbon dioxide than is released in their production through agency partnerships and engagement campaigns. Available at https://www.townoffairfax.org/documents/climate-action-plan_2030/. Adopt an ordinance requiring the use of low carbon concrete in new construction based on the County's model ordinance (Ordinance No. 3717, adopted November 2019).

Policy	Relevant to	Effective date	Status	Summary
Larkspur Climate Action Plan	Climate Commitments	July 21, 2021	Adopted	The City of Larkspur's Climate Action Plan has two small pieces that address embodied carbon: EE-C4: Green Building Reach Code: b) consider adopting low embodied-carbon concrete standards similar to hose adopted by the County of Marin (p28) SA-C2: Carbon Sequestration: a) where appropriate, encourage the use of building materials that store carbon through agency partnership and engagement campaigns (pg36) Available at https://www.ci.larkspur.ca.us/DocumentCenter/View/13508/Final-Larkspur-CAP-2030-October-2021?bidId=.
San Leandro Climate Action Plan	Climate Commitments	August 6, 2021	Adopted	The San Leandro Climate Action Plan has a strategy that directly addresses embodied carbon — CC-3: "Low-carbon building materials." It directs the City to "work with local, regional, and State partners to expand the awareness of, availability, and cost-effectiveness of low-carbon or carbon-free construction materials." Available at https://www.sanleandro.org/DocumentCenter/View/6490/San-Leandro-CAP-ADOPTED-2021-08-06.
San Francisco Construction and Demolition Debris Recovery Law	Waste & Circularity	January 1, 2022	Adopted	Under the ordinance, C&D debris material removed from a project in San Francisco must be recycled or reused. No C&D debris can be transported to or disposed of in a landfill or incinerator or put in a designated trash bin.
San Francisco Climate Action Plan	Climate Commitments	January 24, 2022	Adopted	San Francisco's Climate Action Plan includes embodied carbon. Available at https://sfenvironment.org/sites/default/files/events/cap_fulldocument_wappendix_web_220124.pdf.
Emeryville Mass Timber Development Density Bonus	Climate Commitments	May 26, 2022	Introduced	The City of Emeryville is considering including the use of "Mass Timber," said to be a more "sustainable" building product, be included in a list of community benefits developers can provide in exchange for additional building height. Available at https://www.ci.emeryville.ca.us/DocumentCenter/View/14143/Item-93—-Mass-Timber-Bonus-Points.
Belvedere Climate Action Plan	Climate Commitments	June 13, 2022	Adopted	The City of Belvedere's Climate Action Plan has two small pieces that address embodied carbon: EE-3: Green Building Reach Code: a) consider adopting low embodied-carbon concrete standards similar to those adopted by the County of Marin (p21) SA-2: Carbon Sequestration: b) where appropriate, encourage the use of building materials that store carbon through agency partnership and engagement campaigns (pg32) Available at https://www.cityofbelvedere.org/DocumentCenter/View/8019/Belvedere-Climate-Action-Plan-2030?bidId=.
Tiburon Climate Action Plan	Climate Commitments	September 21, 2022	Adopted	The Town of Tiburon's Climate Action Plan has a couple of pieces that address embodied carbon: EE-C4: Green Building Reach Code - Adopt a green building ordinance for new and remodeled commercial and residential projects that requires green building methods, materials, and efficiency above the State building and energy codes. Consider adoption of low embodied-carbon concrete standards similar to those adopted by the County. EE-C6 Sustainable Building Materials - Study alternatives and draft regulations that require use of Forest Stewardship Council certified material in new constructions, major remodels, and outdoor use and that prohibit use of non-certified old-growth and other materials. WR-C3: Construction & Demolition Debris and Self-Haul Waste - Require all loads of construction & demolition debris and self-haul waste to be processed for recovery of materials as feasible. Investigate creation of an ordinance requiring deconstruction of buildings proposed for demolition or remodeling Available at http://townoftiburon.org/DocumentCenter/View/917/Climate-Action-Plan-2022?bidId=.

Referenced state, national, and international policies

These policies reference state, national, and international policies outside California but referenced within the text of this report. This is not an exhaustive list of every embodied carbon policy outside of California.

Policy	Relevant to	Effective date	Status	Summary
Article 37, Boston Zoning Code	Planning	January 10, 2007	Adopted	As of 2007, Boston's zoning code includes Article 37, which requires all projects to be LEED certified and meet other sustainability and resiliency requirements. Available at http://www.bostonplans.org/getattachment/a77140ba-cdd0-48fb-9711-84540bf31f35.
Deconstruction Ordinance (Code Chapter 17.106) in Portland, Oregon	Waste and Circularity	October 31, 2016	Adopted	Portland's Deconstruction Ordinance, now codified in Code Chapter 17.106, requires all residential projects (single-family and duplexes) seeking a demolition permit to be fully deconstructed if built before 1940 and/or designated as historic. Available at https://www.portland.gov/bps/decon/documents/deconstruction-ordinance/download.
New York SB 542A and AB 2591A: Low Embodied Carbon Concrete Leadership Act (LECCLA)	Clean Procurement	SB 524A: January 6, 2021 AB 2591A: January 19, 2021	Adopted	Both Senate Bill 542A and Assembly Bill A2591A contribute to the New York State Low Embodied Carbon Concrete Leadership Act (LECCLA). The law develops guidelines for low embodied carbon concrete use in state agency procurement. It also provides potential recommendations for use of bid credits of up to five percent, performance-based specifications for concrete, and expediting product evaluations to promote low embodied carbon concrete development. Available at https://www.nysenate.gov/legislation/bills/2021/A2591 and https://www.nysenate.gov/legislation/bills/2021/S542.
New Jersey AB 5223 and SB 3732	Clean Procurement	January 7, 2021	Failed	Assembly Bill 5223 (and Senate Bill 3732) provides a CBT tax credit for certain deliveries of low carbon concrete and for costs of conducting environmental product declaration analyses of low carbon concrete. Both bills were a precursor to A2234 and S3732. Available at https://pub.njleg.gov/bills/2020/A9999/5223_R2.HTM.
Greater London Plan	Planning	March 2, 2021	Adopted	The London Plan, which is issued by the Greater London Authority, now includes whole life-cycle carbon assessment for projects of strategic importance to London as of March 2021. This can be found in Policy SI 2 of the London Plan. Available at https://www.london.gov.uk/sites/default/files/the_london_plan_2021.pdf.
GSA P100	Clean Procurement	March 17, 2022	Adopted	GSA has Low Embodied Carbon Concrete and Environmentally Preferable Asphalt standards in its P100 Facilities Standards for the Public Buildings Service. The design standard also includes a requirement for all new construction and major modernization projects to target a 20% embodied carbon reduction by performing a WBLCA. Available at https://www.gsa.gov/real-estate/design-and-construction/engineering-and-architecture/facilities-standards-p100-overview.
Vancouver Building By-law	Building Codes	May 5, 2022	Adopted	Vancouver City Council approved changes to the Vancouver Building By-law to require designers to calculate, limit, and later reduce, embodied carbon in new commercial buildings over a certain size threshold. The Vancouver Building By-law includes provisions for performing a comparative WBLCA against a baseline building. Available at Report, Climate Emergency – Bylaw and Policy Updates Applicable to New Buildings, May 17, 2022 (vancouver.ca).
New York City Executive Order 23	Climate Commitments	September 22, 2022	Adopted	Executive Order 23 states requirements for Clean Construction in the state of New York. Capital projects should include low-carbon concrete specifications wherever possible, submit product-specific EPDs for concrete and structural steel, specify all-electric equipment where possible, and submit LCA reports. Capital Project agencies will deliver action plans to reduce embodied carbon by October 1, 2023. Available at https://www.nyc.gov/assets/home/downloads/pdf/executive-orders/2022/eo-23.pdf.
San Antonio City Code, Chapter 12 – Vacant Buildings and Deconstruction	Waste and Circularity	October 1, 2022	Adopted	As of 2022, San Antonio added Deconstruction requirements into its City Code that requires certain projects seeking a demolition permit to be fully deconstructed; buildings currently subject to this policy include residential single-family structures, multi-unit structures 4 units or less, accessory structures, and any historically designated buildings before 1940. The ordinance will expand to include larger structures in 2025. Available at https://www.sanantonio.gov/LinkClick.aspx?fileticket=Qck9XLxHGhY%3d&portalid=0.
Inflation Reduction Act	Owner Procurement Guidelines	December 22, 2022	Adopted	Under the Inflation Reduction Act Sections 60503 and 60506, the EPA delivered an interim determination for GSA, the DoT/Federal Highway Administration on low greenhouse has construction materials. It specifies that low-GWP materials qualified for funding should be in the best performing 20% of comparable materials (lowest 20% of embodied greenhouse gas emissions). If materials in the project location do not meet that standard, the materials may be in the top 40%, and if the materials cannot meet the lowest 40% threshold, the materials must perform better than the industry standard. Available at https://www.congress.gov/bill/117th-congress/house-bill/5376.
New Jersey SB 287 and AB 2234: Low Embodied Carbon Concrete Leadership Act (LECCLA)	Clean Procurement	January 30, 2023	Adopted	Senate Bill 287 and Assembly Bill 2234, the Low Embodied Carbon Concrete Leadership Act (LECCLA), into law. This law is an incentive program that provides an income tax credit of up to 8% to manufacturers of low-carbon concrete who supply at least 50 yards of concrete for state-funded projects. Available at https://www.njleg.state.nj.us/bill-search/2022/S287.

Appendix B
Data analysis

Data methodology

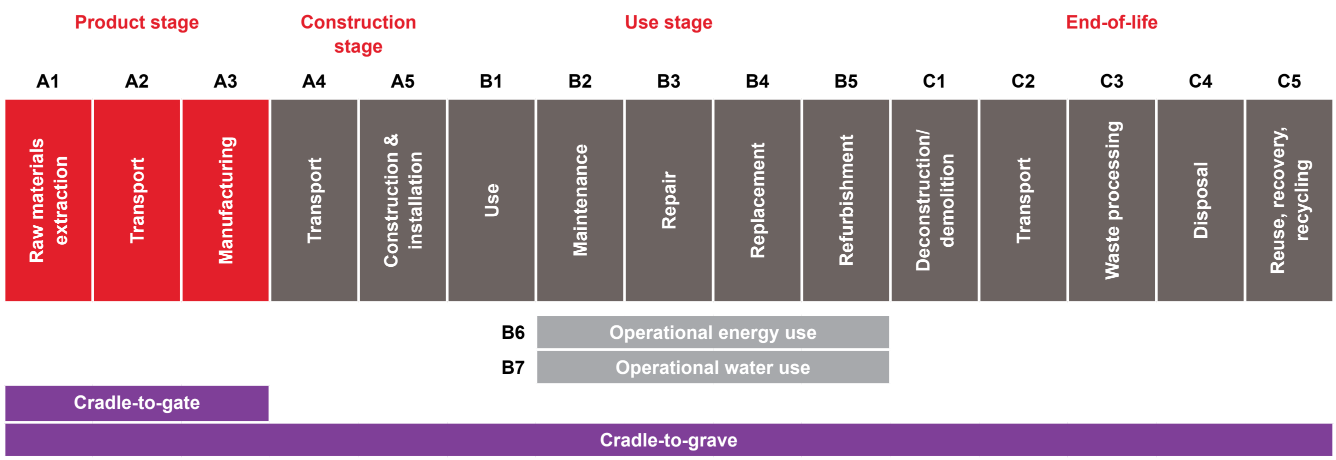
The data methodology for this project is modeled after the methodology used by the CLF report *Developing an Embodied Carbon Policy Reduction Calculator*.[14] However, while the CLF developed their calculator for use by individual cities, counties, or other local agencies, the aim in this report is to account for the entire state of California.

Scope

EN 15978 *Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method* defines the life-cycle stages of whole building life-cycle assessment. These stages include product (A1-A3), construction (A4 and A5), use (B1-B7), and end-of-life (C1-C4). Benefits beyond the building life-cycle are reported in stage D.

For the purposes of this report, the scope of the embodied carbon reduction potential calculation will be focused on the product stage (A1-A3). Building embodied carbon intensity (BECI) values provided in the CLF report account for A1-A3 only. The majority of embodied carbon emissions of buildings occur during the product stage and occur prior to building construction and occupancy.

Strategies impacting other stages beyond A1-A3 are excluded from the reduction potential calculation. This includes any optimize construction strategies, as these occur during A4 and A5 stages. Additionally, any strategies focused on reducing or eliminating demolition and disposal at end of life are excluded, as those occur during the end-of-life stage (C). The following figure shows the full life-cycle stages, with stages included in this report's calculation highlighted in red.



Elements included in the reduction potential calculation are limited to structure, enclosure, and interiors, to align with the BECI values provided in the CLF report. External works (including asphalt) and services are excluded.

14. Brad Benke, Meghan Lewis, Stephanie Carlisle, Monica Huang, and Kate Simonen. Developing an Embodied Carbon Policy Reduction Calculator (Seattle, Washington: Carbon Leadership Forum, University of Washington, 2022), http://hdl.handle.net/1773/48566.

Reduction timeline

Reduction potential is scaled linearly assuming the same square footage is constructed each year and that the reduction strategies are applied to their full extent every year in which they are implemented. The timeline considered is through 2045, to align with the carbon neutrality target set by EO B-55-18.

Strategies are identified as being able to be implemented either in the immediate, near term, long term, or phased. Immediate assumes implementation day one, near term assumes implementation in five years, and long term assumes implementation in 15 years. Phased strategies are assumed to be linearly phased in with 100% implementation possible by 2045.

Data

The following data structure is used. Using publicly available data, the total gross square footage (GSF) of each building type is reported. Based on data availability, only residential and commercial construction estimates are included. GSF is based on data for 2021 and assumes the same GSF will be constructed each year, beginning this year (2023). The residential construction data comes from the Census Bureau and the commercial construction data comes from CoStar. Both datasets are understood to cover the entirety of the state of California. The commercial data is comprised of CoStar reported gross delivered square footage for retail and commercial buildings.

The residential construction data from the Census Bureau is quantified by number of units. The following average unit size is applied to each unit type to determine GSF. These average unit sizes are based on the CLF report using values provided for Portland, Oregon as a proxy for California.

		Average Unit Size (ft^2 per unit)
Residential	Single Family	1900
	Two-Unit Buildings	800
	Three & Four Units	800
	Five or More Units	800

The following table shows the annual GSF estimates from the data described above, along with a corresponding BECI, which is based on the CLF report:

		GSF/ year	Building embodied carbon intensity (kg CO_2e/m^2)
Residential	Single Family	125m	200[15]
	Two-Unit Buildings	1.93m	300[16]
	Three & Four Units	1.30m	300[17]
	Five or More Units	39.6m	700[18]
Commercial	All Types	30.0m	600[19]

Currently, Arup is not aware of any publicly available information on breakdown of construction type (e.g., steel-framed, concrete-framed, timber-framed) for each building type listed above in California. However, in lieu of publicly available data, Arup has made the following estimations on the average material breakdown for each building type based primarily on project experience. A report by Builders for Climate Action and the City of Vancouver was also referenced for low-rise residential typologies.[20] The values have been modified assuming an average of the low range and high range assumptions of frame type in the CLF report. Similar to the BECI assumption, it is expected that the values provided are very rough estimates provided in lieu of widely accepted values.

		Contribution to BECI by Material							
		Concrete	Steel	Wood	Glass	Aluminum	Insulation	Interiors	Other Cladding
Residential	Single Family	30%	10%	10%	10%	0%	15%	10%	15%
	Two-Unit Buildings	30%	10%	10%	10%	0%	15%	10%	15%
	Three & Four Units	30%	10%	10%	10%	0%	15%	10%	15%
	Five or More Units	35%	15%	5%	10%	5%	10%	15%	5%
Commercial	All Types	35%	20%	2%	10%	10%	5%	15%	3%

The above BECI breakdown by material assumes the following:

- "Concrete" is inclusive of cast-in-place and precast concrete
- "Steel" is inclusive of structural steel shapes and reinforcing steel (including post-tensioning tendons)
- "Glass" refers to flat glass
- "Interiors" is inclusive of wall, ceiling, and floor finishes
- "Other Cladding" is inclusive of cladding materials other than aluminum

Data needs and research gaps

The data used for this analysis is very approximate due to limited data availability and sources of uncertainty. The following data needs and research gaps have been identified for potential improvements to the analysis:

Construction growth estimates

- Improved construction estimates for California are needed, including additional building typologies, more granular construction data, and public sector data. The current data set only includes private sector residential and commercial construction, therefore the analysis currently does not correctly account for public sector construction. Certain policy types, such as Buy Clean acts, are only directly applicable to public sector construction. This cannot be properly accounted for with the currently limited data set.

Building Embodied Carbon Intensity (BECI)

- BECI benchmarks were developed from a limited amount of national data and not tailored to California. Actual BECI will vary by region due to a number of reasons, including environmental loading requirements for structural design and material availability.
- BECI breakdowns were also based on results from national data and are not specific to California. The current material breakdown is based on assumptions and may not properly reflect typical construction practices in California.

15. Benke, Developing an Embodied Carbon Policy Reduction Calculator, 37. See Building Embodied Carbon Intensity for "Single Family."
16. Benke, Developing an Embodied Carbon Policy Reduction Calculator, 37. See Building Embodied Carbon Intensity for "1-4 Family Rowhouse."
17. Benke, Developing an Embodied Carbon Policy Reduction Calculator, 37. See Building Embodied Carbon Intensity for "Multifamily, Commercial, Institutional ."
18. Benke, Developing an Embodied Carbon Policy Reduction Calculator, 37. See Building Embodied Carbon Intensity for "Multifamily, Commercial" only.
19. Benke, Developing an Embodied Carbon Policy Reduction Calculator, 37. Estimated from stated values.
20. Chris Magwood, Erik Bowden, and Mélanie Trottier, Emissions of Materials Benchmark Assessment for Residential Construction Report (2022), Passive Buildings Canada and Builders for Climate Action.

- BECI data is currently limited to A1-A3. Future research efforts could include incorporating additional life-cycle stages beyond A1-A3. Subsequent life-cycle stages can be responsible for a large portion of embodied carbon emissions and will occur during the timelines considered in this report. Specifically, the data analysis does not consider the demolition and replacement due to tenant fit-out of commercial buildings, as those impacts would occur beyond life-cycle stages A1-A3. A study by the Carbon Leadership Forum indicates that tenant fit-out embodied carbon impacts can equal or exceed upfront embodied carbon over time.[21] To illustrate the significance of this, a rough calculation that takes into account interior fit-out in existing buildings shows that a strategy addressing this impact, like the reuse of commercial interior building products, can be twice as effective in carbon reductions as reuse of commercial core and shell materials which do not experience as much churn. This is shown in Figure 8.[22]

Building systems and materials out of scope

- Incorporating data for exterior works is needed, such as site paving. Concrete and asphalt are used heavily in exterior works and are currently not captured within the analysis. The policy measures of focus in the study were limited to those affecting buildings.
- Incorporating data for services is needed. Services (i.e., mechanical, electrical, and plumbing equipment) have a measurable embodied carbon impact. BECI values ideally would account for the full embodied carbon impact of a building.
- Incorporating data for interior renovations within existing buildings is needed. As noted above, the frequent churn of interiors products due to commercial tenant improvement and home improvements have a measurable embodied carbon impact. Circularity measures to reuse or reduce the use of new products with each cycle could amount to as much in carbon reductions as renewable energy for steel, as shown in Figure 8.[23] The difference between Figure 8 and Figure 2 demonstrates high sensitivity of results to any given reduction and applicability assumption made in the analysis.

Policy and time value

- Accounting for stepped policy impacts is needed. The current analysis assumes all policies can be implemented "day one," although it is acknowledged that policy implementation will be phased.
- Accounting for staged implementation of strategies to avoid duplicative counting is needed. The current analysis assumes all strategies for a given project type and material will be implemented simultaneously, regardless of whether those strategies are in conflict with one another.
- Quantification of the time value of carbon is needed, lending priorities to more immediate implementation.

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21. Barbara X. Rodriguez et. al., "Electrical, Plumbing and Tenant Improvements Over the Building Lifetime: Estimating Material Quantities and Embodied Carbon for Climate Change Mitigation," Energy and Buildings, Volume 226 (November 2020), https://doi.org/10.1016/j.enbuild.2020.110324.
22. This rough calculation assumes 1.31 trillion sq-ft of existing building GFA in 2035, growing to 1.97 trillion in 2045; 40% Class A/B and 60% Class C according to https://www.commercialcafe.com/commercial-real-estate/us/ca/. Assumes BECI for interiors of 90 kgCOe2/m2 amounting to 1.47 MMT CO2e per year. When 50% of this and interiors of new construction is reduced by 50%, this amounts to 0.587 MMT CO2e reduction per year, which is more than 0.244 MMT CO2e estimated for reuse of core and shell components assuming 10% applicability at 85% savings.
23. The above calculation results in 0.587 MMT CO2e reduction per year which is more than the 0.481 MMT CO2e reduction estimated for conversion to renewable energy for steel.

Figure 8: Interiors reuse sensitivity study

Reduction potential by strategy

Optimize project

Embodied carbon reduction strategy category	Specific strategy	Time horizon (Near Term = 5 years, Long Term = 15 years)	Reduction potential by material per building	Carbon storage potential	Percentage of new construction impacted	Source	Annual reduction (MMT CO2e)	Annual carbon storage (MMT CO2e)
Minimize new construction	Avoid new construction	Immediate	100%		10%	"Progressive target" for enhanced building utilization from C40 Cities *Building and Infrastructure Consumption Emissions*.	6.66E-01	0.00E+00
	Optimize space planning	Immediate	10%		100%	Difference between "ambitious target" and "progressive target" for enhanced building utilization from C40 Cities *Building and Infrastructure Consumption Emissions*.	6.66E-01	0.00E+00
Building reuse	Adaptive reuse	Near Term	100%		30%	Based on data from a Gensler study which determined that only 30% of buildings studied were suitable for conversion. Available at https://www.gensler.com/blog/what-we-learned-assessing-office-to-residential-conversions. Assumes only conversion of office to residential is possible and that only the building structure is maintained (conservatively assumes facade and interiors replaced).	7.11E-01	0.00E+00
	Reuse	Immediate	100%		10%	Average of suggested reduction values for retrofit of existing buildings from Structural Engineering Institute Sustainability Committee Carbon Working Group *Achieving Net Zero Embodied Carbon in Structural Materials by 2050*. Assumes only structural materials impacted and that all building typologies can be impacted by the strategy.	3.58E-01	0.00E+00

Optimize system

Embodied carbon reduction strategy category	Specific strategy	Time horizon (Near Term = 5 years, Long Term = 15 years)	Reduction potential by material per building	Carbon storage potential	Percentage of new construction impacted	Source	Annual reduction (MMT CO2e)	Annual carbon storage (MMT CO2e)
Material reuse	Core and shell component reuse	Near Term	10%		100%	Assume 10% of virgin materials can be replaced by salvaged ones, based on assumptions from Structural Engineering Institute Sustainability Committee Carbon Working Group *Achieving Net Zero Embodied Carbon in Structural Materials by 2050*. Assume applies to all materials that are primarily fabricated off-site (concrete is excluded).	2.87E-01	0.00E+00
	Interiors component reuse	Near Term	50%		50%	Based on Carbon Leadership forum fact sheet *Building Material Reuse: The Overlooked Solution to Carbon Reduction*.	2.20E-01	0.00E+00
Whole building life-cycle assessment	Set building level GWP limits	Immediate				No explicit reduction, reductions captured by other strategies that are reflected in WBLCA.	0.00E+00	0.00E+00
Material efficiency	Optimize materials for efficiency	Immediate	10%		100%	Lower end of assumed value from Structural Engineering Institute Sustainability Committee Carbon Working Group *Achieving Net Zero Embodied Carbon in Structural Materials by 2050*.	5.96E-01	0.00E+00
Material substituion	Use timber in place of concrete or steel	Immediate	20%	75%	50%	Lower end of "progressive target" for material switching from C40 Cities *Building and Infrastructure Consumption Emissions*. Applicable to residential and commercial but assumes lower rise residential is already built with timber. For high-rise residential and commercial, assumes only 50% of buildings could viably switch due to their performance requirements. Timber would replace concrete or steel as a structural material. 20% reduction is based on typical reductions of a timber building compared to concrete building based on Arup project experience.	2.21E-01	8.28E-01
	Use lower carbon insulation	Immediate	30%		30%	Assumes 30% reduction when using polyiso in place of XPS insulation based on comparison of supplier-specific EPDs. Assumes XPS represents approximately 30% of total insulation impacts (balance provided by other insulation types, like batt or blow-in).	6.33E-02	0.00E+00
	Use bio-based/renewable insulation materials	Near Term	10%	250%	70%	Assumes that most bio-based and renewable insulation materials are net "sequestering," so therefore we have 100% biogenic carbon savings.	2.53E-02	6.33E-01
Specify low carbon	Use performance-based concrete specifications with GWP limits	Immediate				No explicit reduction, reductions captured by other strategies	0.00E+00	0.00E+00
	Specify average recycled content and GWP limits for steel	Immediate				No explicit reduction, reductions captured by other strategies	0.00E+00	0.00E+00
	Specify forest management practices and GWP limits for timber	Immediate				No explicit reduction, reductions captured by other strategies	0.00E+00	0.00E+00
	Specify GWP limits for CMU	Immediate				No explicit reduction, reductions captured by other strategies	0.00E+00	0.00E+00
	Specify GWP limits for glass	Immediate				No explicit reduction, reductions captured by other strategies	0.00E+00	0.00E+00
	Specify GWP limits for aluminum	Immediate				No explicit reduction, reductions captured by other strategies	0.00E+00	0.00E+00
	Specify insulation products with lower GWP	Immediate				No explicit reduction, reductions captured by other strategies	0.00E+00	0.00E+00
	Specify interiors products with lower GWP	Immediate				No explicit reduction, reductions captured by other strategies	0.00E+00	0.00E+00

Optimize procurement

Embodied carbon reduction strategy category	Specific strategy	Time horizon (Near Term = 5 years, Long Term = 15 years)	Reduction potential by material per building	Carbon storage potential	Percentage of new construction impacted	Source	Annual reduction (MMT CO2e)	Annual carbon storage (MMT CO2e)
Low carbon concrete	Use Portland-limestone cement	Near Term	9%		90%	Based on projected increase to 15% limestone by 2040 from 5% currently from Portland Cement Association *Roadmap to Carbon Neutrality*. Assumes cement is 90% of concrete embodied carbon. Assumes all ready-mix suppliers will switch to Portland-limestone cement, with only 10% of ready-mix suppliers using near or net zero cement.	1.79E-01	0.00E+00
	Use net-to-near zero cement	Long Term	90%		10%	Assumes cement is 90% of concrete embodied carbon and that the cement used is net zero. Assumes limited market availability by 2040 as technology is still in development and may be cost prohibitive in near term.	1.99E-01	0.00E+00
	Avoid overdesigning mix	Immediate	10%		50%	Estimate by using National Ready Mix Concrete Association benchmark values and using a comparison of a 4,000 psi vs. 5,000 psi mix, which would be reflective of using 56-day vs. 28-day strength. Assume this can only be practically applied to 50% of concrete, representing below grade elements, because above grade elements will be governed by schedule needs.	1.11E-01	0.00E+00
	Increased use of readily available SCMs	Immediate	20%		90%	Based on project experience, lower carbon concrete EPDs indicate potential for up to 40% average cement replacement with SCMs. NRMCA benchmark mixes typically have a 20% cement replacement for "business as usual," therefore net reduction assumed as 20%. Assumes all ready-mix suppliers will increase use of SCMs, with only 10% of ready-mix suppliers using near or net zero cement.	3.98E-01	0.00E+00
	Use novel SCMs	Long Term	7%		90%	Based on lower end of predicted carbon reduction relative to ordinary portland cement per LC3 website. Available at https://lc3.ch. Assumes cement is 90% of concrete embodied carbon and that 20% of cement will already have been removed through other strategies. Assumes all ready-mix suppliers will increase use of SCMs, with only 10% of ready-mix suppliers using near or net zero cement.	1.39E-01	0.00E+00
	Use carbon mineralization technology	Near Term	5%	1%	100%	5% is assumed for carbon reduction based on CarbonCure's website, which states 4-6% GWP savings in a brochure titled ""CarbonCure's Impact on the Global Warming Potential (GWP) of Concrete"" on the website www.carboncure.com (see Resources for Architects and Designers under the ""Specify CarbonCure"" dropdown). 1% carbon sequestration assumed based on prior information received from CarbonCure no longer publicly available on the CarbonCure website.	1.11E-01	2.21E-02
	Use carbon sequestration technology in aggregate	Near Term	5%	180%	10%	BluePlanet sequesters 40 kg of CO2e in 100 kg of aggregate. Technology can be used for coarse and fine aggregates; if used for both, concrete can be net carbon-storing.	1.11E-02	3.98E-01
	Clean energy sources	Phased	6%		100%	From Structural Engineering Institute Sustainability Committee Carbon Working Group *Achieving Net Zero Embodied Carbon in Structural Materials by 2050.*	1.33E-01	0.00E+00
	Plant efficiency improvement	Long Term	16%		100%	Based on emissions reductions estimate for low-risk, high-yield opportunities from RMI *Concrete Solutions Guide.* Assumes cement is 90% of concrete embodied carbon.	3.58E-01	0.00E+00

Optimize procurement

Embodied carbon reduction strategy category	Specific strategy	Time horizon (Near Term = 5 years, Long Term = 15 years)	Reduction potential by material per building	Carbon storage potential	Percentage of new construction impacted	Source	Annual reduction (MMT CO2e)	Annual carbon storage (MMT CO2e)
Low carbon steel	Use EAF steel instead of BOF	Near Term	8%		2%	Estimate from a McKinsey & Company *Net-Zero Steel in Construction* report. The report estimates that moving from BOF steel to EAF could meet 8% or more of abatement potential. Because current steel recovery rates are approximately 98%, this would be applicable to only 2% of new steel construction.	1.54E-03	0.00E+00
	Use DRI steel instead of BOF	Long Term	50%		30%	Assumes DRI is 50% reduced impact compared to BOF. Assumes 30% of domestic steel production is BOF and that steel used in California is domestically sourced. Does not assume hydrogen fuel source as technology is not expected to be widely available by 2040.	1.44E-01	0.00E+00
	Clean energy sources	Phased	50%		100%	Stated reduction potential of grid decarbonization for steel from Structural Engineering Institute Sustainability Committee Carbon Working Group *Achieving Net Zero Embodied Carbon in Structural Materials by 2050*. Reflects the fact that steel is primarily domestically sourced from regions with less progressive grid decarbonization targets compared to California.	4.81E-01	0.00E+00
	Plant efficiency improvement	Long Term	15%		100%	Estimated standard assumption.	1.44E-01	0.00E+00
Low carbon timber	Use sustainable forest management practices	Near Term		29%	100%	Based on comparison of FSC managed forest carbon data compared to business as usual from Ecotrust study. Available at https://ecotrust.org/tipping-the-balance-to-more-carbon-storage/.	0.00E+00	1.17E-01
	Clean energy sources	Phased	33%		100%	Based on assumption that A3 value reduced to zero, using industry-wide EPD for glulam.	1.33E-01	0.00E+00
	Plant efficiency improvement	Long Term	15%		100%	Estimated standard assumption.	6.05E-02	0.00E+00
Low carbon insulation	Use HFC-free insulation	Immediate	80%		30%	Assuming a 1:1 substitution of HFC to HFO blowing agents, a reduction potential of 80% for the material itself is estimated, with building envelope affecting 30% of new construction impacted. Other 70% uses insulation that does not contain blowing agents, e.g. mineral wool, batt, etc. which could be in other parts of the building.	1.69E-01	0.00E+00
	Clean energy sources	Phased	50%		100%	Estimated standard assumption.	3.52E-01	0.00E+00
	Plant efficiency improvement	Long Term	15%		100%	Estimated standard assumption.	1.05E-01	0.00E+00
Low carbon glass	Use higher recycled content glass	Long Term	18%		100%	Based on Arup and Saint-Gobain Glass report *Carbon Footprint of Facades: Significance of Glass*. Uses 78% pre-consumer recycled content as baseline value with 93% pre-consumer recycled content considered feasible.	1.22E-01	0.00E+00
	Clean energy sources	Phased	50%		100%	Estimated standard assumption.	3.33E-01	0.00E+00
	Plant efficiency improvement	Long Term	15%		100%	Estimated standard assumption.	9.99E-02	0.00E+00
Low carbon aluminum	Use higher recycled content aluminum	Long Term	65%		100%	Based on increasing pre-consumer recycled content from 40% (16.42 kgCO2e/kg) to 93% (5.72 kgCO2e/kg). These estimates come from a report prepared by Arup and Saint-Gobain Glass report *Carbon Footprint of Facades: Significance of Glass*.	1.93E-01	0.00E+00
	Clean energy sources	Phased	50%		100%	Estimated standard assumption.	1.48E-01	0.00E+00
	Plant efficiency improvement	Long Term	15%		100%	Estimated standard assumption.	4.44E-02	0.00E+00
Low carbon interiors	Select low carbon interiors products	Immediate	50%		100%	Based on LMN Architects' *Tenant Improvements Embodied Carbon Study* comparing scenario 2 to 2013 LMN Office, which represents changes to interiors material selection only.	4.39E-01	0.00E+00
	Clean energy sources	Phased	50%		100%	Estimated standard assumption.	4.39E-01	0.00E+00
	Plant efficiency improvement	Long Term	15%		100%	Estimated standard assumption.	1.32E-01	0.00E+00

Appendix C

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About Arup

Arup is the creative force at the heart of many of the world's most prominent projects in the built environment and across industry. Dedicated to sustainable development, the firm is a collective of 18,000 designers, advisors, and experts working across 140 countries. Founded to be both humane and excellent, we collaborate with our clients and partners using imagination, technology, and rigor to shape a better world.

Authors

Shikha Srinivas

Christine Tiffin

Lauren Wingo
Technical Lead

Frances Yang
Project Manager

arup.com