Embodied Carbon One-for-One Material Substitution Market Characterization

Final Report

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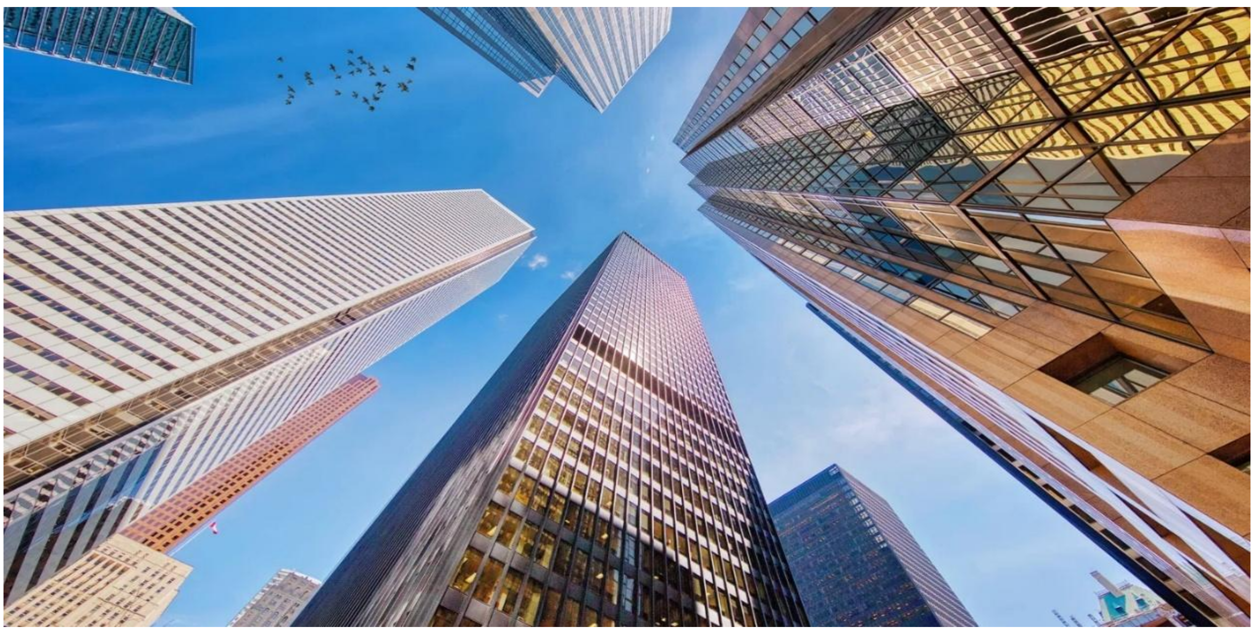

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Executive Summary

This report represents an inaugural study by CalNEXT into embodied carbon, which is defined by the California Air Resources Board as all greenhouse gas emissions resulting from raw material extraction, manufacturing, transportation, construction (including installation and maintenance), and eventual demolition and disposal. Addressing embodied carbon is critical given that it represents 11 percent of global greenhouse gas emissions and increases up to 50 percent of greenhouse gas emissions from buildings as operational carbon is mitigated through energy efficiency and building electrification programs. Addressing embodied carbon is also necessary to achieve California's 40 percent carbon reduction goals below 1990 levels by 2030 and to achieve carbon neutrality by 2045. **While policies are underway** (e.g., CALGreen, Buy Clean California, Senate Bill 596, Assembly Bill 2446, and Assembly Bill 43) **to develop embodied carbon strategies, including the development of an embodied carbon trading system as a potential pathway to implement Assembly Bill 2446, embodied carbon remains largely adjacent to energy efficiency and building decarbonization programs.**

In order to better understand the market dynamics and behaviors of embodied carbon in California, this study attempts to document whether low-embodied carbon building materials are being adopted in California and substituted for standard building materials—also known as one-for-one material substitution. The study team had heard anecdotally that this practice was occurring in other markets, but was not clear on the market adoption trends in California. The project team conducted market research through review of existing studies and reports, accessing and using construction cost and greenhouse gas software, and conducting extensive market actor interviews. Market actor interviewees included architectural, engineering, and construction firms; contractors; building owners; developers; utility representatives; local government officials; sustainability consultants; trade associations and industry consultants; and material manufacturers.

The intent of this study was to document whether market activities for low-embodied carbon materials exists in California and whether incremental greenhouse gas reductions could occur with low-to-no project costs, as well as to identify what the key barriers and market solutions are for reducing embodied carbon in California. The project team focused on three key building materials—concrete, insulation, and steel—to better understand whether material substitutions can result in incremental greenhouse gas impacts. Further, the study aims to highlight future policy and program considerations that may enable harmonization of embodied carbon and energy efficiency programmatic structures. More specifically, **this project sought to test the following four hypotheses**:

1. Embodied carbon can be a ***complementary program pathway*** for energy efficiency and building decarbonization programs that already address operational carbon emissions, but may also present opportunities to reduce embodied carbon impacts while maintaining or potentially increasing energy efficiency savings.
2. One-for-one material substitution can achieve ***incremental greenhouse gas reductions*** at relatively modest project costs by substituting lower-embodied carbon building materials for standard building materials.
3. Embodied carbon can be a ***complementary policy pathway*** to energy efficiency and building decarbonization programs by reducing carbon in buildings.

4. There will be ***limited Environmental Product Declaration data*** for some building material categories, as well as a ***limited understanding of embodied carbon*** among some stakeholder groups, creating opportunities for market awareness for significant greenhouse gas savings from substituting to lower-embodied carbon materials at relatively low to no incremental costs.

Key findings from this market study include:

- **Key drivers** for the adoption of low-embodied carbon materials are ***corporate sustainability goals*** that value Scope 3 emissions, including embodied carbon. On an increasing basis, large corporate customers, such as Prologis, Amazon, and Meta, are announcing plans to adopt low-embodied carbon materials, or the signing of a low-carbon concrete pact (Olick). In this manner, embodied carbon ***is becoming an increasingly recognized and relevant goal,*** especially as certification programs like Leadership in Energy and Environmental Design (LEED) version 5 and green building codes like CALGreen incorporate embodied carbon pathways alongside energy efficiency savings opportunities.
- ***Increasing codes and standards and policies***, such as **CALGreen** (California's Title 24, Part 11) and the **Buy Clean California Act**, use Environmental Product Declarations as a central part of their implementation approach and are increasing overall awareness for embodied carbon.
- ***Overall awareness*** of embodied carbon as a sustainability goal and pathway ***is not yet widely known***. Knowledge of low-embodied carbon products, their availability and pricing are also not well understood. Interviews with embodied carbon stakeholders identified a general expectation of price premiums for low-carbon building materials while also acknowledging a 20 percent greenhouse gas savings potential at low-to-no incremental project cost.

  In particular, concrete suppliers can reduce embodied carbon by 20 percent or more, often without increased cost due to the existing availability of lower-embodied carbon cement products. In most cases, all a customer must do is ask for such a mix. **The cost to achieving a 30 percent or more reduction in embodied carbon does in fact become more expensive**. This points to the need for additional market research to understand the current limits to achieving lower-embodied carbon at low-to-no incremental costs. ***Embodied carbon is increasingly intersecting with other market intervention points of focus.*** During the brief development of this study, the California Air Resources Board announced a Fiscal year 2025-2026 Pre-Proposal Solicitations for Sustainable Transportation and Communities Project focused on **addressing wildfire recovery and sustainable building practices in disadvantaged communities** in California (CARB 2025d).

  Thus, the study of embodied carbon is intersecting with the wildland–urban interface and disadvantaged community impacts, as well as others. The study team also recently became aware of the intersection of Strategic Energy Management programs on reducing embodied carbon in building materials produced in the industrial sector that are installed or delivered to the residential sector. Likewise, there are developing RESNET 1550 standards to characterize and address embodied carbon in residential buildings. **As such, embodied carbon is becoming more relevant for areas of existing energy efficiency programs and developing standards.**

- **One possible next step could target educating and informing the public about embodied carbon.** It is **a common but not entirely accurate perception** among many market actors **that lower embodied carbon automatically makes a material choice more expensive, results in lower performance levels, or negatively extends project schedules. Further, there is a general lack of awareness of Environmental Product Declarations** and how to use them within broad portions of the building market. Sustainability consulting firms and many premier architectural, engineering, and construction firms are well versed in them, but there is limited awareness outside of these circles.
- **Market education activities are underway but on a relatively modest scale.** Key efforts by programs such as Energy Code Ace, Carbon Leadership Forum, the American Institute of Architects, and others are increasing awareness of embodied carbon by offering informational content and the California electric investor-owned utilities already offer embodied carbon education through their education centers**. Yet, there is still a need to inform the market about these opportunities, such as active marketing by the Energy Code Ace team on "Embodied Carbon and CALGreen Embodied Carbon Requirements**" (CEC n.d.), **especially given the reality that embodied carbon represents "upfront carbon,"** meaning the greenhouse gas emissions released during the materials production and construction phases of a building even before it is used or occupied. **These upfront emissions are also not typically reduced over the course of the building's use, but rather, only at key points of design and construction, rehabilitation, or decommissioning. This means that key points of intervention are limited during a building's typical 40-year effective useful life.**
- **There are also various permitting and zoning approaches that may incentivize adoption of low-embodied carbon materials.** For example, a building department could offer a floor area ratio bonus, allowing an extra story to be built on a multistory building, or could offer expedited permitting if low-embodied carbon goals are met.
- Looking forward to future opportunities to harmonize embodied carbon with energy efficiency, a significant step would be **further studies on EC's integration with EE such as the development of an embodied carbon avoided cost calculator**, similar to the refrigerant avoided cost calculator. This would allow quantification of the greenhouse gas benefits of low embodied carbon building materials. There are **additional possible approaches to advance lower-embodied carbon building materials that could involve commercial property assessed clean energy finance, a prize competition format, sales tax waivers, property tax reductions, or reduced permit fees.**

Abbreviations and Acronyms

Acronym	Meaning
AEC	Architecture, engineering, and construction
AHJ	Authority Having Jurisdiction
AI	Artificial intelligence
AISC	American Institute of Steel Construction
BCCA	Buy Clean California Act
BD	Building decarbonization
BOF	Blast furnace (basic oxygen furnace)
CALGreen	California Green Building Standards Code
CARB	California Air Resources Board
CEC	California Energy Commission
CLF	Carbon Leadership Forum
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CPUC	California Public Utilities Commission
C-PACE	Commercial Property Assessed Clean Energy
DAC	Disadvantaged community
DOE	Department of Energy
DPU	Department of Public Utilities
EAC	Environmental Attribute Certificate
EAF	Electric arc furnace
EC	Embodied carbon

Acronym	Meaning
EC ACC	Embodied Carbon Avoided Cost Calculator
EC3	Embodied Carbon in Construction Calculator
EE	Energy efficiency
EPA	Environmental Protection Agency
EPD	Environmental Product Declaration
EPS	Expanded polystyrene
GHG	Greenhouse gas
GSA	General Services Administration
GWP	Global warming potential
HFC	Hydrofluorocarbon
HFO	Hydrofluoroolefin
HVAC	Heating, ventilation, and air conditioning
IOU	Investor-owned utility
$kgCO_2e$	Kilograms of carbon dioxide equivalent
LCA	Life cycle assessment
LCFS	Low-Carbon Fuel Standard
LEED	Leadership in Energy and Environmental Design
NAIMA	North American Insulation Manufacturers Association
NEB	Non-energy benefit
NRMCA	National Ready Mixed Concrete Association
OC	Operational carbon

Acronym	Meaning
PCA	Portland Cement Association
PG&E	Pacific Gas & Electric
PLC	Portland limestone cement
RACC	Refrigerant Avoided Cost Calculator
RMI	Rocky Mountain Institute
SCE	Southern California Edison
SCM	Supplementary cementitious material
SMA	Steel Manufacturers Association
TSB	Total System Benefit
US	United States
WBLCA	Whole-building life cycle assessment
WUI	Wildland–urban interface
XPS	Extruded polystyrene

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Introduction

Historically, energy efficiency (EE) programs have focused on addressing operational energy use and emissions. As California successfully reduces carbon in buildings from operational emissions through increased renewable energy sourcing, EE, and electrification—including building decarbonization (BD) programs, such as TECH Clean California—**embodied carbon (EC) will become an increasing share of the remaining carbon emissions in buildings.** The EC of materials used to construct and maintain buildings contribute significant greenhouse gas (GHG) emissions over the lifetime of a building. EC is defined by the California Air Resources Board (CARB) as **"the life cycle GHG emissions resulting from the extraction, manufacturing, transportation, installation, maintenance, and disposal of goods, including building materials goods."**[1]

EC is a developing policy area in California and nationally. Utilities and Authorities Having Jurisdiction (AHJs) across the country are developing voluntary and mandatory building codes and standards, incentive programs, and other policies to address carbon more holistically, including a focus on EC. These include Massachusetts, Vermont, Colorado, Washington, Minnesota, Oregon, as well as the cities of Vancouver, British Columbia; San Francisco; Chicago; Los Angeles; New York; and Boston, among others. California has also introduced legislation to address EC in cement production—Senate Bill (SB) 596[2]—and to develop EC strategies and trading mechanisms in Assembly Bill (AB) 2446[3] and AB 43.[4] **It has also recently opened a pre-proposal solicitation on the intersection of EC, wildland–urban Interface (WUI), and disadvantaged communities (DACs) (CARB 2025e).**

Meanwhile, California's Department of General Services (DGS) developed a mandatory procurement policy to mitigate EC for public buildings, known as the Buy Clean California Act (BCCA). Additionally, California's Title 24, Part 11 (also known as CALGreen) now has mandatory EC requirements for large nonresidential buildings, which recently went into effect in 2024. Even artificial intelligence (AI) hardware manufacturers like NVIDIA have announced a focus on reducing EC in their products while also increasing EE to address operational carbon (OC) (Kessler 2025). Yet, despite this growing interest in EC as a policy and product focus, research on EC remains relatively limited, especially for market development activities in California.

To achieve the state's goal of carbon neutrality by 2045 and maintain net negative thereafter, per AB 1279, EC will be a critical area to address as part of a total carbon approach. EC can be a complementary policy and program pathway to EE and BD, especially since it represents 11 percent of carbon in buildings (Rempher 2023). EC shares a similar stakeholder base in new construction and major building rehabilitation projects as EE and BD stakeholders, including architects, builders, general contractors, structural engineers, and AHJs. Selection of low-EC building materials is a

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[1] CARB's EC definition and focus requirements can be found at https://ww2.arb.ca.gov/our-work/programs/embodied-carbon.

[2] SB 596 can be found at https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=202120220SB596.

[3] AB 2446 can be found at https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202120220AB2446.

[4] AB 43 can be found at https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202320240AB43.

potential pathway for EC to provide incremental GHG benefits in a manner that may have low to no project cost impacts.

Anecdotal evidence also indicates that some market actors are incorporating these practices, termed “one-for-one material substitution,” to reduce their buildings’ total carbon footprint by selecting lower-EC building materials over standard materials. Through market research and interviews with EC stakeholders, this study will attempt to document the opportunities to harmonize EE and EC through the selection of building materials and/or incorporation of EE during the EC design and building materials procurement stages. **The study will also seek to answer whether low-EC building materials have an incremental price premium compared to standard procured materials.**

According to the Carbon Leadership Forum’s (CLF’s) Embodied Carbon Benchmarking Report, represented in Figure 1, concrete, insulation, and steel are the top three contributing materials to EC emissions from building construction projects, accounting for a total of 68.7 percent (Benke 2025).[5] **To target the largest potential impact, this market study focuses on these three building materials to examine the current EC baseline for materials and construction practices in select target markets within California.**

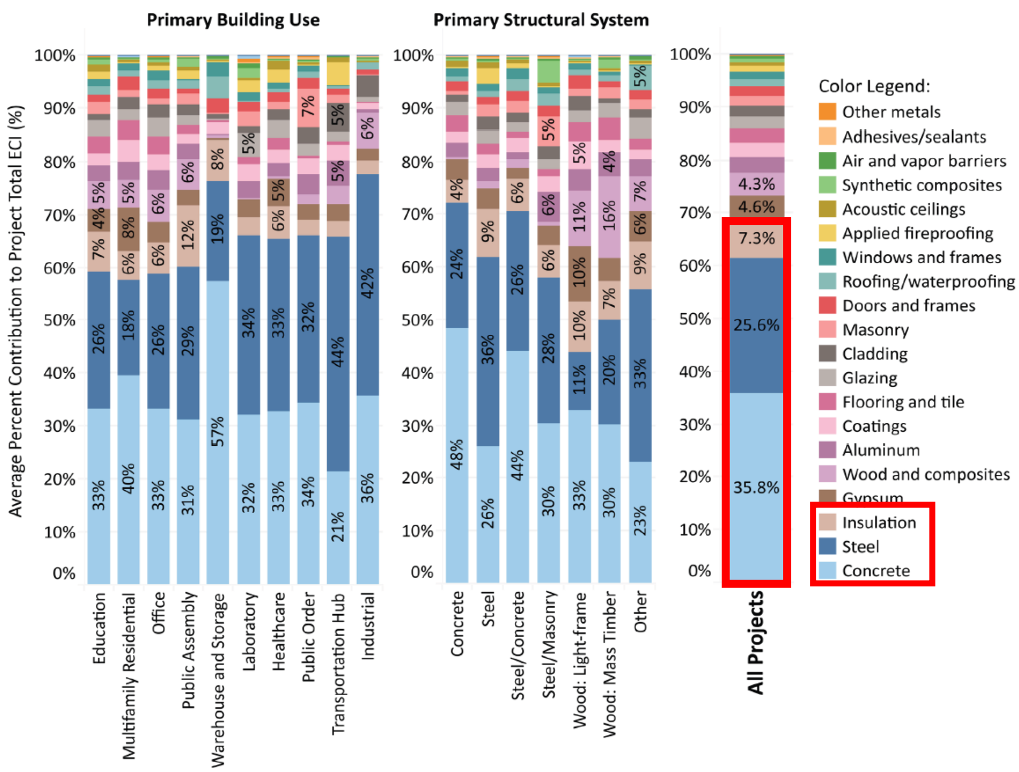

Figure 1: Average percent contribution of material groups to total project embodied carbon intensity across whole-building life cycle stages A–C.[5]

[5] Figure 1 can be found on page 33 of CLF’s “The Embodied Carbon Benchmark Report: Embodied Carbon Budgets and Analysis of 292 Buildings in the US and Canada,” here: https://carbonleadershipforum.org/the-embodied-carbon-benchmark-report/.

Objectives

This CalNEXT study **identifies if material substitution practices are currently being implemented, potential barriers such as perceptions of higher costs and performance concerns for low-EC materials, what market barriers exist to limit scaling of these opportunities, and end-customer feedback.**[6] The study also considers GHG savings for select building materials to identify whether the low-EC material alternatives offer similar GHG savings as standard building products and pathways by which lower EC material requirements can be assessed for future offering in or alongside of existing California investor-owned utility (IOU) EE programs. To explore this, the project team **assessed the existing California market for low-EC concrete, insulation, and steel, and attempted to quantify the GHG emissions reduction potential from material replacements with minimal to no budgetary impacts.**[7]

Additionally, this study assessed the opportunities for harmonizing EC with EE and BD programs by outlining the current policy barriers and likely next steps to outline potential pathways for EC activities to be incorporated alongside existing EE and BD programs. **However, with limited research to inform the market about low-EC materials in California and how to align EC with EE and BD policies and programs, there is limited available data to guide such policy considerations.**

Methodology and Approach

This section describes the approach the project team used to conduct the market study through primary and secondary research. The project team completed this study through three steps:

1. Characterizing the market through primary and secondary research
2. Researching EC and EE program and policy
3. Establishing a baseline of the selected materials

Based on the project team's research, there is **limited market awareness on how to identify and procure low-EC building materials, except amongst the premier sustainably focused architectural firms and large corporate customers** (Roach 2023). There is anecdotal evidence, however, that some members of the sustainability community are working with builders, structural engineers, and clients to implement one-for-one material substitution in new construction projects and/or major rehabilitation projects during early planning and procurement phases. After the initial design plans are submitted to local AHJs, sustainability consultants work with builders to recommend substituting

[6] Although the CalNEXT team and subcontractor attempted various means to engage end-customers for interviews and market feedback, we were only able to obtain feedback from one customer representing the higher-education segment. The CalNEXT team inquired with other market actors on end-customer perspectives to augment this data limitation.

[7] See US General Services Administration's fact sheet, which states that "the use of low-EC construction materials funded by the Inflation Reduction Act could reduce total embodied carbon emissions by at least 22,000 and up to 40,000 metric tons of carbon dioxide equivalent at https://www.gsa.gov/system/files/Final-LEC-Projects-Plan-Factsheet_110323.pdf. The fact sheet also includes a full list of low-EC projects in the United States.

lower-EC building materials in place of industry standard materials at low to no budget impact.[8] However, this practice may not yet be widely adopted.

There are an increasing number of case studies in which projects considering low-EC materials early in the building planning process achieved significant reductions in carbon emissions. One such example is Webcor's "Reducing Embodied Carbon in Construction Without Busting Budgets: A Newark Civic Center Case Study," (Rossie 2024), which showed that project owners, builders, and developers have preconceived notions about the cost and project timeline impacts of low-EC materials. As the study shows, **the perception that low-EC material substitution leads to additional costs and timeline impacts may not be true; low-EC materials may have higher market potential than commonly believed.** While material substitution may be commercially available in some markets, the **project team is not aware of any studies of low-EC material substitution practices that document market barriers and potential solutions through the lens of EE programmatic structures in California.**

BCCA and CALGreen both establish requirements aimed at curbing EC emissions. BCCA is a mandatory procurement standard but only applies to public sector buildings and CALGreen sets mandatory EC building code requirements for nonresidential buildings. However, CALGreen EC requirements are likewise limited to a subset of buildings—e.g., nonresidential buildings over 100,000 square feet, and schools over 50,000 square feet, with other exemptions[9]—and the requirements are seemingly of minor stringency. Likewise, both CALGreen and BCCA only apply to a limited number of building materials. Due to these outlined factors for BCCA and CALGreen, there is a **significant opportunity to reduce EC emissions through increased market awareness of EC and/or development of EC incentive programs.**

Market Characterization

In order to collect primary market information from market actors familiar and involved with one-for-one material substitution practices or material purchase considerations, the project team conducted 28 interviews with diverse stakeholders, detailed in Table 1. Subsections containing information from market actor interviews are labeled as such. All information within this report is anonymized.

Table 1: Stakeholder list.

Stakeholder Type	Number of Stakeholders Consulted
Architects/architectural and engineering (AE) firms	6
Contractors	5

[8] Based on Energy Solutions market characterization interview with a sustainability consultant in Toronto, which was then validated as also being the case in California as well.

[9] At the time of writing this report, there is consideration by state agencies to update CALGreen by reducing square footage thresholds.

Stakeholder Type	Number of Stakeholders Consulted
Customers	2
Developers	1
Utility representatives	3
Local government officials	1
Structural engineers	3
Sustainability consultants	1
Trade associations and industry consultants	4
Manufacturers	2

Embodied Carbon and Energy Efficiency Secondary Research

To assess the relationship between EC and EE, the project team conducted secondary research on policies, codes and standards, and funding mechanisms related to EC. This research consists of publicly available data from various government and legislative agencies and policies on EC, including but not limited to the California Public Utilities Commission (CPUC), CARB, BCCA, and CALGreen. In addition to secondary research, the project team also outlined funding pathways by referencing some of the resources previously mentioned, as well as published case studies on EC projects.

Evaluating Materials for Cost and Carbon

The project team used a combination of cost data from the construction industry's leading database RSMeans[10] and global warming potential (GWP) benchmarking data from the CLF's 2023 North American Materials Baselines Report to establish the low-EC baseline for insulation and perform a carbon cost-benefit analysis for the insulation material category (Waldman 2023).[11]

A similar approach was used for concrete and steel, but with a small change. The main method of lowering EC in insulation is material substitution or switching to a different type of insulation—for example, from extruded polystyrene (XPS) to cellulose. This is because an XPS supplier only has one kind of XPS production process, and therefore do not have a standard version and a low-EC version of XPS, for example. This is not the case with concrete and steel, for which the same product may be

[10] The RSMeans database website can be found at https://www.rsmeans.com/.
[11] See https://digital.lib.washington.edu/researchworks/items/d65b40fe-eb3b-4ff2-97fa-5064d0e9e322 for CLF's North American Material Baseline Report.

made in multiple ways, such as with more or less supplementary cementitious material (SCM) in the case of concrete, and more or less scrap input in the case of steel.

RSMeans does have categorical price differences for XPS and cellulose, which inherently captures both EC and cost differences, even though there is no explicit low-EC version of a particular insulation type listed. In contrast, for both concrete and steel, buyers can opt for a lower-EC version within a single RSMeans category, and so neither the EC improvement nor any cost delta is captured within RSMeans. To estimate the EC and cost impacts in concrete and steel, CLF material baselines were used in conjunction with qualitative percent cost impacts from industry expert interviews.

Embodied Carbon Policies

The team's secondary research focused on EC development from the perspective of California policy, codes and standards, and funding strategies and mechanisms. EC is an emerging policy area that is increasing in focus, statewide and nationally. EC can be a complementary policy and program pathway to EE and BD, which California policymakers are aware of, as evidenced by recent legislation specifically addressing EC. Below is an overview of EC policy developments within California.

California Public Utilities Commission

As directed by the CPUC, the IOU Codes and Standards program supports "broader clean energy goals" per D. 23-04-035.[12] Because the CEC's building and appliance standards and other regulations address broader clean energy goals including transportation electrification and building decarbonization, EC is implied as part of clean energy goals advanced by other state agencies such as the California Air Resources Board (CARB).

BD is inclusive of EC, as noted in the 2024 Semi-Annual Energy Efficiency Evaluation Report for Pacific Gas & Electric (PG&E): "In pursuit of those broader decarbonization goals, the C&S Program would address embodied carbon and other sources of GHG emissions. In addition to operational performance, a significant source of emissions associated with buildings includes the emission generation throughout a building's lifetime from the extraction, manufacture, transport, demolition and disposal of the materials."[13]

Moreover, PG&E's evaluation report shares details about the CPUC-approved Code Readiness program. The Code Readiness program will develop a holistic strategy to identify potentially high-impact measures and technologies that will be good candidates for code adoption. These measures and technologies will require additional performance testing or market-related data to support a code-adoption proposal. The program will develop a long-term strategy to ensure that key measures adequately support adoption, and will also conduct research and data collection in support of:

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[12] CPUC decision 23-04-035 can be found at https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M505/K808/505808197.PDF.

[13] See PG&E Energy Efficiency Semi-Annual Independent Evaluator's Report at https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M549/K465/549465224.PDF.

- Building standards advocacy
- Appliance standards advocacy
- The alignment of voluntary new construction programs with long-term codes and standards objectives

Based on the study team's discussion with a member of the Code Readiness team, EC is an area of interest for the Code Readiness team but for the lack of program attribution that currently exists for EC. However, the Code Readiness team member also supported the development of an EC avoided cost calculator (EC ACC) to quantify the GHG benefits of EC activities.

California Air Resources Board

While CARB has oversight of EC and EE is referenced as a means for achieving emissions reductions, EE is not within CARB's direct scope.[14] EC is achieved by entities instructed through CARB regulations within the industrial sector, such as reducing carbon intensity.

Directed by the legislature through the passage of AB 32 in 2006, CARB must develop a scoping plan for the state to reach its emissions reductions goals inclusive of industrial emissions that, in part, cover EC. CARB is also required to manage the Cap-and-Invest program (formerly Cap-and-Trade), which includes industrial emissions.

Through subsequent legislation, CARB has been directed by the legislature to address EC in the following areas:

- **SB 596**: Develop a comprehensive strategy for the state's cement sector to achieve net-zero emissions of GHG associated with cement used within the state as soon as possible, but no later than December 31, 2045.
- **AB 2446 and AB 43:** Develop a **comprehensive strategy** for the state's **building sector to achieve <u>a 40 percent net reduction</u> in GHG emissions of building materials**. CARB was authorized per AB 43 to establish an EC trading system and integrate it into the framework for measuring the average carbon intensity of the materials used in the construction of new buildings, as described above, on or before December 31, 2026, and to implement the system on and after January 1, 2029. The bill authorized CARB to adopt rules and regulations for the credit allocation approach, the anticipated carbon price in the scheme, and trading periods. The bill also required CARB to periodically review and update its emission reporting and compliance standard requirements, as necessary. It is reasonable to assume that this carbon-trading system could include environmental attribute certificates (EACs) which define the *additionality* (principle that a project's GHG benefits would not have occurred without the support of the carbon market) from EC activities. However, the bill does not explicitly state that it will fund the development of EACs but regardless, development of this carbon-trading mechanism will require quantification of EC emissions.

[14] See CARB 2022 Scoping Plan for Achieving Carbon Neutrality, page 210, which stated "Across industrial subsectors and processes, California facilities also could realize significant reductions in GHG emissions and energy-related costs by implementing advanced energy efficiency projects and tools."

- The market is already developing market-solutions for low-EC adoption such as Microsoft's recent announcement that a low-EC cement project with Sublime Systems in Massachusetts, which generates EACs, could in principle generate EACs that could trade on an AB 43 type EC trading platform, dependent on platform structure and rules (Glabets 2025). In the future, these types of EC EAC market solutions can conceivably be a resource for bidding into the EC trading system once established.

Additionally, as mentioned above, CARB recently released a pre-proposal solicitation on wildland–urban interface. The pre-proposal states that it is meant to support CARB's "Sustainable Transportation and Communities Division efforts to reduce embodied carbon in California's building sector." DACs are also a key focus of the solicitation (CARB 2025e).

Codes and Standards

In the section below, the project team details the current codes and standards set forth by California that impact EC.

Department of General Services

BUY CLEAN CALIFORNIA ACT

The California DGS, in consultation with the CARB, is required to establish and publish the maximum acceptable GWP levels for four eligible materials under BCCA. **BCCA is a procurement standard which targets carbon emissions associated with the production of structural steel (hot-rolled sections, hollow structural sections, and plate), concrete reinforcing steel, flat glass, and (low- and high-density) mineral wool insulation. As a state procurement standard, <u>BCCA requires contractors to disclose GWP information in their bids on public works projects.</u>** Note that concrete is not included on the list of materials, but there are ongoing efforts to add it. The first GWP limits went into effect on January 1, 2022, and were then revised to be slightly more stringent, effective January 1, 2025. The DGS will review and potentially update the GWP limits every three years.

Building Standards Commission

CALGREEN

California's Title 24, Part 11, also known as CALGreen, was recently updated to include EC requirements that went into effective on July 1, 2024. The requirements **apply to nonresidential commercial buildings greater than 100,000 square feet and school buildings greater than 50,000 square feet.** There are three compliance pathway options for the EC requirements:

1. **Section 5.105.2.** Reuse of existing building: for additions or alterations to an existing building, reusing a minimum of 45 percent, combined, of an existing building's primary structural elements (foundations, columns, beams, walls, floors, and lateral elements) and existing building enclosure (roof framing, wall framing, and exterior finishes).
2. **Section 5.409.2.** Whole-building life cycle assessment (WBLCA): Conduct cradle-to-grave WBLCA in accordance with ISO 14040 and ISO 14044, excluding operating energy, to demonstrate a minimum 10 percent reduction in GWP. This will be compared to a reference baseline building of a similar size, function, complexity, type of construction, material specification, and location that meets the requirements of the California Energy Code currently in effect.

3. **Section 5.409.3.** Product GWP compliance, prescriptive path: all permanently installed products that are listed in Table 5.409.3 shall not exceed maximum GWP values specified in Table 5.409.3, as determined by either a product-specific or factory-specific Type III Environmental Product Declaration (EPD).

CALGreen also includes voluntary Tier 1 and Tier 2 requirements that are available for local jurisdictions to adopt if they desire stricter requirements.

Title 24 as a whole, including CALGreen, is updated on a 3-year triennial cycle. However, CALGreen is typically updated on an 18-month intervening cycle, which allows revisions to be made halfway through the 3-year cycle. Concepts under consideration for the new intervening code review cycle are deconstruction, rewarding the use of reclaimed or salvaged materials, expanding the WBLCA compliance path with an EC intensity target, and reducing the building area trigger for nonresidential commercial building types.

Local Reach Codes

Across California, a few localities have implemented, or are in the process of implementing, EC policies and ordinances that go beyond the state requirements. **In Marin County, new projects are required to meet cement limits or maximum GWP limits for concrete mixes.**[15] In Berkeley, an amendment to the California Green Building Standards Code adds a requirement for cement used in concrete mix designs to be reduced by 25 percent or more, per Chapter 19.37 of the Berkeley Green Code.[16] In Los Angeles, a motion has to be passed to address the need to regulate EC resulting from building construction. The city is looking at developing a local ordinance to further reduce EC by leveraging CALGreen's EC framework to establish EC limits, lowering the CALGreen area threshold triggers, or adopting CALGreen's Tier 1 or Tier 2 options for various types of buildings or projects (CF 23-1391). Finally. the city of Dublin, California also includes a low-carbon concrete building code as part of its Climate Action Plan.[17]

[15] The County of Marin Website has more information on the County's low carbon concrete code found at https://www.marincounty.gov/departments/cda/sustainability/green-build-req/lcc.

[16] Barkeley Green Code, Chapter 19.37, can be found at https://berkeley.municipal.codes/BMC/19.37.

[17] The City of Dublin, CA's Climate Action Plan can be found at https://dublin.ca.gov/2531/Development-Permits-Climate-Action-Plan.

Market Characterization Findings

The section below contains the findings collected from the market actor interviews that the project team conducted. The project team interviewed several market actors from a variety of backgrounds, detailed in Table 1, about low-EC material substitution. All information within this report is anonymized.

Policy[18]

EC policies, like CALGreen and Buy Clean in California, are playing an important role in raising broad industry awareness of EC. As one sustainability consultant noted, **even though the CALGreen requirements are "very easy to comply with," they help bring attention to EC.** Moreover, they said that for more ambitious customers, the future Leadership in Energy and Environmental Design (LEED) v5 certification will provide helpful benchmarks for market actors to strive for in their building projects. However, architects also commented that they would like to see more EC building code requirements to help advance EC market adoption.

For instance, concrete manufacturers recommended a policy that has GWP-based goals for concrete products, while an insulation manufacturer recommended tax credits tied to low-EC products. One utility representative, when asked about barriers in the policy realm, pointed to California's AB 130 bill, which was recently signed into law by the governor. **AB 130 imposes a moratorium on new or modified building standards for residential units from June 1, 2025, until June 1, 2031, hindering potential near-term residential EC policies.**

Interestingly, contractors and utility representatives offered a different perspective on EC policy that incorporates building reuse, which is the practice wherein the structure, envelope, or other portions of an existing building are retained rather than completely demolishing and constructing a new building on the same site.[19] Building reuse aligns with the practice of circularity—extending a building's life and maximizing the use of its components and materials to minimize waste and environmental impact—and aligns with the broader circular economy principles of reducing, reusing, recycling, and regenerating (Laar 2025).

Contractors commented that program implementers should find ways to incorporate building and material reuse into an incentive program structure. On the utility side, interviewees discussed the opportunities for building codes to create flexible pathways for adaptive building reuse, the process by which an existing building is repurposed for a new use.[20] Adaptive reuse projects may require a conditional use permit, when the proposed use differs from the original purpose of the building, depending upon local zoning requirements (LegalClarity Team 2025). **Architects shared examples of**

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[18] During the market characterization interviews, the project team asked the following question to target policy: "What, if any, legislative, regulatory, or policy barriers that exist on the local, state, or federal level limit you from adopting low-EC building materials and what are the solutions to address these barriers?"

[19] Find CLF's factsheet regarding Deconstruction, Salvage, and Reuse Policies here https://carbonleadershipforum.org/deconstruction-salvage-reuse/.

[20] Adaptive reuse is often used for historic or culturally significant buildings, where a building owner will make renovations or modifications to a building while preserving the building's original character.

projects in which they have struggled to get conditional use permits and noted that a policy to fast-track conditional use permit approvals, particularly in cities with sustainability goals, would be effective in reducing EC. Market actors agreed that encouraging adaptive reuse through building codes could be a highly impactful means to mitigate EC emissions.

Market Drivers[21]

CALGreen as a Market Driver

EC is an emerging topic in the building sector and has recently gained considerable traction. When asked about market drivers, architects and contractors agreed that **CALGreen is a significant driver of low-EC adoption and awareness in California.** However, one contractor noted that their clients who were previously invested in sustainability were often already in compliance with the CALGreen standards when they came into effect. In a similar vein, contractors and architects commented that **customers with clearly stated sustainability goals are the ones most drawn to pursuing low-EC material substitutions.** For example, if a company already has carbon neutrality goals and has invested in EE measures, **EC is often next on their list of sustainability priorities. Additionally, one interviewee noted that customer feedback loops play an important role in driving adoption of low-EC products because when a critical mass of customers are requesting low-EC products, prices decrease and availability increases.**

Permitting, Regulations, and Market Incentives

Other facets of low-EC adoption are permitting, regulations, and incentives. One contractor noted that tying low-EC adoption to expedited permitting could help drive adoption. Architects supported this claim, noting that **the current process for getting a permit is expensive and lengthy, and expedited permitting tied to EC would help.** Additionally, state legislation—such as Colorado's SB 25-182, which incorporates financing options and tax credits for using low-EC materials, and New York's SB S7998, which includes a 15 percent EC reduction target by 2030—are helping to spur awareness and adoption of lower-EC materials and practices broadly (Wingate 2025) (Kavanagh 2025).

Likewise, the **LEED v5 rating system**, which will require building projects to quantify and assess the EC in all building materials, is helping to increase visibility of the impact of EC among sustainability-motivated building owners. Every LEED v5 project must quantify, assess, and disclose the EC impacts of major structural, enclosure, and hardscape materials using life-cycle assessment standards, with points awarded for demonstrated reduction in GWP.

Software Innovations

Technological innovations in the construction industry are also driving industry adoption and awareness of low-EC materials. For instance, the Embodied Carbon in Construction Calculator (EC3) is a tool that can identify low-EC material alternatives.[22] **Using the EC3 tool, contractors have found that as many as 95 percent of the low-EC products were within their budget and, in fact, were products they had used in the past.** One developer shared an anecdote in which they asked their

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[21] During the market characterization interviews, the project team asked the following question to target market drivers: "What are the primary market drivers of low-EC adoption?"

[22] The EC3 tool can be found at https://www.buildingtransparency.org/tools/ec3/.

general contractor to provide cost estimates on low-EC alternatives, and found that several manufacturers had their product data detailed in the EC3 database.

In addition to EC3, another architect mentioned the Building Emissions Accounting for Materials (BEAM) estimator as another resource they use to evaluate EC in their projects.[23] This software tool provides a comprehensive list of building materials and their respective carbon footprints. It is used by building professionals to estimate and reduce EC on their projects.[24] Market actors cited other software programs such as Tally,[25] a software tool that helps designers and builders calculate the environmental and cost impacts of low-EC material substitutions.

Product Innovations

Along with the innovative software tools, **advances in building material technology** have removed some of the barriers to low-EC materials adoption. For concrete in particular, a common drawback of low-EC concrete mixes are the additional time they take to set and strengthen, which impacts overall project timelines. However, interviewees pointed to **low-EC concrete mixes with shorter set times, which are helping to mitigate timeline delays and drive adoption**. On the insulation side, low-EC insulation options like cellulose are prized for fire resistance, thermal performance compared to fiberglass batt insulation, and in some cases cost-effectiveness relative to spray foam insulation. **As building material technology and construction design tools evolve, the barriers to low-EC material adoption will also lessen.** However, technological advances alone will not be enough to scale and standardize low-EC building materials. **Market demand, demonstrated in purchase agreements** for low-EC building materials, is likewise important to spur investment in the production of low-EC products.

Market Barriers[26]

When evaluating the market for low-EC materials, stakeholders were generally aligned on the most significant market barriers for low-EC materials: **market education, supply chain and project timelines, and perception of higher cost**—each described in the following sections. Naturally, sentiments surrounding different low-EC materials vary. For instance, one contractor noted that they have seen low-EC steel and concrete alternatives written off on the assumption that their performance and reliability were worse than standard concrete and steel options. Meanwhile, the same contractor stated that low-EC insulation substitutions, like cellulose, present fewer challenges for industry adoption because they are easy to install, available, and can be more cost-effective than carbon-intensive alternatives.

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[23] The BEAM estimator can be found at https://www.buildersforclimateaction.org/beam-estimator.html.

[24] More information on the BEAM estimator can be found on the Builders For Climate Action website here https://www.buildersforclimateaction.org/beam-estimator.html#:~:text=You%20can%20use%20BEAM%20to,reduce%20emissions%20from%20your%20projects..

[25] The Tally website can be found at https://choosetally.com/.

[26] During the market characterization interviews, the project team asked the following question to target market barriers: "What market barriers block you from using low-EC materials, and what are possible solutions to those barriers?"

Market Education

Market education as a barrier can be understood as a set of smaller barriers that amount to an overarching lack of market education on low-EC materials. Plenty of customers and market actors are **simply unaware of the existence and availability of low-EC materials**. Architects indicated that this **lack of awareness exists on both the client and design sides**, with customers not knowing how to ask for low-EC materials and designers not knowing to offer them. Even for industry actors who are aware of low-EC materials, there can be **resistance to entertaining these products.** One market actor commented that they have worked with contractors who are unwilling to pursue low-EC material substitutions because they are **afraid to move away from the** "**status quo**" and are less familiar with the installation process for low-EC materials, particularly insulation.

For others, the resistance has more to do with their **experience with low-EC materials and the perceptions around them.** One contractor offered an anecdote in which they had to educate a client who was resistant to a low-EC cement alternative because of a bad experience the client had 15 years prior. Importantly, in that instance, the contractor pointed out that the client's bad experience was not due to a specific issue with the low-EC cement itself, but other factors. **The perception that lower-carbon products translate to lower-performance materials is still prevalent throughout the industry.**

According to one concrete manufacturer, the primary barrier to low-EC concrete adoption is **the way in which builders approach product selection for low-EC materials.** Rather than including performance and carbon specifications for building materials into the project plan, builders will often default to the low-EC concrete products they are familiar with, even if it means timeline delays or project cost increases. This practice reinforces market perceptions that EC materials are cost- and timeline-prohibitive. That said, the interviewee said that they have begun to see more building projects take **a specification approach rather than a product approach** when pursuing low-EC material substitutions.

Interviewees on the local government and utility side shared that EC is neither a big priority nor well-understood among city officials and utility staff. **Municipalities are more focused on other decarbonization measures, such as electric vehicle infrastructure** and other, more visible areas of sustainable development. And even where there are local ordinances on EC, which is fairly uncommon, **there is little to do when a building project is non-compliant**. As one local official said, "[We are] never going to tell people to pull concrete that's been poured." Furthermore, the local official noted that the EC policies are new, which allows builders to claim ignorance when they are noncompliant.

For utilities, the biggest barrier identified was a **lack of education among internal staff.** EC is not commonly discussed nor is it on the radar of the utility strategy teams. According to one California utility representative, there **needs to be a pathway to incorporate EC into the Total System Benefit (TSB) framework**. Moreover, **EC needs to be viewed as a complement to electrification rather than as a detractor or substitution.**

Supply Chain and Project Timelines

Another significant barrier to low-EC adoption is the **limited availability of low-EC materials** and the impact this can have on **project timelines.** All interviewees agreed that scheduling delays are a key opposition point to low-EC material substitutions. A crucial strategy to avoid scheduling delays is to

incorporate low-EC materials from the beginning of a project and ensure alignment between all the parties involved. Otherwise, a project may be subject to supply chain and construction delays. In one instance, a sustainability consultant on a project was using a low-EC concrete alternative that took too long to set and ultimately led the project team to switch concrete mixes mid-project.

The barriers that low-EC materials can present to project timelines are exacerbated by limitations in the low-EC materials supply chain. Insulation manufacturers commented that the **raw materials** required to produce low-EC insulation products are limited and **can be difficult to obtain**. Similarly, several interviewees cited the **limitation of low-EC concrete alternatives**, like fly ash and slag, as major barriers to scaling adoption because the materials are, in the words of one contractor, "the byproducts of dying industries." Furthermore, interviewees identified a need for **a more diverse array of low-EC concrete replacement options,** such as glass pozzolan and Portland limestone cement (PLC), which are more reliable in the long term but are still emerging technologies with limited market adoption. Manufacturers added that although low-EC material alternatives are promising and adoption levels are increasing, the **market demand for these products is not enough for manufacturers to justify the cost investment** required to achieve market scale.

Cost

In tandem with the project timeline risks that low-EC material substitutions can present, another major barrier identified across the spectrum of market actors are the **cost implications**. In some cases, the fear surrounding the cost of low-EC materials is driven by a **preconceived notion that the low-EC alternatives will cost more money**, leading customers to default to products they already know. On the owner and designer side, there is **hesitation to include EC limits in their design specification** because they are concerned it will drive up the overall project cost. In some cases, low-EC materials drive up the project cost directly; however, there are also instances where cost increases stem from the builders.

One concrete manufacturer described a project in which the cost differential between the standard concrete and the low-EC concrete was minimal, but the **contractor tacked on additional costs to account for the risk associated with using a product that was less familiar to them**. The manufacturer noted that often, builders will select the supplier with the most competitive price, regardless of whether there is an option for a low-EC product that is cost-neutral to the client. An architect shared a story in which a client requested a net-zero-carbon project but ultimately decided against it when they could not fit the costs for the low-EC materials into their budget. Instead, the client opted to shift their focus to OC to achieve building carbon neutrality. In general, market actors commented that **customers have less of an appetite for low-EC material substitutions because they have "bigger priorities,"** and EC is a **more complicated pathway** for lowering carbon emissions in building projects.

Other Market Drivers

Interviewees offered suggestions for how to address the market barriers identified above. **Establishing industry baselines for low-EC materials** would be beneficial, as there is currently little standardization across the industry. In addition to industry baselines, architects proposed—and contractors agreed—that **permit cost reductions and expedited permitting** could motivate clients to incorporate low-EC materials into their projects. They hypothesized that their clients would accept a 10 percent EC reduction below the baseline if it meant they could qualify for an expedited permit. By contrast, a utility representative stated that with the current regulations, the barriers to permitting are not compelling enough to motivate builders to use low-EC materials unless they are pursuing a project that raises concerns from the building department.

Interestingly, one developer noted that they submit their project plans in parallel with their permits which, in some cases, has resulted in them receiving their permits before they are ready to begin the project. Another interviewee stated that a program that **offered rebates for low-EC material substitutions** would be a good tactic to spur the market towards low-EC material adoption. Ultimately, developers posited that the industry needs to **identify ways to demonstrate the value of low-EC material substitutes to market investors.** They cited LEED certifications and local government advocacy as two mechanisms where the added value of prioritizing carbon reduction in building projects is clearly articulated. One large developer backed by a real estate investment trust commented on asset value as a driver in decision making at the finance level. Holistically, incentives for low-EC, policies favoring or requiring it, and public-facing signaling like LEED v5 certification all increase asset value for low-EC projects and increase enterprise value of market actors that can construct such projects.

Environmental Product Declaration Awareness[27]

In a similar vein to the market barriers to low-EC adoption, large agencies within California face a unique challenge. While Buy Clean California and CALGreen apply to them, their extensive procurement protocols and rules—without EC considerations—have been learned and implemented for many years by facilities managers and staff. This creates an "**unfunded mandate**" situation in which facilities department staff **do not have personnel with subject matter expertise or budget** to cover the necessary training to educate their staff (CARB 2025a) (CARB 2025c).

In fact, sustainability personnel reported that that they have had to **educate themselves** on EPDs and how to use them. At large agencies with many sites, local staff do not have the means to establish EPD literacy. An architect commented that they had not heard of EC-reduction benchmarks or EPDs and that their firm deals mostly with OC reductions. On the local government side, officials noted that their teams are very aware of EPDs. However, the interviewee shared that their **county does not review EPDs** when assessing a new material for a low-EC qualifying status, and as a result, they take measures to avoid EPDs because it is more expensive.[28]

In contrast, several market actors commented that they **use EPDs** in their building projects to **help identify low-EC options,** particularly for insulation, and to **support their clients' pursuit of sustainability certifications,** such as LEED v5. A developer in the multifamily sector noted that they do not use EPDs as part of their low-EC strategy but rather **use the residential LEED rating system**, which does not emphasize the value of EPDs in achieving lower-EC in the same way that the commercial LEED rating system does. An insulation manufacturer provided a perspective on EPDs as a marker of a "**manufacturer's progress towards decarbonization**" rather than an exact

27 During the market characterization interviews, the project team asked the following question to target EPD awareness: "What is your awareness of EPDs and does your industry or department utilize them?"

28 As noted above, EPDs are technical documents that require some level of familiarity or education to be used. Reviewing EPDs takes additional time, even for individuals with expertise.

measurement of a product's environmental performance. However, the interviewee went on to say that "the reality is [that] **EPDs are being used to compare manufacturers against each other**," and as a result, the accuracy of the statistics within the EPD are not fully considered. Though awareness and applicability of EPDs varies across different market actors, interviewees agreed that EPDs are an asset in the broader effort to increase market adoption of low-EC material substitutions.

Establishing Market Baselines for Concrete, Insulation, and Steel

The sections below provide baseline determinations for concrete, insulation, and steel using existing published data, such as **CALGreen's EC requirements, the CLF North American Material Baseline Report, and the EC3 EPD database tool. The CLF Material Baseline Report** covers several construction materials, including but not limited to concrete, steel, insulation, and glass. The CLF Report cites other sources specific to each industry, such as the **National Ready Mixed Concrete Association (NRMCA)** regional baselines for concrete. The NRMCA regional baseline covers the entire Southwest region, whereas the project team looked in more detail at differences within California. The team wanted to evaluate at least one non-structural building component and considered two material categories: insulation and windows. While the EC attributes of insulation and windows are similar, the data availability for insulation indicates that there would be fewer obstacles to achieve lower-EC through insulation material substitution at this stage of the study.

The project team considered existing baseline information from a number of sources, listed in Table 2 below. The project team considered using the current CALGreen EC requirements as the market baseline because it represents the minimum that is required by the building code; CALGreen's requirements are mandatory and therefore, all covered buildings applicable to CALGreen would comply by installing products that meet (or are lower) than the maximum GWP levels in the prescriptive pathway. However, using CALGreen wouldn't necessarily reflect real-world conditions of products actually being installed; the project team has heard from multiple stakeholders that it takes little to no effort to meet CALGreen's requirements, and something more stringent than CALGreen is likely more realistic. The project team thinks CLF's data is likely a better proxy of existing market conditions, and therefore, more appropriate to use as a baseline. However, CLF's data outlines industry averages based on what manufacturers are producing, which is different from what buildings are actually installing. The project team recognizes potential issues with both approaches but thinks CLF's data is likely the best proxy to use for a baseline at this point.

While there are over 18,000 ready-mix concrete EPDs in California, **EPDs are lacking for other material categories, e.g., steel and insulation.** Furthermore, existing EPD databases—such as EC3—are set up to parse EPDs down to the state level only. **Ideally, more regionally specific market information would be collected.**

Table 2: GWP baseline data.

Material Type		Declared Unit	CALGreen[29]	CLF (2025)
Ready Mix Concrete[30]	3,000 psi	m3	489	279
	4,000 psi	m3	566	323
	5,000 psi	m3	661	378
	6,000 psi	m3	701	401
Steel	Concrete reinforcing bar (fabricated)	1 metric ton	1,560.00	854
	Hot-rolled structural steel sections (fabricated)	1 metric ton	1,770.00	1,080.00
	Hollow structural sections (fabricated)	1 metric ton	3,000.00	1,990.00
Insulation	Light density mineral wool	1 m2@RSI-1	5.83	2.68
	Heavy density mineral wool	1 m2@RSI-1	14.28	6.82
	Expanded polystyrene (EPS)	1 m2@RSI-1	N/A	2.53
	Polyisocyanurate (wall)	1 m2@RSI-1	N/A	3.5
	Extruded polystyrene (XPS) (25 psi)	1 m2@RSI-1	N/A	8.9
	Fiberglass batt	1 m2@RSI-1	N/A	1.06
	Closed-cell spray foam (medium density)	1 m2@RSI-1	N/A	2.63
	Open-cell spray foam	1 m2@RSI-1	N/A	1.17

[29] The CALGreen GWP limits that are effective January 1, 2026 remain unchanged from the previous CALGreen GWP limits.

[30] The main specification criterion for concrete is strength. The main strength classes lie between 3,000 and 6,000 psi. Increasing the strength of concrete typically increases both cost and EC of a mix.

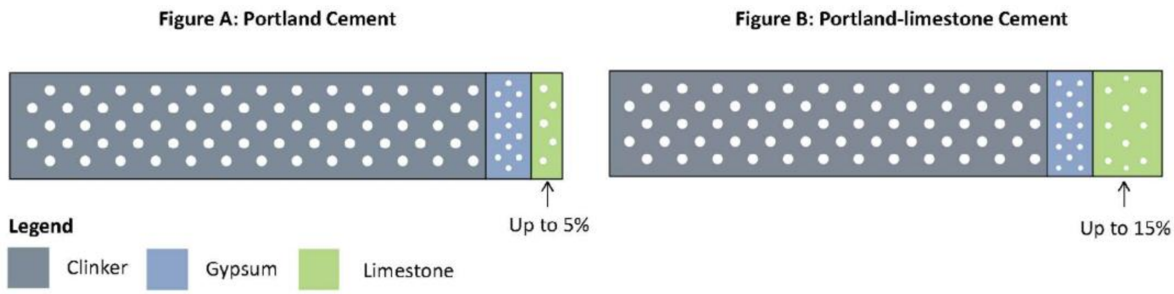
Concrete: Background

Concrete is the most widely used construction material and is made of aggregates, such as gravel and sand, water, cement, admixtures, and supplementary cementitious materials (SCMs). **Cement typically comprises 7 to 15 percent of concrete but contributes up to 50 percent of the overall cost, along with 90 percent of concrete's GHG emissions (Draft SB 596 Cement Strategy).** Market actor interviews reinforced the point that cement is a unique ingredient in concrete, as one interviewee stated that cement constitutes 10 percent of the volume of concrete, 50 percent of the cost, and 90 percent of the EC of concrete.

Currently, the primary means of lowering EC in concrete is to use SCMs to reduce the amount of cement in a mix. Another strategy is to add up to 15 percent limestone, or PLC. PLC and cement with SCMs are both considered "blended cement," but they differ in that SCMs have high chemical reactivity similar to clinker, whereas limestone has low chemical reactivity. A significant amount of blending happens downstream from cement production itself, at the level of concrete suppliers.

Because of the high relative cost of cement as a percentage of the total cost of concrete, using PLC or cement with SCMs can also have beneficial impacts on cost. Two main SCMs are slag, which is a byproduct of the steel-making process, and fly ash, a byproduct of coal power plants. Since fly ash is a byproduct of combusting coal, which has largely been phased out in California, the state's supply is limited. There are alternative SCMs, including natural pozzolans, which come in various forms and exist in various natural deposits in California, such as natural clay. In general, concrete buyers can specify global warming potential targets, strength, and other performance metrics, and concrete suppliers can substitute low-EC materials in place of standard materials to meet these needs.

There are two primary drivers of GHG emissions in cement production, and both are part of the processing of the main material input, which is almost always limestone. The limestone must be heated in a kiln to temperatures in the range of 2,600°F. This heating drives a chemical reaction in the limestone, which drives off carbon dioxide (CO_2) in the mineral. The resulting material is called "clinker," which is the main ingredient in what is called "grey Portland cement," often shortened to "Portland cement." Gypsum is the other ingredient in Portland cement, but it typically comprises only 3 to 5 percent of the total. As shown in Figure 2, Portland cement is different than PLC, which contains 5 to 15 percent pure, unheated limestone in the mix. **Using PLC can reduce EC in concrete, as the emissions created from converting limestone to clinker** and the energy needed to generate the heat—often by burning fossil fuels—are the two main sources of GHG emissions in concrete.



Source: https://cement.ca/sustainability/portland-limestone-cement/

Figure 2: Portland cement (A) vs. Portland limestone cement (B).

The concrete market is divided into large operators that may own many plants, as well as smaller family-owned businesses that may own just one plant. The industry largely delivers concrete to construction sites through ready-mixed concrete trucks. Ready-mixed concrete is the single largest type of concrete used in construction, and these trucks operate from roughly 400 ready-mixed concrete plants. As of May 2025, there are 382 ready-mixed concrete plants in California (Polygon Group. n.d).[31]

These 382 concrete plants source most of their cement from seven large cement plants in California, with some supply coming in from out of state. Five of those seven plants produce PLC, which is detailed in Table 3.[32]

[31] See the Material Plants Status at https://dot.ca.gov/-/media/dot-media/programs/construction/documents/construction-standards/material-plant-quality-program/list-of-active-material-plants/active-plants-mpqp-aug-2025.pdf.

[32] Portland Cement Association (PCA) was renamed on May 7, 2025, to American Cement Association (ACA). See https://www.cement.org/wp-content/uploads/2025/03/PCA_California_One-Sheet_03-19-25_FINAL.pdf.

Table 3: California large cement plants.

Facility Name	GHG Emissions (MTCO2e)[33]	Produces PLC?	EPD Link (Source for PLC Production)
Cemex Construction Materials Pacific LLC, Victorville	1,910,079	Yes	EPD link
CalPortland Company, Oro Grande	1,250,996	Yes	EPD link
CalPortland Company, Mojave	1,124,475	Yes	EPD link
Mitsubishi Cement 2000, Lucerne Valley	1,068,736	Yes	EPD link
National Cement Company, Lebec	795,651	Yes	EPD link
Tehachapi Cement Plant	556,466	No	EPD link
CalPortland Company, Redding	292,886	No	EPD link

It should be noted that in Table 3, approximately 52 percent of GHG emissions are process emissions due to CO2 being driven off of limestone in clinker production. The other 48 percent of emissions are operational emissions from other parts of the value chain.[34]

Concrete: Baseline

Market actors reported that using SCMs was a reliable method to reduce EC in concrete mix design and estimated that EC reductions of as much as 15 to 25 percent were possible in SCM mixes, with negligible cost impacts. Using the median of the reported reduction range—20 percent—summarizes possible EC reductions for various SCM mixes in two of California's largest regions, Los Angeles and San Jose. EC content for Table 4 was taken from the 2023 CLF Material Baseline Report, and baseline cost data was taken from RSMeans. One large concrete supplier has made the strategic

[33] Table 3 in: California Air Resources Board. CARB 2025b. Draft Net-Zero GHG Emissions Strategy for the Cement Sector. March 14, 2025. https://ww2.arb.ca.gov/sites/default/files/2025-03/Draft%20Net-Zero%20GHG%20Emissions%20Strategy%20for%20the%20Cement%20Sector.pdf.

[34] Table 2 in: California Air Resources Board. CARB 2025b. Draft Net-Zero GHG Emissions Strategy for the Cement Sector. March 14, 2025. https://ww2.arb.ca.gov/sites/default/files/2025-03/Draft%20Net-Zero%20GHG%20Emissions%20Strategy%20for%20the%20Cement%20Sector.pdf.

decision to convert all production in California to PLC, which yields a significant reduction in EC below baseline.

EC baselines for the mixes are shown in the column marked "CLF Material baseline." **Based on interviews with market actors, it was determined that a 20 percent reduction in EC for concrete is possible in most cases with no- to low-cost approaches. In general, thoughtful mix design and incorporating SCMs from the beginning of the project is the enabling approach.** This EC reduction is shown in Table 4's column labeled, "No-to Low-Cost EC Reduction Possible with SCMs." Based on industry estimates of the additional cost necessary to reduce EC in concrete beyond the 20 percent threshold, a nominal carbon price of $200 per metric ton was used, which the project team chose as an upper bound on the price of carbon for the foreseeable future. The additional EC reduction this carbon price would unlock based on current market structure and dynamics is shown in the last column.

It should be noted that concrete is used predominantly for structural purposes, which typically does not have a significant impact on the operational energy performance of a building. Therefore, a correlation between low-EC concrete and building-level EE cannot be easily drawn.

Table 4: EC concrete reductions for Los Angeles and San Jose.

Ready Mix Concrete Mix	Cost ($/CY) Including Overhead and Placement (Los Angeles)	Cost ($/CY) Including Overhead and Placement (San Jose)	CLF Material Baseline ($kgCO_2e$/CY)	No-to Low-Cost EC Reduction Possible with SCMs ($kgCO_2e$/CY)	Additional EC Reduction Possible at a Carbon Value of $200/tonne ($kgCO_2e$/CY)
3,000 psi	$189	$213	213	43	48
4,000 psi	$197	$221	247	49	62
5,000 psi	$204	$230	289	58	82
6,000 psi	$210	$236	307	61	89
LW 3,000 psi	$217	$243	382	76	135
LW 4,000 psi	$225	$253	417	83	155
LW 5,000 psi	$235	$264	454	91	175

Note: LW = Lightweight; CY = Cubic yard

Insulation: Background

Insulation is largely used within a building's envelope to slow heat transfer, which impacts heat load, resulting in reduced runtime for heating and cooling and ultimately saving energy. However, **by adding more insulation to a building to improve operational performance, more material quantity is used, resulting in potential increases in EC material content** compared to a typical building project.

There are a variety of insulation material types, all consisting of their own unique material property profiles, including but not limited to thermal resistance, fire resistance, water resistance, and sound attenuation. Each material type also has its own GWP, which varies in impact depending on the source of raw material and the manufacturing process:

- **Fiberglass** is made from molten glass, heated by fossil-fuel-burning furnaces to temperatures ranging from 2,700 to 3,100°F, and spun or blown into fibers. Fiberglass can be made into blankets, also called "batts," or blown into place (US Environmental Protection Agency (EPA) AP-42 Chapter 11).
- **Mineral wool** is made from natural minerals like basalt or diabase or from blast furnace slag, which is a byproduct of metal manufacturing. Like fiberglass, it is heated by fossil-fuel-burning furnaces to temperatures ranging from 2,400 to 3,000°F. Mineral wool can be made into low-density semi-rigid batts or blankets, or high-density rigid board (EPA AP-42 Chapter 11).
- **Cellulose** is made by shredding recycled paper products and blending it with a fire retardant. It is typically blown into place by air.[35]
- **Expanded polystyrene (EPS) and extruded polystyrene (XPS)**[36] are made by expanding small polystyrene plastic beads with a blowing agent. There are several blowing agents, including pentanes, air, hydrofluorocarbons (HFCs), and hydrofluoroolefins (HFOs). Temperatures for the process usually range from 212°to 230°F, and there are typically rigid board products.[37]
- **Polyisocyanurate foam board and polyurethane spray foam** are made from a chemical reaction between polyols and isocyanates when the two are mixed with a blowing agent similar to EPS and XPS. These can be either rigid board products or sprayed into place.[38]

As a key component of a building's enclosure system, insulation has a specific opportunity for decarbonization through material substitution or specification.

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[35] The US Department of Energy Insulation Materials list can be found at https://www.energy.gov/energysaver/insulation-materials.

[36] See https://my.civil.utah.edu/~bartlett/Geofoam/3a%20-%20JACKON%20presentasjon%20EPS%202011%20Lillestrom%20-%20final%202011-03-28%20RWA.pdf to find more information on how each insulation product is made, from the raw materials used to the temperatures needed to heat for manufacturing the product.

[37] DOE Insulation Materials and EFCTC HFCs, HFOs, HCFOs.

[38] POLYISO Applications and EFCTC HFCs, HFOs, HCFOs.

Insulation: Baseline

Using a combination of cost data from the construction industry's leading database, RSMeans, and GWP benchmarks from the CLF's North American Materials Baselines Report from August 2023, the project team performed a carbon cost-benefit analysis for the insulation material category, as shown below in Table 5. The building insulation products most commonly used in the industry were evaluated, which can vary in thermal performance (R-value per inch) and product thickness (total effective R-value); therefore, it was critical to normalize the data to a standard R-value. To accomplish this, a value of RSI-1, or R5.678, was used to establish both cost (shown in the "Cost per 1 ft² at R5.678" column) and EC (shown in the "$kgCO_2e$ per 1 ft² at R5.678" column), which establishes a like-for-like comparative basis for each material.

The "$kgCO_2e$ per 1 ft² at R5.678" column shows the EC for the various options if one holds the area covered and R-value the same across all rows. In terms of GHG emissions, the lower the number, the better. However, it is also important to assess the cost to achieve lower EC, displayed in the last column, "EC Value Normalized by R-Value. Dollars per $kgCO_2e$," which shows the results of dividing the cost per square foot of the material by the carbon content. The best performing materials in this column will have a large amount of EC avoided per dollar spent—put simply, the highest cost values. **The results indicate that fiberglass batt insulation is the most carbon cost-effective insulation option at $47.92 to $50.77 per $kgCO_2e$, with blown cellulose and EPS coming in next at $4.61 to $7.13 per $kgCO_2e$.** The product types that performed the worst are XPS at $0.48 to $0.54 per $kgCO_2e$, and closed-cell spray foam at $0.72 per $kgCO_2e$.

It should be noted that the contribution manufacturing energy has on the carbon footprint of insulation varies substantially depending on the product type, with foam-based products in the 20 percent range, and bio-based products in the 50 percent range. The project team found that most insulation EPDs elect to bundle A1-A3 LCA stages together, making it challenging to break out A3 (Manufacturing) into a singular contributor.

Table 5: Insulation cost per R-value.

Material Type	Cost per 1 ft²	Total R-Value per 1 ft²	Cost per 1 ft² at R5.678	$kgCO_2e$ per 1 M2 at R5.678	$kgCO_2e$ per 1 ft² at R5.678	EC Value Nor-malized by R-Value. Dollars per $kgCO_2e$
Light density mineral wool 3.5"	$1.74	15	$0.66	3.33	0.31	$2.13

Material Type	Cost per 1 ft^2	Total R-Value per 1 ft^2	Cost per 1 ft^2 at R5.678	$kgCO_2e$ per 1 M2 at R5.678	$kgCO_2e$ per 1 ft^2 at R5.678	EC Value Nor-malized by R-Value. Dollars per $kgCO_2e$
Light density mineral wool 5.5"	$2.46	23	$0.61	3.33	0.31	$1.97
Heavy density mineral wool at 1"	$1.83	4.2	$2.47	8.35	0.78	$3.17
Heavy density mineral wool at 2"	$3.20	8.4	$2.16	8.35	0.78	$2.77
Expanded polystyrene (EPS) at 1"	$1.20	3.85	$1.77	2.67	0.25	$7.08
EPS at 2"	$1.55	7.69	$1.14	2.67	0.25	$4.56
Polyiso-cyanurate at 1"	$1.78	6.5	$1.55	4.19	0.39	$3.97
Polyiso-cyanurate at 2"	$2.11	13	$0.92	4.19	0.39	$2.36
XPS at 1"	$1.80	5	$2.04	41.00	3.81	$0.54
Extruded polystyrene (XPS) at 2"	$3.20	10	$1.82	41.00	3.81	$0.48
Fiberglass batt, unfaced, 3.5" at 16oc	$1.08	13	$0.47	0.10	0.01	$47.00

Material Type	Cost per 1 ft^2	Total R-Value per 1 ft^2	Cost per 1 ft^2 at R5.678	$kgCO_2e$ per 1 M2 at R5.678	$kgCO_2e$ per 1 ft^2 at R5.678	EC Value Nor-malized by R-Value. Dollars per $kgCO_2e$
Fiberglass batt, unfaced, 6" at 16oc	$1.49	19	$0.45	0.10	0.01	$45.00
Closed-cell spray foam, 3.5"	$4.44	24.15	$1.04	15.50	1.44	$0.72
Closed-cell spray foam, 5.5"	$6.95	37.95	$1.04	15.50	1.44	$0.72
Blown cellulose at 3.5"	$0.67	13.65	$0.28	0.49	0.05	$5.60
Blown cellulose at 5-3/16"	$0.90	20.23	$0.25	0.49	0.05	$5.00

The North American Insulation Manufacturers Association (NAIMA) published the Carbon Payback Scenario Analysis in October 2024, which evaluates both the OC and EC impacts of insulation, and identifies the time required for OC savings to break even with the upfront EC emissions (ICF 2024). In Figure 3 below, the average carbon payment period for residential prototypes shows similar findings to the study done by the project team, **with cellulose and fiberglass (loose fill or unfaced batts) products having the quickest payback period at 0.8 and 1.5 months, respectively.**

Spray foams appear to score better, likely due to updated EPD data from newer products that leverage HFO blowing agents. **The longer payback periods were for XPS, high density mineral wool, and HFC closed-cell spray foam at 7, 10.9, and 15.3 months, respectively.** It should be noted that warmer climates require less heating than colder climates and thus, the payback periods were significantly higher—upwards of 2.5 times—in warmer climate zones, which include California Climate Zones 2, 3, and 4.

Insulation Material	Embodied Carbon (kg CO_2e per FU)	Carbon Payback Period (Months)																
		1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8	All
Cellulose Loose Fill	0.61	2.0	1.6	1.1	1.1	1.1	1.3	0.9	1.0	1.0	0.7	0.8	0.9	0.6	0.6	0.5	0.4	0.8
Fiber glass Loose Fill	1.07	3.5	2.8	1.9	1.9	2.0	2.3	1.6	1.7	1.8	1.3	1.3	1.6	1.0	1.1	0.9	0.7	1.5
Fiber glass (unfaced) Batts	1.08	3.6	2.8	1.9	2.0	2.0	2.3	1.6	1.8	1.8	1.3	1.4	1.7	1.0	1.1	0.9	0.7	1.5
HFC (open cell) Spray Foam	1.68	5.5	4.4	3.0	3.0	3.1	3.6	2.5	2.7	2.8	2.0	2.1	2.6	1.6	1.7	1.4	1.2	2.3
HFO (open cell) Spray Foam	1.68	5.5	4.4	3.0	3.0	3.1	3.6	2.5	2.7	2.8	2.0	2.1	2.6	1.6	1.7	1.4	1.2	2.3
Mineral wool Loose Fill	2.07	6.8	5.4	3.7	3.8	3.9	4.5	3.1	3.4	3.5	2.4	2.6	3.2	1.9	2.1	1.7	1.4	2.8
Sheep's Wool Batts	3.11	10.3	8.1	5.6	5.6	5.8	6.8	4.6	5.0	5.2	3.7	3.9	4.8	2.9	3.2	2.6	2.2	4.3
HFO (closed cell) Spray Foam	4.21	14.0	11.0	7.6	7.6	7.8	9.1	6.3	6.8	7.1	5.0	5.3	6.5	3.9	4.3	3.5	2.9	5.8
Mineral Wool (light board) Batt	4.22	14.1	11.1	7.6	7.7	7.9	9.2	6.3	6.8	7.1	5.0	5.3	6.5	3.9	4.4	3.5	2.9	5.8
HFC (closed cell) Spray Foam	11.07	40.8	30.2	20.3	20.5	21.0	24.6	16.7	18.2	18.9	13.1	13.9	17.2	10.3	11.4	9.2	7.7	15.3
Cellulose Batts	N/A	N/A																
Wood Fiber Batts	N/A																	
Wood Fiber Loose Fill	N/A																	
Phenolic Foam	1.62	5.4	4.2	2.9	2.9	3.0	3.5	2.4	2.6	2.7	1.9	2.0	2.5	1.5	1.7	1.3	1.1	2.2
Polyisocyanurate-Roof Foam	2.30	7.6	6.0	4.1	4.2	4.3	5.0	3.4	3.7	3.9	2.7	2.9	3.5	2.1	2.4	1.9	1.6	3.2
EPS Board	2.80	9.2	7.3	5.0	5.1	5.2	6.1	4.2	4.5	4.7	3.3	3.5	4.3	2.6	2.9	2.3	1.9	3.8
Polyisocyanurate- Wall Foam	4.29	14.3	11.2	7.7	7.8	8.0	9.3	6.4	6.9	7.2	5.1	5.4	6.6	4.0	4.4	3.6	3.0	5.9
XPS Board	5.08	17.1	13.4	9.1	9.2	9.5	11.0	7.6	8.2	8.6	6.0	6.4	7.8	4.7	5.2	4.2	3.5	7.0
Mineral Wool (heavy density) Board	7.97	27.4	21.3	14.5	14.6	15.0	17.6	11.9	12.9	13.5	9.4	10.0	12.3	7.4	8.2	6.6	5.5	10.9
Wood Fiber Board	N/A	N/A																

Figure 3: Residential average carbon payback period Analysis.

Note: FU=Functional units.

In Figure 4, which shows the carbon payback scenarios for commercial prototypes, the results are the same as in the residential market, as shown in Figure 3. It is important to note that the differences in payback periods across climate zones were not as extreme in the commercial scenarios as they were for the residential scenarios. The results are similar, **with cellulose and fiberglass leading the way at 0.4 and 0.8 months, respectively.** As seen above, the longer payback periods were for XPS, high density mineral wool, and HFC closed-cell spray foam at 3.5, 5.6, and 7.7 months, respectively (NAIMA, 2024).

Insulation Material	Embodied Carbon (kg CO_2e per FU)	Carbon Payback Period (Months)																
		1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8	All
Cellulose Loose Fill	**0.61**	0.5	0.5	0.4	0.5	0.4	0.8	0.4	0.4	0.5	0.4	0.4	0.5	0.3	0.4	0.4	0.3	0.4
Fiber glass Loose Fill	**1.07**	0.9	1.0	0.7	0.8	0.8	1.4	0.7	0.7	0.9	0.7	0.6	1.0	0.6	0.6	0.6	0.6	0.7
Fiber glass (unfaced) Batts	**1.08**	0.9	1.0	0.7	0.8	0.8	1.4	0.7	0.7	1.0	0.7	0.6	1.0	0.6	0.6	0.6	0.6	0.8
HFC (open cell) Spray Foam	**1.68**	1.3	1.5	1.2	1.3	1.2	2.1	1.2	1.1	1.5	1.1	1.0	1.5	0.9	1.0	1.0	0.9	1.2
HFO (open cell) Spray Foam	**1.68**	1.3	1.5	1.2	1.3	1.2	2.1	1.2	1.1	1.5	1.1	1.0	1.5	0.9	1.0	1.0	0.9	1.2
Mineral wool Loose Fill	**2.07**	1.7	1.8	1.4	1.5	1.5	2.6	1.4	1.3	1.8	1.3	1.2	1.8	1.2	1.2	1.2	1.1	1.4
Sheep's Wool Batts	**3.11**	2.5	2.8	2.2	2.3	2.2	3.9	2.1	2.0	2.8	2.0	1.9	2.8	1.7	1.8	1.8	1.6	2.2
HFO (closed cell) Spray Foam	**4.21**	3.4	3.7	2.9	3.1	3.0	5.3	2.9	2.7	3.7	2.7	2.5	3.7	2.4	2.4	2.4	2.2	2.9
Mineral Wool (light board) Batt	**4.22**	3.4	3.8	2.9	3.2	3.0	5.3	2.9	2.7	3.8	2.7	2.5	3.8	2.4	2.4	2.4	2.2	2.9
HFC (closed cell) Spray Foam	**11.07**	8.9	9.9	7.7	8.3	8.0	14.1	7.6	7.2	9.8	7.1	6.6	9.9	6.2	6.4	6.4	5.8	7.7
Cellulose Batts	**N/A**	N/A																
Wood Fiber Batts	**N/A**																	
Wood Fiber Loose Fill	**N/A**																	
Phenolic Foam	**1.62**	1.3	1.4	1.1	1.2	1.2	2.1	1.1	1.1	1.4	1.0	1.0	1.4	0.9	0.9	0.9	0.9	1.1
Polyisocyanurate-Roof Foam	**2.30**	1.8	2.0	1.6	1.7	1.7	2.9	1.6	1.5	2.0	1.5	1.4	2.0	1.3	1.3	1.3	1.2	1.6
EPS Board	**2.80**	2.2	2.5	1.9	2.1	2.0	3.5	1.9	1.8	2.5	1.8	1.7	2.5	1.6	1.6	1.6	1.5	2.0
Polyisocyanurate- Wall Foam	**4.29**	3.4	3.8	3.0	3.2	3.1	5.4	2.9	2.8	3.8	2.8	2.6	3.8	2.4	2.5	2.5	2.3	3.0
XPS Board	**5.08**	4.1	4.5	3.5	3.8	3.7	6.4	3.5	3.3	4.5	3.3	3.0	4.5	2.8	2.9	2.9	2.7	3.5
Mineral Wool (heavy density) Board	**7.97**	6.4	7.1	5.5	6.0	5.7	10.1	5.5	5.2	7.1	5.1	4.8	7.1	4.5	4.6	4.6	4.2	5.6
Wood Fiber Board	**N/A**	N/A																

Figure 4: Commercial average carbon payback period analysis.

While insulation is the one material category that the project team investigated that could impact both EE and EC of a building, **it was observed that no meaningful reduction in building-level EE would occur when considering fiberglass, mineral wool, EPS, and XPS as insulation options within a building envelope. The R-Value per inch differences between the options of fiberglass batt (R3.1-R4.3), mineral wool batt (R3.7-R4.2), mineral wool board (R3.8-4.4), EPS (R3.6-R4.2), and XPS (R5) are all close enough that over an entire project's energy use, the difference would be negligible. While the NAIMA study above found that mineral wool has longer payback periods than other insulation types, it does offer wildfire mitigation benefits, such as being noncombustible, that are highly desirable in the California region.**

Steel: Background

Steel is the second most used construction material in the world, after concrete (Zhong 2021). The steel supply chain is very different than the concrete and insulation supply chains. There is far less variety and diversity of both the product and the ingredients. There are two types of steel plants: blast furnace–basic oxygen furnace (BF–BOF, or for short BOF) and electric arc furnace (EAF).

The plant type is a primary driver of EC in steel production. A BOF plant typically uses coal as the main energy input and, in general, will have a higher EC profile; an EAF plant's main input is grid electricity. **One of the main influences of steel EC, as it pertains to EAF mills, is the degree to which the local electric grid is decarbonized.** If an EAF facility is powered by a grid that has a high percentage of renewable energy sources, the EC of the steel produced by that plant can be very low. **Renewable penetration of a plant's local grid is an important variable for steel EPDs which have a five-year lifetime.** By way of example, if a mill has not made any changes to its processes or inputs within the last five years, but their local grid has improved its renewable penetration, that mill could see improved EC content on an updated EPD.

Additionally, the percentage of recycled steel or "scrap" used in the process can also impact the overall EC level. The main variable is the percentage of scrap in the input stream. In the case of BOF, the percentage of recycled content is typically 25 to 35 percent, whereas EAF typically uses a much higher scrap content of about 75 percent (Oberoi 2019) (Thompson 2018). There are global suppliers that use as much as 97 percent scrap content in their steel production.[39] As one might expect, EC content goes down significantly with increasing scrap content.

About 75 percent of the mills in the United States use EAF to produce their steel (Thompson 2018). According to one structural engineering firm the project team consulted**, the steel used by the building industry is almost exclusively from EAF mills, whereas BOF mills typically supply cold rolled steel, commonly used by the automotive industry.** There is at least one steel manufacturer with a corporate headquarter listed in California.[40] Pacific Steel Group recently announced the development of its Mojave Micro Mill which is the first steel plant in California in nearly fifty years and utilizes renewable generation in its steel products manufacturing process (Office of Governor Gavin Newsom News 2025). Steel production in the United States is concentrated in the Midwest and South. Within California, the market is served by service centers which act as value-added distributors. The service centers will often cut, bend, and weld steel reinforcing bar (rebar), which is used to strengthen concrete in construction. Other structural pieces, such as I-beams or hollow steel sections (HSS), are also kept in stock and can be cut to length by the service center. **Service centers buy steel in bulk and sell to smaller market players.**

Some construction projects are large enough that they can buy directly from a steel mill and do not have to go through a service center. In general, service centers do not segregate their stock based on EC content or by the mill from which a piece of steel was sourced. However, EC content and mill production information are tracked by service centers, so it is possible to gather EC information for a particular piece of steel at a service center if the mill it came from has an Environmental Product Declaration (EPD) available**. Thus, it is possible, at least in principle, to specify lower-EC steel in building plans even for smaller projects, although sourcing steel directly from a mill is the most reliable pathway to specify low-EC steel for a building project.** There may be an opportunity for lower-EC material substitution by using EPDs originally from the steel mill.

Steel: Baseline

In Error! Reference source not found. below, dollar values were extracted from the online tool, RSMeans, for three common steel components used in construction. It should be noted, GHG emissions in steel making are due almost entirely to the energy input used for heat – either the fuel for a BOF or the power source for an EAC – which is different than in cement making, where CO_2 emitted from heating limestone is a significant contributor to EC in addition to energy used to heat the kilns. The cost is shown in dollars per metric ton ($/ton). The CLF Material Baseline Report has EC values for these three steel types, which is shown in the next column. **Based on interviews with**

[40] For more information on the Pacific Steel Group, see https://pacificsteelgroup.com/about-us/.

steel market actors, the project team established that with a focus on EC in steel beginning in the early stages of the design process, it is sometimes possible to implement low-to-no cost methods to reduce EC for steel in a construction project. An early focus allows both a design approach that reduces the volume of steel used as well as a procurement approach that favors mills with high recycled scrap content and a high percentage of renewable energy on the local grid.

This low-to-no cost reduction is on a case-by-case basis. The column marked "Cost Neutral EC Reduction Possible" shows what the EC reduction is for those cases where a 10 percent reduction below baseline is possible. Column 3 in Table 6 was calculated by the project team to include a 10 percent reduction. Such cases are possible if a project can select steel from a mill that uses a high percentage of scrap, or uses an EAF and is on a grid with a high penetration of renewables. Beyond the 10 percent threshold, market actors we spoke to were less sanguine about the ability of suppliers to provide EC reductions without additional cost. Based on industry estimates of the additional cost necessary to reduce EC in steel beyond the ten percent threshold, a nominal carbon price of $200 per metric ton was used, which the project team chose as an upper bound on the price of carbon for the foreseeable future. Column 4 in Table 6 was calculated by the project team to illustrate the additional EC reduction this carbon price would unlock, based on current market structure and dynamics.

Table 6: Low-EC cost-effectiveness in steel.

Steel Type	$/ton	CLF Material Baseline (kgCO2e/tonne)	Cost Neutral EC Reduction Possible (kgCO2e/tonne)	Additional EC reduction possible at a Carbon Value of $200/tonne (kgCO2e/tonne)
Concrete reinforcing bar A615 grade 60, "rebar"	$2,571	854	85	57
Hot-rolled structural steel sections W 18 x 35 total with overhead and placement (O&P)	$5,012	1,200	120	57
Hollow structural sections 8"x8" x 3/8" x 14' total with O&P	$5,071	1,990	199	156

It should be noted that steel is used predominantly for structural purposes, which typically does not have a significant impact on the operational energy performance on a building. Therefore, a correlation between low-EC steel and building-level EE cannot be easily drawn.

Embodied Carbon Evaluation of a California Project Dataset

The project team compiled a dataset, shown below in

Figure 5, that includes 8 new construction projects in California, ranging from 75,000 to over 1,000,000 square feet. Within the dataset, **seven projects have a primary structural system of steel, and one is mass timber.** Project programs include hospitals, outpatient healthcare, an institutional lab, and a city hall. In terms of completion status, **three projects are completed, three are in construction currently, and the remaining two are currently in the Construction Documents phase of design.**

A total of 43 data points for specific EPDs, or design target GWP limits for projects still in design, have been collected for these projects.

Figure 5 provides a high-level overview of which projects had EPDs for the listed material categories, and the GWP for each data point relative to the baseline. In nearly all cases, we used the 2023 CFL baseline[41] for the GWP baseline. Where a baseline was missing for a specific material, the team used the CALGreen or EC3 material baseline.

	Project 1	Project 2	Project 3	Project 4	Project 5	Project 6	Project 7	Project 8		% GHG Change
Ready Mix Concrete										
3,000 psi										-26%
4,000 psi										-8%
5,000 psi										-23%
6,000 psi										-27%
LW 3,000 psi										10%
LW 4,000 psi										-18%
Steel										
Concrete Reinforcing Bar										-16%
Hot-rolled Structural Steel Sections										23%
Hollow Structural Sections										-3%
Glass										
Flat Glass										0%
Insulation										
Light Density Mineral Wool										-44%
Heavy Density Mineral Wool										-62%
Polyisocyanurate										107%
Interior Finishes										
Gypsum 5/8"										-6%
Resilient Flooring										32%

GWP lower than baseline
GWP equal to baseline
GWP higher than baseline

Figure 5: California building-specific EC data for 8 anonymous new construction projects.

The majority of the data collected for this study was from LEED v4 projects that pursued the Building Product Disclosure and Optimization credits for EPDs. Since the LEED v4 Building Product Disclosure and Optimization credit does not require a specific GWP threshold for selected products, the project team characterizes many of these lower-carbon substitutions as unintentional. Essentially, the design team for the building provided EPDs for common materials to achieve LEED points for disclosure, but in all cases, did not do a comparison with a baseline material. **In many cases reductions were achieved, but in some cases, the EPDs revealed EC emissions higher than the**

[41] Find CLF's 2023 Baseline Report at https://carbonleadershipforum.org/it/clf-material-baselines-2023/.

regional baseline. The 2023 CLF Baseline was used for all materials except light density mineral wool, which used the CALGreen Baseline.

Looking more closely at the instances where GWPs were higher than baseline, **the average for hot-rolled structural steel exceeded the regional baseline due to multiple EPDs from steel manufactured in South Carolina. Despite using an electric arc furnace and recycled steel, the electricity emissions of the plant's local grid are one likely driver of the emissions, resulting in a higher GWP than the California baseline.** This indicates a potential need for steel manufacturing options within California that have EPDs.

Potential Greenhouse Gas Savings in California

The market potential for GHG reductions of a low-EC material substitution approach can be estimated for cement and steel by analysis of estimates of annual tonnage of those two materials sold in California. Cement and steel are by far the two biggest contributors to EC in the building sector, which is why we considered them here, and **used a conservative estimate of a 10 percent reduction possible with low-to-no cost solutions.** As referenced in Table 3, the sum of GHG emissions from the seven cement plants in California is 7,767,670 $MTCO_2e$. **A 10 percent reduction would equate to a 776,767 $MTCO_2e$ annual savings.**

Steel is more difficult to estimate, as California-specific data is not readily available. The American Institute of Steel Construction AISC estimates that 3.5 million tons of hot rolled steel sections and hollow structural sections are sold annually in the United States.[42] Estimating California's share, based on California's 12 percent share of the US population, yields 420,000 tons per year in California. From **Error! Reference source not found.**, the average of the cost-neutral GHG reduction per ton of hot rolled steel sections and hollow structural steel sections is 0.1595 $MTCO_2e$ per ton, which yields 66,990 $MTCO_2e$.

Steel rebar market size nationally is 15 million MT per year.[43] Applying a population-based market share for California yields a 1.8 million MT per year size. Taking a cost-neutral reduction potential from **Error! Reference source not found.** of 0.085 $MTCO_2e$, this yields 153,000 $MTCO_2e$ per year, and the sum for steel is thus 219,000 $MTCO_2e$ per year. **The cost-neutral reductions theoretically possible for cement and steel together add up to just under 1 million $MTCO_2e$ per year.**

[42] Find the American Institute of Steel Construction Sustainability webpage at https://www.aisc.org/sustainability/made-in-america/.

[43] Find the U.S. Concrete Reinforcing Bars – Market Analysis, Forecast, Size, Trends And Insights at https://www.indexbox.io/blog/concrete-reinforcing-bar-united-states-market-overview-2024-8.

Embodied Carbon Baselines and Reductions[44]

Across the board, when asked about EC baselines for concrete, market actors identified the NRMCA baseline as their go-to for concrete baselines. Additionally, interviewees referenced the CLF baseline report, which is primarily based on industry-wide EPDs and updated regularly, as an important low-EC resource for setting project baselines. Contractors also mentioned that baselines are industry-specific, referencing the AISC baseline for steel as an example. Interestingly, **interviewees were also unanimous in identifying the difficulty surrounding statewide baselines in California, given the regional differences across the state.** For example, as one architect noted, **"in California…the baseline EPDs in San Francisco, Los Angeles, and San Diego are all different, which presents a significant challenge to establishing an industry baseline."**

It should also be noted that **price per material varies**, not just across cities from different regions of the state, but also whether the project is being constructed in an **urban versus rural setting.** This results in a potential equity issue when considering singular baseline metrics across the entire state. Understandably, several market actors reported that they do not concern themselves with the baselines, but rather **they choose the right product for the right application and let the building designers and customers set the baselines.**

Cost-Neutral Approaches to Low-Embodied Carbon Material Substitutions[45]

An important consideration when assessing the market for low-EC material substitutions is whether there is a cost-neutral way to incorporate low-EC alternatives into building projects. Interviewees were unanimous in identifying that **low-EC material substitution cost neutrality is highly dependent on design, baseline assumptions, and material availability.** It should be noted that in contrast to material suppliers, sustainability consultants, and architectural, engineering, and construction (AEC) firms, customers reported that they **were not aware of cost-neutral approaches to low-EC material substitutions** and that they "stumbled in the dark for a long time…[and] attended webinars and conferences to educate themselves."

They further shared that they have "heard similar concerns from other stakeholders" about a **lack of awareness of cost-neutral low-EC material alternatives.** Interestingly, utility and architectural market actors noted that a key method for reducing EC at no additional cost is to **simply "build less."** In other words, building projects can reduce EC by taking a holistic approach to design and employing optimization strategies in which designers identify opportunities to cut down on carbon-intensive materials. Design optimization can translate to less concrete use, fewer or shorter structural steel members, or any number of other design efficiencies. This optimization mindset requires early planning and typically, the involvement of specialized designers, **but all interviewees agreed that the project-wide impact can reduce overall EC.** However, even for projects that can take an optimization

44 During the market characterization interviews, the project team asked the following question to target EC baselines and reductions: "How do you think about EC baselines in your industry? Is there a specific target reduction amount for each material, and if not, how do you handle that?"

45 During the market characterization interviews, the project team asked the following question to target EC cost-neutral approaches to low-EC material substitutions: "Are you aware of any low- or no-cost pathways to reduce EC in construction projects? Who would you work with to explore low or no-cost EC-reduction pathways?"

approach, **low-EC material substitutions are still essential and require careful consideration and planning.**

In the realm of low-EC concrete, contractors, architects, and industry trade associates all commented that a 15 to 20 percent EC reduction below the NRMCA baseline is standard and can be done with relative ease, often without additional costs (NRMCA 2022). In some cases, interviewees noted projects can achieve more than a 20 percent reduction with marginal or even no additional costs (Concrete-AI 2022). **However, in general, achieving beyond the 20 percent threshold for concrete mixes requires far more intentionality and creativity in how water, admixtures, and aggregate gradations are used.** That said, several market actors shared instances in which they were able to achieve a reduction of more than 30 percent from the NRMCA concrete EC baseline. However, as previously noted, these projects set a GWP limit for their concrete mix from the onset and employed integrated design strategies during the project planning to reach their target.

Additionally, **investment in low-EC substitutions** for concrete mixes—and other materials—**will vary greatly by region and by customer type.** Often, Fortune 500 companies in Northern California or the Pacific Northwest are the ones doing large-scale building projects, and are the most invested in pursuing low-EC solutions. Interestingly, one concrete manufacturer shared that for projects in Southern California, **they consider a 10- to 15-percent EC reduction to be a "low-EC building project," whereas in Northern California, "low-EC building projects" tend to be at or above a 15-percent reduction.** The interviewee explained that historically, **Northern California had easier access than Southern California to the high-quality aggregates produced in Vancouver**, which require less water and subsequently, less cement, to produce concrete. Over the past several years, the accessibility of high-quality concrete aggregates in Southern California has improved significantly, but familiarity with low-EC concrete products among industry professionals is still lower than among their counterparts in Northern California.

In contrast to concrete, market actors commented that the **applications for low-EC insulation are more accessible in residential, multifamily, and small commercial settings than large commercial or industrial building projects. Moreover, there are several retrofit applications for low-EC insulation that do not exist for concrete or steel.** However, an obstacle for low-EC insulation adoption is that different types of insulation are better suited to certain building applications and configurations than others. For instance, fiberglass insulation is affordable, easy to install, durable, and fire-resistant, while cellulose is beneficial for its thermal performance, sound dampening, resistance to pests and mold, and retrofit applications.

Using one type of insulation over another impacts the size and configuration of a building's walls due to the variation in thickness and density of different insulation types. As such, the question of cost neutrality for low-EC insulation substitutions is complicated by the configuration and function of the building. Nevertheless, one contractor noted that individual manufacturers have EPDs that are lower than the industry EC average for insulation, and that by working through these manufacturers, one can find a low- or no-cost option for insulation. **However, this practice of sourcing low-EC insulation directly from the manufacturer is not widespread and will depend on the location of the building project.**

The landscape for low- or no-cost low-EC steel substitutions is sparse. According to contractors, the most referenced baseline for steel is the AISC's 2021 specification, which sets benchmarks for EC values for plate steel, hollow structural steel, and hot-rolled structural steel.[46] One contractor shared that **if a project is sourcing its steel from a plant in the United States, they can achieve as much as a 10 percent EC reduction at no additional cost.** This is because most of the American steel manufacturers that produce the steel components used in building projects use EAFs rather than BOFs.

However, **depending on where one is located, the steel sourced from a United States steel mill may be more costly than steel sourced from a mill overseas,** particularly for steel metal decks. Furthermore, another interviewee noted that **they rarely see reliable reductions for steel, and in the cases where they do, it is most often because the customer is willing to pay a premium.** The interviewee explained that when projects set GWP limits on their steel, the number of steel mills to choose from shrinks, which typically results in modest premiums. **The most cost-effective approach to reducing EC in steel is not necessarily procurement but rather through design optimization,** working with a structural engineer to optimize the material quantities used for the building and ultimately, using less steel.

Across the board, when asked who they work with on low-EC projects, **market actors reported that EC is not a priority in most building projects.** One architect who focuses mostly on multifamily housing projects in California noted that it has been challenging to incorporate EC and other sustainability features into their projects due to an increased scrutiny on residential projects in California (AB 306). **Most of the building projects in California that are focused on lowering their EC are large pharmaceutical, healthcare, or technology companies with large-scale construction projects.** Projects of this nature fall under California's current Title 24 CALGreen standards, which require new construction nonresidential commercial building projects over 100,000 square feet and school building projects over 50,000 square feet to meet certain EC specifications (2025 California Green Building Standards Code, Title 24, Part 11.).[47]

One contractor shared that, out of the 34 active clients in California with projects that are greater than $20 million dollars and are in pre-construction or construction, four have EC limits beyond what is required by California code. Moreover, five out of the 34 of the contractor's projects that are in pre-construction or construction must meet the BCCA standards, which set maximum acceptable GWP limits for concrete, insulation, flat glass, structural steel, and reinforcing steel with which all public work projects must comply.[48] **However, multiple contractors noted that while CALGreen helps, it is also "super easy to do" and that "these companies would [meet the standards] even without CALGreen."**

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[46] The American Institute of Steel Construction includes a webpage providing information on steel's environmental footprint here https://www.aisc.org/sustainability/steels-environmental-footprint/#112582.

[47] CALGreen also has EC requirements for existing buildings.

[48] The California Department of General Services has information regarding the Buy Clean California Act on their website here https://www.dgs.ca.gov/pd/resources/page-content/procurement-division-resources-list-folder/buy-clean-california-act.

Customers shared that they have never been penalized for failing to comply with the BCCA standard or opting not to enter EPD data into the DGS reporting tool, which was created to track standard compliance. Interviewees reported low usage rates of the DGS reporting tool, which is unsurprising for several reasons: **The tool has been cited "difficult to use," EPD literacy levels in the market are generally low, and there are no rewards for compliance nor penalties for non-compliance with the BCCA standard.** On the utility side, interviewees commented that they have heard similar criticisms of CALGreen—that it is **lenient and easy to comply with.** In addition to the state regulations, interviewees cited the **Green Building Council's LEED standards** as an important mechanism for driving sustainably motivated customers to incorporate EC analyses into their building projects.

Added Cost Approaches to Low-Embodied Carbon Material Substitutions[49]

When discussing the cost implications of lowering EC with stakeholders, a common theme emerged: For multiple reasons, **there is no simple formulaic approach that yields a specific amount of tons of EC reduction per project dollar spent. The location and timing of projects matters, especially in terms of availability of low-EC cement.** SCMs such as fly ash and slag have time-varying, unpredictable levels of availability in the market and face occasional supply constraints. Further, some regions have permanent structural differences in low-EC cement availability. **Compounding the problem further, contractors must exert significant effort to generate quotes for construction projects, incurring tens or even hundreds of thousands of dollars in expense**, prior to knowing if they are even going to win a bid. It is cost prohibitive to generate two different quotes, such as a status quo bid and a low-EC bid. **For this reason, quantitative apples-to-apples comparisons for standard and low-EC versions of the same project are extremely rare**. Despite these barriers, market actors still have qualitative cost feedback to offer.

Over the last decade, the cost landscape for lowering EC in a building project has improved a great deal. According to one architect, **it used to be that a 10 percent EC reduction on a project would mean the customer paid 10 percent more; this is no longer the case.** This interviewee added that **five years ago, low-EC cement in California had a 10 percent premium and is now becoming the standard offering.** Sustainability consultants commented that the question of additional costs for low-EC concrete is not straightforward and is highly dependent on the ready-mixed supplier. Developers noted that the first thing they discuss with customers interested in a low-EC concrete material substitution are the potential schedule impacts because, in some cases, "the budget [impact] is easier [for customers] than the time [impact]."

Some suppliers can achieve a 20 percent EC reduction without significant additional costs, while others, particularly those outside of California, will market their low-EC concrete alternatives at added cost. Contractors shared a similar sentiment, **noting that the cost of low-EC concrete varies significantly across different regions, even within California**, and that once a project reaches 30 percent below the NRMCA baseline, the additional cost is largely tied to scheduling impacts. The scheduling and subsequent cost implications of pursuing low-EC concrete substitutions will also vary

[49] During the market characterization interviews, the project team asked the following question to target added cost approaches to low-EC material substitution: "What low-EC materials or methods require additional costs, and what are those costs? How do you go about assessing costs?"

depending on whether the low-EC concrete is a cast-in-place, which must be set before formwork can be removed, or if it is slab on a metal deck, which does not rely on formwork. More specifically, if a low-EC concrete mix takes 56 days to reach full strength, and a standard mix takes 28 days, the low-EC concrete mix will double the project timeline and increase costs significantly, as construction crews and equipment must be mobilized for twice as long.

Much like concrete, the costs of low-EC insulation vary depending on the type of insulation. Mineral wool, for instance, is generally more expensive than fiberglass and cellulose, but offers better fire resistance than either of the other two. A utility representative pointed out that there are material classes for insulation, and that the differences between insulation materials within the same class are minor when one considers EC impact. In some cases, a project will have design criteria that cater to one type of material over another, but otherwise, materials in the same class can be interchangeable. In some instances, low-EC insulation materials will also provide health benefits, which may result in a premium; however, this cannot be solely linked to a customer's pursuit of lowering the EC of their building. Interestingly, insulation manufacturers commented that they have **"never heard of someone choosing a product specifically for EC…products [are] typically chosen for other reasons."** The interviewee explained that **there are too many other variables associated with a building's insulation type for a project to choose a product solely based on the EC content.** Ultimately, the question of costs associated with low-EC insulation is a matter of customer priorities and building use.

Interviewees agreed that the cost implications of **low-EC steel are often a matter of procurement practices to achieve substitution of low-EC material in place of standard EC material.** Contractors were unanimous that **building projects can generally meet the AISC baseline for steel at no additional cost.** At ten percent below the AISC baseline, depending on where the steel is sourced, there tends to be some premium, even if it is minimal. Contractors said steel that is more than 10 percent below the AISC baseline is not common and when available, can carry a significant cost premium. Structural engineers were more circumspect, claiming that a project can reach up to 20 percent EC reduction; however, they did not comment on the associated cost implications. It is worth noting that structural engineers are not typically responsible for the procurement of building materials and thus are not directly linked to the logistical difficulties that contractors face when securing low-EC steel. With that in mind, engineers are aware of suppliers who stock steel that is 20 percent below the baseline, even if they are not privy to the volume of this steel available in the market or the specific cost implications**. The supply chain for steel is such that specifying low-EC for small and large products can be a difficult task.**

For smaller projects that require less steel, contractors typically source it through a warehouse distributor rather than a mill. There are several instances where warehouses do not have low-EC steel in stock, but even when they do, warehouses are not set up to specify a specific type of steel for a specific customer, which presents a barrier to reducing material GWP**. The specificity needed to select steel based on GWP, while technically feasible, incurs a cost penalty for the distributor.** Even for larger projects that procure their steel directly from a mill, a manufacturer may produce low-EC steel at one mill but not others, which can make the acquisition process timely and costly. **The result is a convoluted landscape for sourcing low-EC steel, particularly for market actors that are less familiar with the specifications and manufacturers working in the low-EC steel space.**

When one considers EC in the context of OC,[50] architects noted that it is important to look at carbon holistically. For instance, one architect stated that "a 30 percent reduction in EC can equate to offsetting the GHG emissions from a year's worth of energy bills." It is important for designers and customers to evaluate the EC and OC of their building when making strategic decisions on how to reach their carbon goals. One architect referenced a project in which the client had both low-EC and net-zero energy goals for their building, and they had to balance the tradeoffs between low-EC and EE and OC building materials.

Representatives of the insulation industry and architectural firms asserted that using thicker insulation always results in less OC over time, which translates to carbon reduction and subsequently, cost savings due to the energy savings generated from the thicker insulation. **Insulation manufacturers shared that they tend to "live in the OC space" because they have products with high R-values. However, they did acknowledge that there is a growing demand to consider EC in their product development. Cost tradeoffs in insulation are primarily related to non-EC performance metrics like fire resistance, acoustics, and other properties.**

Beyond the actual building, the decision on whether to prioritize EC or OC is highly influenced by how each topic is perceived by industry actors. According to architects, there is not much of a trade-off between EC and EE, but the two are discussed with clients differently**. With EE, the client can see direct benefits on their monthly energy bills, whereas EC requires more education and can be thought of as a passive, one-time carbon-reduction option. The result is a natural inclination among customers and clients toward EE and OC savings opportunities over low-EC material substitutions.** Utility representatives from the California IOUs, which use the TSB metric to assess the impact of EE programs, provided a similar perspective on the perceptions of EE and EC: **EC is not heavily emphasized in EE programs. While non-energy benefits (NEB) like GHGs are incorporated into the TSB model, there needs to be a mechanism to also include EC GHG emissions reductions.** The study team identified **two market gaps in order to harmonize EC with EE, which are: 1) Need for establishing a program attribution model, also referred to as "additionality", in order to document an EC program's impact on market adoption of low-EC building materials, and 2) a methodology to quantify the incremental GHG benefits from EC activities such as development of an EC ACC.** Development of an EC ACC would be similar to the transformation in thinking related to low-GWP refrigerants that led to the creation of the Refrigerant Avoided Cost Calculator (RACC).[51]

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[50] During the market characterization interviews, the project team asked the following question to target operational carbon: "What is the relationship between operational energy use, carbon emissions, upfront costs, and recurring costs?"

[51] See Executive Summary (p. 8) of the Low Global Warming Potential Refrigerants Memo, created by Energy Solutions on behalf of San Diego Gas & Electric (SDGE), on June 28, 2023. At the time of the memo, there were no electronic Technical Resource Manual (eTRM) measure packages that explicitly promoted equipment containing low-GWP refrigerants as an alternative to standard high-GWP refrigerants in use. "Prior to the introduction of the refrigerant avoided cost calculator (RACC) and Total System Benefit (TSB) metrics, there would not have been a mechanism for IOUs to claim savings for this type of measure." Likewise, similar circumstances prevent IOUs from claiming savings from Embodied Carbon GHG savings. The memo noted that "With these metrics being added by CPUC in recent years, savings claims are now possible" (for low-GWP refrigerants).

Energy Efficiency[52]

The project team focused on utility representatives when asking about distinctions between OC emissions and EC emissions. Both interviewees noted that EC and OC emissions are highly correlated and can even fall into the same bucket. **However, there is also opportunity for emissions to be miscategorized. For instance, the emissions from the energy usage of machines to manufacture a material might be considered OC. However, from the perspective of a project installing those manufactured materials, those emissions are EC emissions.** Ultimately, utilities did not report a definite yes or no, but rather said that the way in which they evaluate EC and OC emissions will vary by customer segments and larger discussion topics. **As noted earlier, utility representatives also stated that unless or until EE policy incorporates EC, there is little consideration of EC**—at least among EE program staff—while still being addressed among EE Codes and Standards activities such as Energy Code Ace or CALGreen.

Both sustainability consultants and architects reported that they do consider operational savings in their project plans. In fact, one architect emphasized that they make a point of discussing operational savings with customers. Another architect shared that many codes require buildings to incorporate OC savings and that the "American Institute of Architects (AIA) is actually more focused on OC [than EC]." Sustainability consultants referenced targeted studies their firm conducted on the carbon payback of insulation and exterior shading.

Emerging Technology[53]

The construction space is full of emerging technologies, innovations, and exciting optimizations that can improve the industry's ability to decrease EC. For instance, architects shared that across the industry**, they are hoping to see "any kind of incentive: permit expediting, rebates, financial incentives to do the right thing.**" One such example is a policy in which a building's allotted floor area ratio (FAR) is tied to sustainability requirements, requiring building projects to include certain EE and low-EC building materials based on building size. A potential strategy could be a FAR bonus, which could allow a midrise or high rise building to have an additional floor (allowing higher rental value) than would otherwise be allowed, if they exceed low-EC requirements. **Contractors shared that mass timber, such as cross-laminated timber, is becoming more cost-effective and in some instances, the cheaper option, depending on the site conditions.**

University customers mentioned a parking lot rehabilitation project in which recycled asphalt and tires were used as low-EC alternatives. Sustainability consultants commented that they have seen architects start to use whole-building life cycle assessment (WBLCA) for their projects, with some AECs building their own in-house WBLCA tools. Industry consultants discussed how AI software tools have enabled building projects to reduce overdesign or overutilization of EC materials, such as

[52] During the market characterization interviews, the project team asked the following question to target energy efficiency: "Do you (or your industry/department) make a distinction between OC emissions and EC emissions?" and "Do you consider operational savings as part of your project planning? And if so, in which product categories, e.g., lighting, HVAC, insulation, etc.?"

[53] During the market characterization interviews, the project team asked the following question to target emerging technology: "What emerging trends, innovations, or other new ideas are you seeing that will decarbonize your industry? What new production methods, emerging product types, or product substitutes are you particularly excited about?"

cement. Utilities identified material prefabrication as an area with potential for substantial energy savings. Structural engineers shared a similar sentiment, noting that the potential solution for reducing EC in steel is to “green the grid” by identifying ways to reduce carbon emissions in the production process. Similarly, a concrete manufacturer shared that one of their newly designed plants was built to run entirely on alternative fuels—including pistachio shells—rather than coal, petroleum, or other carbon-intensive fuels. **Waste reduction, renewable fuel sources, and material transportation optimization are some examples of ways in which manufacturers can significantly reduce their energy usage, although these practices are not yet widely adopted. Additionally, if these production processes can include EE equipment or processes, there is potential to achieve combined reductions in OC and EC.**

Utility Findings[54]

The project team spoke to utility representatives specifically about how their respective organizations view EC, particularly as it relates to EE and BD. **One utility interviewee commented that the deemed energy savings model that many EE programs use would not translate well to an EC program.** The interviewee went on to say **that their utility does not have an official position on EC but from their perspective**, “EE and BD are not really different things,” and that the line between EE and BD is blurry. **Other utility representatives shared that they are unsure where EC fits into their portfolio of efficiencies programs and that, beyond codes and standards, “no one is talking about EC from a programmatic standpoint.” Without metrics to measure attribution of EC, the interviewee noted, it will be a “tough sell for a resource program.”** That said, an interviewee did note that their utility has a sustainability team that evaluates their internal construction projects and has influenced utility projects to include decarbonization measures.

[54] During the market characterization interviews, the project team asked the following question to target utility organization’s view of EC: “What is your utility's perspective on EC? Does it fall under EE, BD, or a different policy perspective, and what are the barriers to harmonizing EC with EE or BD?”

Funding

Incentives are a compelling strategy to encourage market adoption of EE measures, practices, and technologies. Most EE incentives take the form of cash rebates or incentives, however, in the team's research on EC, non-financial incentives such as zoning allowances—e.g., floor-to-area ratio (FAR) bonuses—can have a compelling impact on certain segments of the EC market without requiring the provision of cash incentives.[55] In other words, these allowances have financial implications for the builders in terms of increased rentals or units to offer for sale, but do not necessitate "cash" incentives like EE programs and thus, does not require a continual funding source.

The team explored where EC practices might be incorporated into existing EE programs, such as the California Energy Design Assistance (CEDA) new construction EE program, while also considering potential funding opportunities for EC reductions. However, an initial scan of existing incentive programs under the California Climate Investments (CCI) portfolio yielded no results for EC funded programs in California.[56] In lieu of existing EC incentive programs under the CCI portfolio, the project team provided examples of existing programs outside of California that support EC adoption in the paragraphs below.

One example of an EC incentive program is the **US Environmental Protection Agency's (EPA's) C-MORE Grant Program**, Reducing Embodied Greenhouse Gas Emissions for Construction Materials and Products. This program offered nearly $160 million in grants for the creation of robust EPDs, the development of robust product category rule standards and associated conformity assessment systems, robust tools to support and incentivize the development and verification of EPDs, and robust EPD data platforms and integration.[57]

In addition to the C-MORE Grant Program, **the US Department of Energy (DOE) projects** announced $428 million for 14 projects, three of which were startups focused on lowering EC in concrete. The DOE announcement was originally made under the agency's Advanced Energy Manufacturing and Recycling grants program, which set out to help companies build manufacturing facilities. At the time, funding for the grants came from the 2021 Infrastructure Investment and Jobs Act (IIJA) (U.S. Congress 2021). The $750 million program was aimed at small firms moving to establish or expand manufacturing or recycling facilities involved in clean energy, low-carbon materials, or reduced GHG emissions.

Grant recipients of this program included, Terra CO_2, which was awarded a $52.6 million grant to produce SCMs that can displace much of the Portland cement in concrete; Furno Materials, which received a $20 million grant to build a facility that would have produced 55,000 tons of cement per year, primarily from recycled concrete; and Urban Mining Industries, which received a $37.1 million federal grant to use ground glass pozzolan ("pozzotive"), a cement replacement that can account for

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[55] The City of Los Angeles Zoning Code has a Frequently Asked Questions page here https://zoning.lacity.gov/faq/form/how-does-bonus-farheight-work.

[56] The California Climate Investments website includes information on all California Climate Investments Programs here https://www.caclimateinvestments.ca.gov/all-programs.

[57] The EPA website includes more information on the C-More Grant Program here https://www.epa.gov/greenerproducts/grant-program.

as much as 50 percent of the cement in concrete with just six percent of the carbon footprint of traditional cement. However, due to recent changes in federal administration policies, funding for these programs may have been withdrawn or subject to reduced funding levels.

Beyond the DOE's EC startup grants, another instance of EC funding is the **General Services Administration's (GSA's) low-EC program,** including Buy American requirements and low-EC requirements. This funding was enabled by the Inflation Reduction Act of 2022, which provided $3.375 billion to GSA to invest in federal buildings. Section 60503 appropriated $2.15 billion for the procurement of low-EC construction materials. The agency has aligned this investment with the Trump Administration's priorities, including from Executive Order 14154, through consultation with the Office of Management and Budget (OMB) and may continue projects in core assets where no cost premium is realized.[58] Additionally, the **Federal Highway Administration (FHWA) Sustainable Pavements Program** advances knowledge and practice of sustainability related to pavement systems, including life cycle assessment (LCA) best practices, standards, and tools, such as the Pavement LCA tool (Lewis 2021).

California funding for EC programs remains a key market barrier due to the lack of EE and BD funding policies supporting EC. Additionally, CARB policies (SB 596, AB 2446) and market mechanisms (AB 43, Cap and Invest) are areas of development that could, in the future, enable potential funding for EC. Lastly, private capital providers such as Nuveen Capital support Commercial Property Assessed Clean Energy (C-PACE) loans which are a state policy-enabled financing mechanism that allows building owners and developers to access the capital they need to make energy-related deferred maintenance upgrades in their existing buildings, support new construction costs, and make renewable energy more accessible and cost-effective.[59]

Energy Efficiency

Under the current CPUC cost-effectiveness policy, EC is treated as a NEB that is not captured under the TSB metric. **TSB** includes GHG emissions from the direct generation, transmission and distribution of energy, **but does not include other NEBs such as health and safety benefits from fuel substitution programs, job creation from the EE industry, or other non-energy related GHG reductions such as EC.**[60] As mentioned previously, low-GWP refrigerants were not captured in cost-effectiveness policy until the development of a RACC that quantified the benefits of GHG emission

[58] See https://iratracker.org/programs/ira-section-60503-funding-for-low-carbon-materials-at-federal-facilities/#:~:text=Section%2060503%20of%20the%20IRA,available%20until%20September%2030%2C%202026.

[59] On the Nuveen website, see https://www.nuveen.com/greencapital/about-c-pace/what-is-c-pace and https://documents.nuveen.com/Documents/Nuveen/Default.aspx?uniqueId=6bbe59f6-4611-400b-9fc3-35be85a6f0fa.

[60] TSB is defined as an expression, in dollars, of the life cycle energy, ancillary services, generation capacity, transmission and distribution capacity, and GHG benefits of energy efficiency activities, on an annual basis. The 2021 Energy Efficiency Potential and Goals study states that TSB represents the total benefits, or "avoided costs," that a measure provides to the electric and natural gas systems. The factors included in avoided costs are defined through the CPUC Integrated Distributed Energy Resources (IDER) proceeding. See pg. 1 of https://pda.energydataweb.com/api/view/2530/DRAFT%20TSB%20Tech%20Guidance%20081621.pdf.

reductions from avoiding higher-GWP refrigerants (DNV 2024).[61] **One potential pathway for enabling EC to be effectuated in EE programs is to follow the precedent of the RACC's creation, by enabling the creation of an EC ACC to capture the benefits of avoided emissions from EC, namely CO_2 equivalents.** However, the creation of an EC ACC tool would likely require the following steps,

1. Completion of verified studies of GHG savings across various building materials categories to establish baselines and incremental GHG savings (e.g., cement, steel, insulation, windows)
2. Establishment of an approved cost of carbon (currently $114/ton of CO_2e) for avoided EC
3. Regulatory approval for the inclusion of EC as an avoided cost adder

Currently, there are different proceedings for measuring cost-effectiveness, such as Rulemaking (R.) 22-11-013, which details cost-effectiveness of distributed energy resource programs, data access and use, and equipment performance standards.[62] It is important to note that this Rulemaking covers cost-effectiveness across a number of separate policies including EE, demand response, energy storage, and more.[63] Additionally, R.25-04-010 establishes goals and frameworks for the oversight and evaluation of EE portfolios, policies, and programs (California Public Utilities Commission 2025). R.25-04-010 is sometimes referred to as "the new EE rulemaking" in light of the fact that the ruling supersedes R.13-11-005, which was closed in late 2024. EE Cost Effectiveness is expected to be a high focus of R.25-04-010, especially in light of the Governor's Executive Order, N-5-24, which directed the CPUC and CEC to recommend ways to mitigate the rising cost of electricity service in California including the reduction or elimination of non-cost-effective programs in California.

A possible regulatory pathway for EC to be included in EE is:

- CPUC policy guidance to expand the definition of Scope 3 emissions counted in TSB to include EC; currently, methane and refrigerants are included in TSB; however, EC is not classified as a methane or as a refrigerant but is a CO_2 equivalent which impacts GWP
- CPUC regulatory guidance (under R.25-04-010) to include EC into a future Potential and Goals study (in order to guide TSB potential related to EC activities)
- Development of an Avoided Cost Calculator for EC (as part of R.22-11-013)

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[61] The Total System Benefit Technical Guidance, Version 1.1 (dated August 16, 2021) states that the output of the ACC consists of hourly avoided costs, in six categories, for a 30-year period. The six types of avoided costs are: energy, ancillary services, generation capacity, transmission and distribution capacity, and GHG benefits. The GHG benefits include both carbon (expressed through the GHG adder) and high global-warming potential gasses, such as methane and refrigerants. GHG savings from EC is not currently included in these definitions of methane or refrigerants. See pg. 2 of https://pda.energydataweb.com/api/view/2530/DRAFT%20TSB%20Tech%20Guidance%20081621.pdf.

[62] See the CPUC webpage outlining Energy Efficiency Procurement and Solicitations: https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/demand-side-management/energy-efficiency/energy-efficiency-proceeding-activity.

[63] This Order Instituting Rulemaking (OIR) has a particular topic assigned for Portfolio Oversight and Cost-Effectiveness and the CPUC has pointed out that "Work to refine the Avoided Cost Calculator, which underpins much of the cost-effectiveness analysis, is ongoing in R.22-11-013. As part of a process of continual improvement of energy efficiency programs, adjustments may be needed to cost-effectiveness policies and their application within energy efficiency portfolios and programs. In addition, EE-specific cost-effectiveness policy should be coordinated with broader distributed resource cost-effectiveness work being undertaken in R.22-11-013. This proceeding may also evaluate actions that could improve the efficacy of energy efficiency portfolios and explore ways to reduce ratepayer funding for programs."

- Formal inclusion under EE as part of R.25-04-010; this may require the identification and application of EC specific programs or expansion of existing EE programs to include EC program elements as well as approval for budgets and program scope

Additionally, in support of establishing an EE funding mechanism for low-EC materials, the California IOUs could fund an EC study, similar to the Low-GWP Refrigerants Memo funded by SDG&E. The study would document the items related to EC and possible harmonization strategies with EE, including federal regulations for low-GWP EC, California legislation for low-GWP EC (SB 596, AB 2446, AB 43), California regulations for low-GWP EC (e.g., CARB policy developments) along with continuing CARB SB 596 workshops and comment filings, as well as AB 2446 and AB 43 workshops.

Additionally, the EC study could include policy drivers for California agencies (e.g., CEC, BSC, CPUC), model codes (e.g., ASHRAE), details on existing low-GWP EC incentive programs (e.g., BCCA and the Vermont Insulation EC program[64]), and document EC-related activities in other states and jurisdictions such as Massachusetts, Vermont, Colorado, New York, and Vancouver. Lastly, the EC study could incorporate the policy background and definition for TSB, as well as an accounting for EC, EC ACC, and the effects of low-GWP on EE.

However, **given continual sensitivities to electricity rate affordability pressures in California—** California has the highest electricity rates in the country—and exploration of alternative funding means for EE programs in other states such as Massachusetts**, there may be scrutiny of EC programs as an additional benefit under TSB.** A similar fate was seen by the Massachusetts Department of Public Utilities (DPU) in their reduction of Mass Save's 2025−2027 EE and Decarbonization program application from $5 billion to $4.5 billion, and the removal of their EC program which, would have been one of the first in the country. A primary question the Massachusetts DPU had in their review centered on how a rebate level for low-EC materials was chosen and how the GHG benefits would be measured. No equivalent of an EC ACC was offered to quantify the carbon benefits from the program's EC activities, highlighting the possible benefit of creating an EC ACC.

Building Decarbonization

EC is not currently included in BD programs such as TECH Clean California, which are primarily focused on fuel substitution via building electrification measures (e.g., clean heat solutions such as heat pump HVAC) and heat pump water heaters (HPWHs). CARB's 2022 Scoping Memo also does not discuss EC but does mention carbon capture and sequestration. **While EC could theoretically fit under this category, it is generally referred to separately as its own category. As a result, clarification is needed on how EC falls under BD, as CARB's website does show EC as being part of the BD program.**[65]

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[64] See Vermont's Department of Public Service website with information regarding RBES SECTION R408 Insulation Embodied Carbon Calculation DRAFT, https://publicservice.vermont.gov/document/rbes-section-r408-insulation-embodied-carbon-calculationdraft.

[65] More information on EC and CARB's work on EC can be found at https://ww2.arb.ca.gov/our-work/programs/embodied-carbon.

From a policy perspective, legislation focusing on EC has been adjunct to existing BD policies, such as AB 2446 and AB 43. Currently, CARB is conducting various workshops to capture benchmarking data and measurement data to inform EC policy.

Other Funding Mechanisms

The Rocky Mountain Institute (RMI) and Microsoft conducted a study on "Structuring Demand for Lower-Carbon Materials, An Initial Assessment of Book and Claim for the Steel and Concrete Sectors" to ascertain whether Environmental Attribute Certificates (EACs) could be created as a meaningful market mechanism to fund market demand for low-EC steel and concrete by assigning the GHG benefits to funders while separating the environmental benefits from the product itself. While this allows market actors to take a financial stake in investing in the market adoption of low-EC building materials, it is still an untested market mechanism (Dougherty 2024).

The policy development for AB 43, which would create a carbon-trading mechanism similar to the Low-Carbon Fuel Standard (LCFS), is still pending development. Commercial Property Assessed Clean Energy (C-PACE) is also being used as a funding mechanism for low-EC projects in certain jurisdictions.[66] Lastly, private entities, such as Concrete Transition Capital, are also exploring funding mechanisms for low-EC concrete.

[66] See the ACEEE 2024 Summer Study presentation by Genevieve Sherman, formerly with Nuveen Green Capital. According to this quote from Jessa Coleman, Director of NGC, "In C-PACE, we see continued expansion of eligible measures under C-PACE programs. Already, programs across the country are trying to work out how to use C-PACE to incentivize investments in resilient and climate adaptive building measures, such as seismic hardening, green roofs, hurricane hardening, etc. The cutting edge of building sustainability is in implementing low embodied carbon construction materials in new buildings. The federal government and California, among others, have already developed “buy clean” policies that require builders and developers to source low embodied carbon materials. We expect this trend to continue to develop across the country and to become another eligible C-PACE measure."

Key Takeaways and Recommendations

The project team had four original hypotheses to test when planning the project. Throughout the project, the team connected findings with the four hypotheses to develop key takeaways.

Embodied Carbon, Energy Efficiency, and Building Decarbonization: Congruent Savings

Hypothesis: EC can be a **complementary program pathway** for both EE and BD programs that already address operational emissions. Ideally, these EC opportunities also maintain or increase EE savings.

Key Takeaways: The project team found that EC can be a complementary program pathway for EE and BD programs that already address OC emissions. During stakeholder interviews, it became apparent that personnel throughout the value chain who engage with operational emissions reductions policy and programs are often the same personnel tasked with reducing EC. Therefore, EE program touchpoints can be leveraged as market engagement opportunities, which at a minimum can be used to educate and inform market actors that there are significant no- to low-cost approaches to reduce EC in building projects.

At the building level, interactions between EE and EC are quite complex. Both concrete and steel products are predominantly used for structural system purposes, which most often do not have a significant impact on the operational energy performance of a building. Therefore, a correlation between low-EC concrete and/or steel and building-level EE cannot be easily drawn. The sustainability consultant on the project team, indicated that no meaningful reduction in building-level EE would occur when considering fiberglass or, mineral wool as insulation options for a building's cavity wall insulation. The R-Value per inch differences between those materials are close enough that across an entire building's energy use, the difference would be negligible. XPS insulation has a much higher EC per R-Value, and should be avoided in large quantities when possible as the EE benefits may not outweigh the high upfront EC. Along with EPS, foam plastic insulations are often limited in application by building code for their combustibility but may be necessary in below-grade applications or to achieve a high R-Value wall in a thinner wall profile than can be provided with fiberglass or mineral wool. In addition to smart insulation choices, best practices for energy efficiency (including optimized building orientation, appropriate glazing types and window-to-wall ratios, and efficient building systems) should be studied on each project to understand the EE benefits that can be achieved with minimal increases in EC.

Recommendation: This is a complex area of building performance that requires further review and study, especially as it relates to intersecting policies such as Wildland-Urban Interface. The study team recommends additional studies to consider market barriers to EC program development, co-benefits of wildfire mitigation, and coordination with existing EE programs.

One-for-One Material Substitution

Hypothesis: One-for-one material substitution can **achieve incremental GHG reductions at relatively modest project costs** by substituting lower-EC building materials for standard building materials.

Key Takeaways: The project team found that while this is generally accurate, there are still barriers. Stakeholders confirmed that it is possible to substitute standard building materials with low-EC materials that reduce EC by 10 to 20 percent, depending on the product, with little to no increase in cost. **However, lack of transparency in pricing can be a barrier**. Project teams oftentimes determine prices based on asking their suppliers, general contractors, or builders for quotes. Because there's not a "known" price ahead of time, many stakeholders assume lower-EC products automatically come with a higher price tag. Additionally, stakeholders indicated that even if pricing is equivalent for a lower-EC option, if it is an unfamiliar version or viewed as a premium product, subcontractors may intentionally inflate prices. Furthermore, prices will vary depending on both the product and the location. For example, concrete pricing can be highly dynamic and dependent on location as it is largely manufactured and sold regionally. So even if a project owner knows they can obtain a lower-EC concrete mix, the price will still be variable depending on the location of the project.

Recommendation: Stakeholders need further education so that they can discuss low-EC materials with their project team during early design phases and then specify low-EC materials in their projects. Through educational platforms, it should be noted that 10-20 percent of EC can be reduced at a low to no incremental cost.

Embodied Carbon, Energy Efficiency, and Building Decarbonization: Policy Barriers

Hypothesis: Building on the first hypothesis, EC can be a **complementary policy pathway** to EE and BD if not for certain policy restrictions. The main barrier is that EC benefits are currently treated as a NEB, which is similar to how low-GWP refrigerants were previously classified as NEBs. The development of an RACC allowed the benefits of low-GWP refrigerants to be captured and quantified, which ultimately allowed low-GWP refrigerants to be included within EE and BD programs. If EC benefits can be quantified and used in conjunction with a yet to be developed methodology to capture the benefits within the EE and BD program environment, then EC can be incorporated within EE and BD programs.

Key Takeaways: A program attribution model for EC must be ultimately developed, or else EC will never fit within the current EE and BD program scope. This was validated by code readiness implementation staff as a current need for the program. Likewise, program attribution would be required if EACs from private funders or a LCFS program, such as what is potentially being created by AB43, could be utilized for EC. Ultimately, the program attribution would need to prove that the benefits of reducing EC outweigh the costs of EC, either using the current EE and BD program metrics, or more likely, developing or updating to create a new metric. Completing this task would require the development of baselines and measurement and verification methods to determine the incremental GHG savings and incremental costs associated with low-EC building materials. These elements would be necessary to create an EC ACC which would allow EE and BD programs to monetize the benefits of EC mitigation activities.

Another key takeaway is that a financial pathway to fund incentives for EC reductions is needed, as there is currently no financial incentive structure for EC reductions that would award dollars per kgCO_2e avoided. This cannot be implemented until after EC benefits are captured through the EC ACC, but research and development can begin now. Other potential financial pathways include C-

PACE and other less mainstream incentive programs. Funders such as Nuveen Green Capital have already demonstrated market interest in clean energy projects, and further expansion of these projects could increase market awareness and adoption of low-EC material substitution practices. It should be noted that dollars for avoided EC may be the most obvious definition of an incentive pathway, but other potential pathways exist:

- **A "challenge and prize" approach** could improve awareness and perception around EC at a relatively low cost. The "challenge" would be for building design teams to submit building project plans that incorporate EC building material reductions. The "prize" would be awarded to the project(s) that incorporate replicable strategies to reduce EC in their building design plans. A program like this was executed successfully by the Massachusetts Clean Energy Center, with the following accomplishments:
    - 50 architecture and sustainability firms learned how to use LCA software tools.
    - 16 case studies were created to provide replicable strategies to reduce EC.
    - Over 1,200 people participated in or viewed the webinar.
    - The program demonstrated a reduction of 25,000 metric tons of CO_2e in constructed projects compared to baseline
- **Sales tax waivers** on building materials that meet defined GWP thresholds, and property tax reductions for buildings that use low-EC materials.
- **Waived or reduced permit fees** for buildings that use low-EC materials
- **Cash stipends for building projects** to offset the costs of calculating and documenting their project's GWP reduction.
- Other interventions such as **permitting and tax incentives.**

Financial incentives are not the only pathway forward, and non-financial incentive structures for EC reductions should also be explored. For example, stakeholders had the highest interest around a **floor area ratio (FAR) bonus** for meeting low-EC requirements. This would operate as a zoning incentive that would allow building projects to exceed the maximum allowed building floor area for their lot size. FAR bonuses have historically been used by municipalities to incentivize the construction of specific building types and features, ranging from increased affordable housing to buildings that meet Passive House requirements.

Because these bonuses are not based on "cash" incentives, there are minimal to no financial impacts on ratepayers, although they require coordination with zoning officials and AHJs. **Stakeholders had mixed interest on expedited permit incentives**, but a program design that encourages low-EC approaches in exchange for faster permitting times is low cost. Express and expedited permitting have historically been offered across the country to incentivize green building measures.

Recommendation: Develop an EC ACC that would be used as the new metric to include EC within the current EE and BD system. **Further research is needed** and could be accomplished through a low-GWP memo, similar to the one created for the RACC. Coordination with policymakers is required to update codes and policy to allow EC within the current EE and BD ecosystem. **Organizing local**

action from cities and municipalities, as well as creating a coalition, can be used to help petition policymakers to implement these changes.

Environmental Product Declaration Data and Stakeholder Education on Embodied Carbon

Hypothesis: There are limited EPDs and data for some building materials and limited understanding of EC among some stakeholder groups. Therefore, education can increase GHG savings by increasing the implementation of one-for-one material substitution with lower-EC materials.

Key Takeaways: While there are over 18,000 ready-mix concrete EPDs in California, there is an increasing library of educational materials available that many stakeholders are still unaware of. Energy Code Ace is a utility-funded, publicly available resource that exists explicitly to increase knowledge and awareness of existing California codes and standards. Energy Code Ace already has existing EC content, but many stakeholders are unaware of both Energy Code Ace and the EC content. This includes stakeholders within state agencies, as well as public stakeholders such as builders, general contractors, architectural firms, and others. **Interviews indicated that beyond the largest architectural firms and larger corporate customers, general awareness about EC is minimal.** Ideally, EE programs that already engage with relevant market actors (e.g., architects, engineers, consultants) via California Energy Design Assistance (CEDA) EE program as well as other programs could be updated to educate these market participants on EC. Additionally, interviews indicated that the public has the wrong perception about cost, quality, and other attributes with respect to EC. These interviews also illustrated how many stakeholders are unaware of EPDs and are unclear on their use or value.

Recommendation: Expand Energy Code Ace efforts on EC to increase stakeholders' awareness and education. This should be done in conjunction with other market education strategies to yield a high-impact intervention. In addition to general EC education, awareness of EPDs and how they can be used is specifically needed. This is especially integral if future incentives rely on EPDs for compliance, which is a likely scenario.

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