Coining the Carbon: Can California Commercialize (Embodied) Carbon?

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ABSTRACT

Addressing embodied carbon (EC), which represents 13 percent of global greenhouse gas (GHG) emissions, is essential for California to meet its climate goals. While energy efficiency (EE) and building decarbonization (BD) programs have reduced operational energy use through codes and standards, incentives, and other market structures, the carbon emissions contained within building structures remain largely stranded. Meanwhile, EE programs face portfolio challenges as renewable generation becomes a larger share of utilities' resource mix, diminishing EE's benefit as a direct alternative to carbon-based electricity generation.

Market transformation (MT) frameworks have been successfully used by EE and BD programs to address market barriers and utility EE portfolios have delivered robust energy savings, allowing EE to remain as a low-cost GHG abatement resource. Given the imperative to reach carbon neutrality by 2045 and net negativity thereafter, there is a general need for adaptive policies such as a climate-forward efficiency framework outlined by Specian and Gold to align energy savings with periods of high carbon intensity on the grid, unlock the benefits of electrification, better integrate demand flexibility, and maintain a reliable, secure, and low-cost electric system. This framework opens the door to explore full carbon abatement solutions such as aligning EE and BD programs with a to-be-developed EC program framework. This paper focuses on such a program framework of centralized statewide policies and strategies, customer and industry engagement, scalable models through pilots, and distribution of data collection and reporting to ensure strategic alignment while outlining a holistic approach to mitigate carbon in California.

Introduction: Why Embodied Carbon?

To meet California's climate goals, statewide greenhouse gas (GHG) emissions need to be reduced by 40 percent below 1990 levels by 2030 (Senate Bill (SB) 32), achieve carbon neutrality by 2045, and meet net negativity thereafter (Assembly Bill (AB) 1279). As noted in the California Air Resources Board's (CARB's) 2022 Scoping Plan, this outcome will require rapid deployment of solutions in all sectors, especially the industrial sector where a majority of manufactured products (e.g., cement, steel, and insulation) include carbon embedded within these building materials (i.e., embodied carbon (EC)).

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Buildings comprise 40 percent of global GHG emissions; of that, EC represents 13 percent while operational carbon represents 27 percent;[1] operational carbon is addressed by energy efficiency (EE) and building decarbonization (BD) programs (AIA 2023). However, "unlike operational carbon emissions, which can be reduced over time with building energy efficiency renovations and the use of renewable energy, embodied carbon emissions are locked in place as soon as a building is built" (CLF 2019). In fact, EC emissions are stranded in buildings over their entire lifetime, thus, as California successfully reduces carbon from operational emissions, EC will become an increasing share of remaining carbon emissions (Huynh 2023). Additionally, EC in buildings represents an opportunity not only to reduce, but potentially reverse emissions; EC in buildings should be first reduced, and then carbon sequestering building materials (as they become more readily available) can be encouraged and required, which will help make achieving net negative emissions (required by AB 1279) possible (CLF 2021). Figure 1 from Carbon Leadership Forum (CLF) illustrates the importance of targeting both EC and operational carbon.

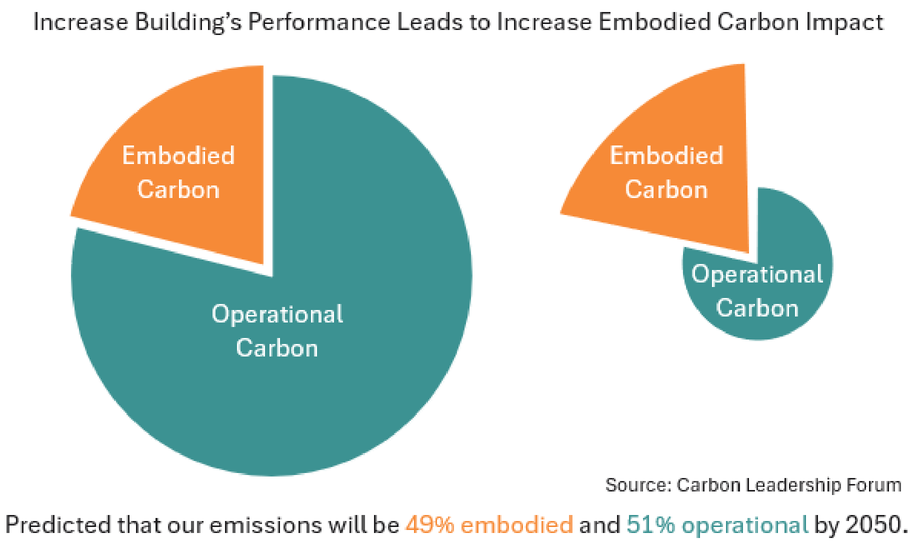


Figure 1. Addressing both operational and embodied carbon emissions is essential.

To address building emissions holistically, California needs to leverage the successful tools and market interventions it has deployed for decades to reduce operational carbon, including codes and standards, incentives, and other EE market structures. In other words, EC can be addressed in coordination with existing EE and BD programs rather than developing new approaches and solutions.

[1] Operational carbon refers to the GHG emissions from building energy consumption sourced from the use of different equipment such as HVAC, lighting, and appliances (CLF 2020).

Embodied Carbon: The Next Frontier for Energy Efficiency in California?

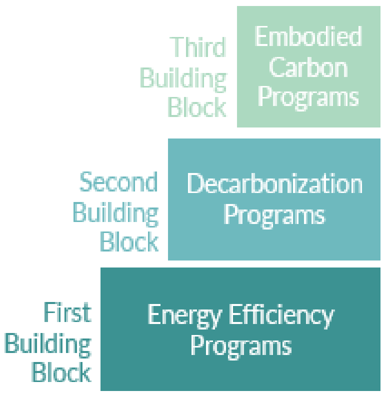
The LED revolution in the mid-2000s provided utility EE programs with a low-cost, easy-to-install technology that allowed utilities to efficiently meet ambitious savings goals. Today, EE portfolio cost-effectiveness goals are becoming increasingly difficult to meet as noted in San Diego Gas & Electric's (SDG&E's) motion for approval of the San Diego Regional Energy Network:

> California has set ambitious, meaningful climate goals, adopting Senate Bill (SB) 100 into law, which requires 100% zero-carbon energy by 2045. The state must undertake major transformational change to achieve these targets and mitigate the impacts of climate change. **Contrary to this objective, energy efficiency program administration, intended to help customers reduce emissions, has become increasingly difficult.** As the California Energy Commission adopts more stringent codes and standards, particularly with respect to electric measures, **cost effective, claimable savings are harder to identify and obtain. It has also become progressively more challenging to develop programs that have a quantifiable impact on the market** (emphasis added) (SDG&E 2024).

As implied in SDG&E's statements, with renewables comprising a larger share of utilities' resource mix, the value of EE programs as an alternative to carbon-based electricity generation declines, directly impacting EE portfolios' cost-effectiveness. However, EE remains a low-cost resource for GHG abatement and offers additional value streams of demand flexibility, grid resiliency, customer comfort and bill savings, and potentially mitigation of stranded emissions from EC.

The EE program industry has the resources to support EC activities but requires key policy changes to unlock its potential. For example, although EC is already within the scope of codes and standards programs, EE incentive programs do not currently address EC since it is considered to be a non-energy benefit. While CARB has been directed to address EC under SB 596 (Net Zero Cement Strategy), AB 2446 (EC Construction Materials), AB 1279 (Carbon Neutrality), and AB 43 (EC Trading Framework), increased interagency coordination is necessary to develop holistic market strategies and achieve legislative deadlines. Most importantly, much more work and collaboration are needed to allow EE and BD programs to support EC.

This paper argues for the application of a climate-forward efficiency framework to EC as originally outlined by Specian and Gold in *The Need for Climate-Forward Efficiency: Early Experience and Principles for Evolution* (Specian and Gold 2021). A climate-forward efficiency approach elevates GHG mitigation and adaptation as the main drivers to meet EE portfolio and statewide decarbonization goals. This framework incorporates the need to align energy savings with periods of high carbon intensity on the grid; unlock the benefits of electrification; better integrate with demand flexibility; maintain a reliable, secure, and low-cost electricity system; expand equity and reach; and animate local markets (Specian and Gold 2021). Under this framework, the tools of EE (e.g., codes and standards, incentives, emerging technology programs, and more) can be repurposed to meet the challenges of tomorrow. Figure 2 depicts the complementary nature of EE and BD as the initial building blocks of a holistic GHG strategy. EE programs created a pathway for BD programs, which can provide a pathway for future EC programs.



Target	Agency	Measurement
Addresses remaining "stranded" carbon in buildings not removed by Operational Efficiency programs. Becomes the largest unaddressed GHG category after operational efficiency savings.	TBD	CO2 emissions equivalent reduction
Addresses Operational Efficiency Savings but does not address embodied carbon. Program examples include Codes & Standards, New Construction, and Fuel Substitution, Electric Vehicle programs.	CPUC, CARB	TSB and CO2 emissions reduction
	CPUC	Total System Benefit (TSB)

Figure 2. Taking a holistic approach to greenhouse gas emissions mitigation. *Source:* Energy Solutions.

Existing EE programs, like the California Energy Design Assistance (CEDA) program, already engage key market actors in the new construction industry. This includes architects, structural engineers, and builders who would be similarly targeted by an EC program. A combined EE and EC program approach, utilizing CEDA's existing program design (including building modeling, building assessments, and efficient architectural design plans) and incorporating whole building life cycle assessments (LCAs), environmental product declarations (EPDs), and other EC tools would create market awareness for total carbon emissions in buildings. This can be extended to net negative opportunities by purposely storing carbon in innovative building designs and materials (Magwood 2022).

Pathway Toward Integrating Embodied Carbon with Energy Efficiency and Building Decarbonization Programs

More states, including California, are moving toward holistic EE metrics that are in line with existing climate goals. These updated approaches, demonstrated in Table 1 from *The Need for Climate-Forward Efficiency: Early Experience and Principles for Evolution (*Specian and Gold 2021), typically incorporate alternate metrics such as avoided GHG, peak demand reduction, demand flexibility, fuel switching, transmission, and distribution capacity.

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Table 1. Approaches taken by leading states and utilities to quantify progress toward greenhouse gas reduction goals through energy efficiency

Approach	Description	Location or utility
Avoided GHG	Sets common metric of avoided GHG emissions (e.g., carbon dioxide equivalent) for efficiency and electrification programs.	• Sacramento Municipal Utility District (SMUD) • Vermont • Washington, D.C. • Maryland (under consideration)
All fuel savings	Annual or lifetime energy saved across all fuel categories, usually measured in Btu.	• Massachusetts • New York • Maryland (under consideration)
Total System Benefit (TSB)	Uses the total economic benefits of EE to set resource efficiency goals.	• California investor-owned utilities (IOUs)
Proxy metrics	Goals are set using proxy metrics that do not involve measures of energy, power, or emissions (e.g., number of heat pumps (HPs) installed, electric vehicles (EVs) purchased).	• Vermont

Source: The Need for Climate-Forward Efficiency: Early Experience and Principles for Evolution (Specian and Gold 2021).

In California, the California Public Utilities Commission (CPUC) adopted the TSB metric, which ties program administrator goals directly to the value of avoided cost benefits including energy, generation capacity, ancillary services, transmission and distribution capacity, high global warming potential (GWP) gases, and GHGs (CPUC 2022). Although California has commendably started incorporating metrics beyond traditional kilowatt-hour (kWh) reduction through TSB, this only addresses operational carbon savings. As EC is currently treated as a non-energy benefit, it is not included in the TSB and requires the development of a dedicated avoided cost calculator (ACC), similar to the Refrigerant Avoided Cost Calculator (RACC) for low-GWP refrigerants, to monetize the value of EC mitigation activities.

Planning for the use of low-EC products, alongside plans to optimize energy operations, is a natural extension for EE programs. Similar to how fuel switching, EVs, and energy storage solutions were once thought to be beyond the reach and scope of EE programs, under a climate-forward efficiency framework, EC can be incorporated as well. EE needs to shift towards a “climate-forward efficiency” orientation to better target remaining emissions opportunities and program administrators should repurpose existing EE resources to address climate challenges such as EC.

Market Transformation as a Market Development Approach in California

MT has been used by EE programs for decades to increase market adoption of societally beneficial technologies with relatively low uptake. Examples of successful EE MT programs in California include midstream foodservice, HVAC, and business and consumer electronics programs. These programs target specific market barriers and use incentives, marketing, education and outreach, contractor training, supplier coordination, as well as other resources to reduce product development and supply costs while increasing the availability of EE products to end users.

Another successful MT program is the Technology and Equipment for Clean Heating (TECH) program, branded as TECH Clean California. TECH Clean California is a multiyear MT initiative focused on accelerating the adoption of HP technology for space and water heating while collecting best practices and sufficient metered impact data; the goal of TECH Clean California is to create a long-term strategy to meet California's goal of carbon-free homes by 2045. Created by California SB 1477 and now in its third year of implementation, TECH Clean California has installed over 32,000 HPs across California and demonstrated the potential of a well-designed MT initiative (TECH 2024).

TECH Clean California's success was built on three pillars: spur the clean heating market through statewide strategies, create scalable models through regional pilots, and inform the long-term BD framework. Like the low market awareness of EC today, TECH Clean California faced market challenges of relatively low statewide HP adoption. Through a holistic and statewide approach based on the three pillars outlined above, TECH Clean California has successfully been able to drive down product costs for HPs, train contractors on this new technology, and create market awareness that did not previously exist statewide (Rory Cox, et al. 2022). In addition to the installation of thousands of HPs across California, TECH Clean California has developed a robust network of contractors trained to install HPs, broken down policy silos through coordination with the California Energy Commission (CEC), and demonstrated an approach to piloting and scaling effective strategies that are a model for future MT programs.

Building on TECH Clean California's success with a holistic and centralized approach to BD, this paper borrows and adapts the three-pillar approach to better fit the unique challenges of EC. The four pillars outlined in this paper provide a MT blueprint for EC.

Model Market Transformation Pillars of Embodied Carbon

To characterize the shape and activities of an EC MT program, the four pillars are listed in Figure 3.

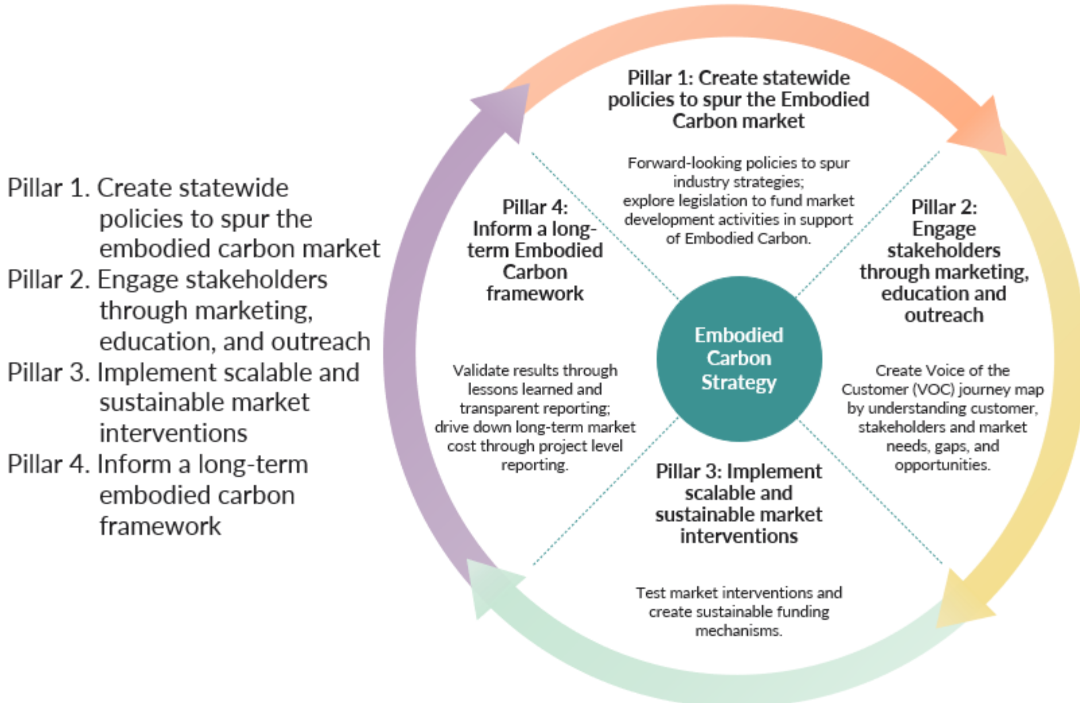

Figure 3. Four pillars of embodied carbon market transformation. *Source:* Energy Solutions

Pillar One: Create Statewide Policies to Spur the Embodied Carbon Market

Over the past few years, California has advanced significant policy to begin to transform the EC landscape. Figure 4 below highlights California EC policies, including those which grant CARB authority to develop long-term strategies. SB 596 requires CARB to develop a net-zero emissions strategy for the cement sector; AB 2446 and AB 43 together require CARB to develop a framework for measuring and then reducing the average carbon intensity of the materials used in the construction of new buildings. If determined necessary, AB 2446 and AB 43 include the potential for an emissions trading mechanism like low-carbon fuel standards. This framework also includes a comprehensive strategy for the state's building sector to achieve a 40 percent net GHG reduction no later than 2035 (CARB 2024).

CARB's two strategies are in development and offer key opportunities for the state to address emissions in this sector. This paper proposes that CARB has an opportunity to include market development activities, such as an MT approach, in the plan to meet SB 596 and AB 2446. As outlined in CARB's 2022 Scoping Plan, incentives ("carrots") are imperative for helping reach these goals. This would augment the traditional regulatory ("sticks") approach. Ultimately, there needs to be coordination with other agencies and stakeholders (second pillar) to identify what market interventions will be most effective (third pillar). While "sticks" are effective at creating foundational certainty for markets, "carrots" are key for advancing the market toward best-in-class outcomes, an essential ingredient for the speed and scale of obtaining net carbon neutrality by 2045.

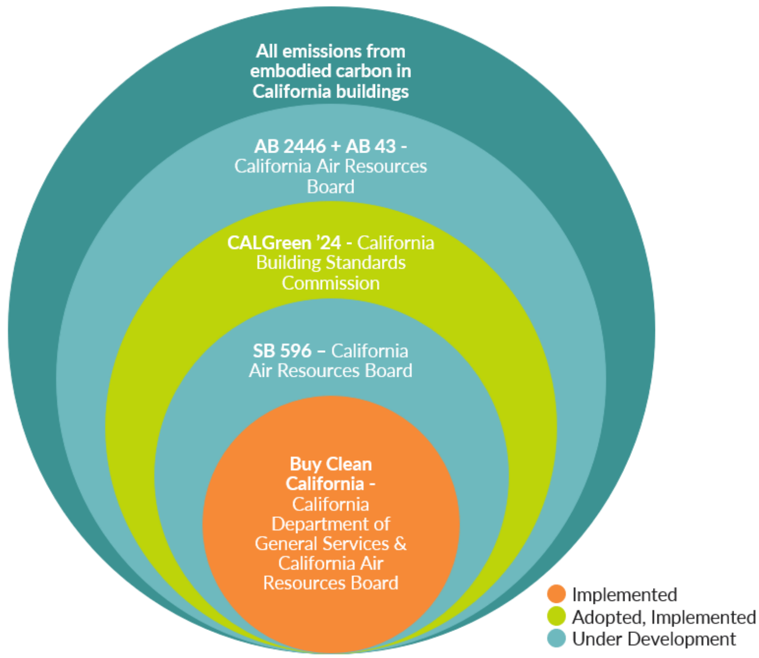

Figure 4. Concurrent California policies to-date to support embodied carbon. Figure 4 is ordered by size of scope of the sector and emissions, not to scale. *Source:* Energy Solutions.

There are several potential policy interventions a centralized MT program can take to reduce EC emissions. One of the main benefits of a centralized approach is that policies can be designed to complement one another and be better coordinated across relevant agencies. For example, a regulation requiring the use of low-EC insulation materials (first pillar) can spur utility program administrators to begin incorporating educational materials on the new insulation materials (second pillar) and encouraging their adoption before the regulation goes into effect. This could be coordinated ahead of time with existing utility weatherization programs, currently under CPUC's jurisdiction (third pillar).

Using cement as another example, a policy requiring low-EC cement procurement would send a clear signal to the market that EC needs to be taken seriously (first pillar). Both producers and consumers of cement would need to determine how it affects their business, so they are not caught flat-footed when the policy takes effect (second pillar). Policy can create a favorable market for low-EC products through direct intervention and long-term commitments. As the U.S. Department of Energy (DOE) stated in their recent report, *Pathways to Commercial Liftoff: Low-Carbon Cement:*

> Liftoff for all technologies will hinge on creating a strong demand signal from coordinated low-embodied carbon procurement—a signal that may come from the

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government through public procurement. This demand signal will be vital to incentivize the rapid uptake of new technologies, drive aggressive deployment, and mobilize capital at the required scale. Half of U.S. cement demand is driven by federal and state procurement. With their commanding market share, government agencies and large private buyers are in the leading position to send this demand signal and transform the market (DOE 2023).

The newly adopted Title 24, Part 11 (CALGreen) already includes EC thresholds and the recently adopted Buy Clean California Act (BCCA), which is a new low-EC procurement standard (although cement is noticeably absent from BCCA, but seemingly likely to be included in the future) are likely to be ongoing policy activities, so the next three pillars of MT can begin to fall into place.

As outlined before, at a minimum, a two-fold policy strategy can help enable broader EC traction: 1) development by the CPUC of an ACC dedicated to EC, similar to the RACC, to enable EC to be counted in TSB and 2) inclusion of market development strategies in CARB's strategic frameworks as part of SB 596 and AB 2446.

Pillar Two: Engage Stakeholders Through Marketing, Education, and Outreach

A centralized stakeholder engagement and feedback approach is critical to understanding what factors hinder the adoption of low-EC products. Engagement with stakeholders throughout the product lifecycle will provide insights into which products need the most support, where incentives are most effective (i.e., upstream, midstream, or downstream), and for which specific products. Despite policy advances as EC entered the spotlight, there remains a general lack of knowledge on the topic among market actors such as manufacturers, architects, structural engineers, and builders.[2] Additionally, disadvantaged communities have been historically excluded from these conversations which can be addressed as part of the second pillar.

In researching for this paper, stakeholders from across the EC space were consulted for feedback. Two cement manufacturers discussed funding challenges needed to create a low-EC cement plant at a cost-competitive scale. Both stakeholders explained that in order to spur a low-EC cement market, bankable commitments in the form of upfront purchase commitments would be more effective than a downstream incentive for cement buyers. This would allow cement manufacturers to raise capital and scale upwards more easily by demonstrating to investors that a market exists for their product. On the other hand, in discussions with policymakers, one of the major challenges cited was putting a policy in place without being certain there would be sufficient product supply. Without sufficient engagement with manufacturers to ensure that supply will be able to meet demand, any policy will struggle to be successful in achieving the desired outcome.

In discussions with architects and sustainability professionals, the lack of education and knowledge of EC was highlighted as a major barrier. Unless a client is particularly interested in sustainability, or the architectural firm is large enough or has in-house EC experts, the topic will

[2] Information listed is based on interviews the authors conducted with EC stakeholders.

most likely be excluded from building designs and purchase decisions. This is especially true if there is a cost premium associated with the low-EC product. One interviewee stressed there are not enough EPDs on the market and suggested incentivizing manufacturers to publish EPDs as a starting point, although there has been recent momentum with the U.S. Environmental Protection Agency's (EPA's) $100 million EPD development program (EPA 2024). Also, while there are standards for creating EPDs, issues of comparability still exist for a variety of reasons. Likewise, another interviewee noted significant knowledge gaps generally surrounding EPDs, GWP, and greenwashing related to material labeling, which adds to the confusion.

A MT effort focused on decarbonizing cement cannot just mandate the purchase and production of low-EC cement. Engaging with cement mixers upstream is needed to understand the current state of the technology, feasibility, timeline, and barriers to widespread market adoption. Significant education efforts with mid and downstream construction firms, and other large customers for low-EC cement, will also need to take place to ensure there is widespread buy-in from the market; stakeholders must be made aware that these products exist, where they can be purchased, and how they can be used. Insurance companies will need to be reassured that low-GWP cement is just as stable and reliable of a building material as traditional cement. Understanding the typical customer journey to purchasing low-EC cement, and low-EC products more generally, will be essential to ensuring the success of a MT effort.

The best tactic to understand industry pain points is through robust engagement and outreach efforts with stakeholders throughout the supply chain. Taking a centralized MT approach allows the incorporation of outreach feedback into intervention and program design, keeps policy intervention afloat with technologically feasible approaches, and closes knowledge gaps of educational resources and incentives for incorporating low-EC products.

Pillar Three: Implement Scalable and Sustainable Market Interventions

After policy lays the groundwork, and in consultation with key stakeholders, identifying scalable and sustainable market interventions is the next pillar. To spur the widespread adoption of low-EC products, the market needs to have confidence in the effectiveness of the product's adoption. Once stakeholders have confidence in the product, promoting acceptance of low-EC products entails careful consideration of incentive design and how to stimulate widespread adoption most effectively. Incentives help the market bridge the gap between a new technology or product and the eventual adoption of a code or standard requiring its use. This is the virtuous cycle of MT, where policy informs the market and vice versa (fourth pillar).

Additional coordination with existing EE and BD programs can also extend market awareness and impact. As mentioned previously, EE programs like CEDA already engage key market actors (e.g., architects, structural engineers, and builders) that an EC program would also need to target. To determine what outreach strategies breakthrough, where incentives will be most effective (upstream, midstream, or downstream), and how to identify and address both financial and non-financial barriers, different market interventions will need to be rigorously tested and evaluated to determine what is most effective. There will likely be regional differences in a state as large and diverse as California. Additionally, equity must be considered to ensure disadvantaged communities are not overlooked by EC programs and measures.

To use appropriated funds dedicated to an EC MT program effectively and prudently, a market characterization study, including a baseline assessment of normal adoption (NOMAD) criteria, should be conducted for the targeted product markets. This will help better understand the current and future anticipated market barriers, including upfront cost, market awareness, and the need to establish the value-add (i.e., business case) for addressing EC. Market interventions that are working to transform the overall market should be included in the framework as well; this will ensure that funds are being spent on interventions that are cost-effective and meaningful while also growing market awareness from the ground up by building support for scaled programs through successful pilot demonstrations. Fortunately, EE program administrators have years of experience with this approach. Before offering incentives for new EE measures in their portfolio, utilities typically test and validate new measures to validate performance in the field and study the optimal program delivery model(s). Findings from these interventions support widespread adoption and measure success. Program pilots are often evaluated to ensure that achieved results align with pilot objectives.

Tactically, once a centralized MT program is created, a similar approach will be necessary for a market as diffuse and with as low awareness as EC. For example, creating a self-sustaining market for low-EC cement will likely require multiple interventions throughout the supply chain; it will likely be very difficult to know in advance what will be the most successful approach. Initial stakeholder outreach outlined in the second pillar will be essential to initially estimate what market interventions are likely to be most successful in the third pillar. In this scenario, experimenting with incentives at different points in the supply chain to determine what stimulates the most demand for low-EC concrete, as an example, would be crucial data to collect (fourth pillar). Contractor training programs to educate builders on differences in cement performance or lack thereof is another example of a pilot project that can be experimented with and scaled up if successful.

To provide the scale of potential EC emissions reductions in buildings and the impacts an EC incentive approach could have, three incentive pathways were calculated for this paper. CLF recently examined the EC emissions from a subset of buildings in California and estimated an average EC impact of 390 kg CO_2e per square meter, with the lowest value being 190 kg CO_2e per square meter (CLF 2024). To be conservative, the lowest value, which is less than half of the average intensity, was used. Applying this conservative value to recently adopted CALGreen EC requirements and yearly new construction estimates for California illustrates how incentivizing EC requirements beyond CALGreen could result in significant emissions impacts. Three scenarios were modeled and are described in Table 2.

Each scenario assumes 100 percent of applicable new construction (for one year of new construction) meets the incentivized goal and therefore presents the maximum achievable GHG savings. In the real world, 100 percent of new construction would not meet the incentivized goals, but the exercise is still useful for illustrating how much of an untapped market it represents. To provide context on the magnitude of these savings, the 2022 Title 24, Part 6 update is estimated to result in a reduction of 0.33 million metric tons CO_2e per year (CEC 2021). In other words, Scenario 3 outlined in Table 2 represents nearly equivalent emissions reductions as the entire 2022 Title 24, Part 6 updates.

Table 2. Modeled incentive pathway approach and outcomes

Scenario	Market intervention	Maximum GHG emissions reduction potential for one year of new construction (metric tons CO_2e)
1	Buildings currently exempt from CALGreen EC requirement are incentivized to meet CALGreen EC requirements.	197,273
2	Buildings already required to comply with CALGreen EC requirements are incentivized to go 10 percent above CALGreen EC requirements.	118,703
3	Combination of Scenario 1 and Scenario 2.	315,976

Source: Energy Solutions

The example above demonstrates the emissions reduction potential of a CALGreen-based incentive approach, which is just one of many possible incentive pathways. Under a centralized MT framework, different incentive designs (or other market interventions) could be tested and evaluated at a small scale to determine what incentives will be most effective and sustainable if scaled upwards. Ultimately, the third pillar identifies the most successful market interventions and scales this to transform the market so that low-EC products become the industry and market standard.

Pillar Four: Inform Long-Term Embodied Carbon Framework

For California to accomplish decarbonization goals, state policy needs to support the adoption of low-EC products like actions taken in California for the HP market. Before launching TECH Clean California, the HP market, particularly for HP water heaters (HPWHs), was in a similar place as EC is today with relatively low market adoption. There was a lack of motivation up and down the supply chain for considering HPWHs in purchasing decisions, a lack of market incentives, policy drivers in early stages across the state, limited transparent project data and reporting, and overall low market awareness among customers and the supply chain.

The fourth and last pillar of EC MT can be thought of as the pillar that provides results and ties it all back together in the long run. Results are validations of assumptions, lessons learned, and other information gathered: policy sets the stage and leads the way for the work to begin, stakeholder engagement guides scalable models by providing insights into where the market currently stands and what’s needed, scalable models complete the work by providing

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information and testing market engagement approaches for low-EC products, and finally, all of the information gathered in every step is fed back into the process to improve and pivot as needed.

Sticking with the example of cement, as more people participate in low-EC cement pilot programs and marketing campaigns, more data will be collected and centralized. This will then be used to further refine incentives and address market barriers, and ultimately feed into developing codes and standards and/or enhancements to the existing EC incentive programs. At this stage, program administrators will have the data needed to address barriers such as imperfect information by providing more transparency about actual project costs, barriers to customer adoption, and other information to help manufacturers produce low-EC cement. Customers will adopt new low-EC cement products, and policymakers will track the long-term success of these market interventions.

Incentive programs can gather information by specifically collecting cement EPDs and data on costs (e.g., installation and product costs) and documenting other issues as they arise. This information helps determine what costs were incurred in the production and adoption of low-EC (as well as other products) whether additional incentives are needed, and at what levels. Likewise, additional codes and standards can emerge and set appropriate levels for low-EC cement as all the data collected will tell the story of where the market stands. This program-to-code approach is a way to intentionally develop requirements for EC (i.e., codes and standards), but works backwards by setting the stage and allowing the market both time and a means (i.e., incentives) to properly adopt the low-EC products before they become requirements.

Next Steps

California has ambitious goals to reduce GHG emissions by 40 percent below the 1990 level by 2030, achieve carbon neutrality by 2045, and continue with net negativity thereafter. To meet these goals, innovative market interventions are implicit, yet to date, few market development activities have occurred to address EC emissions and to complement the work started by CALGreen and BCCA. While developing legislation and policies will help to fill the void by creating much needed strategies to guide the market, concurrent market development activities should be funded to meet quickly approaching legislation.

Given proper policy support, market engagement, and legislative action, this paper proposes that California can successfully commercialize EC to ensure it follows a similar pathway as EE and BD programs. However, the time to act is now to limit the development of new buildings with stranded emissions over the product's lifetime. The following steps are critical for EC to become transformative in California:

- Continued focus by CALGreen and BCCA in developing additional nation-leading green EC requirements. The market requires both "sticks" (i.e., building codes) and "carrots" (i.e., market incentives) to create change.
- Carbon mitigation strategies for low-EC cement require significant capital investment by manufacturers to reduce GHG emissions in the production process. Further investment is

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required from federal and state funding to support cement manufacturers to upgrade their manufacturing facilities while also changing the product market for low-EC products.

- EPA's EPD program is a great start, but more is needed (EPA 2024).
- While supply-side solutions have the potential to create significant GHG mitigation impacts, demand-side interventions can likewise have significant market influence with sufficient legislative, regulatory, and market support. A high-level analysis of the potential impact from a demand-side incentive approach toward low-EC cement indicates that the investment could have a positive impact. As such, market interventions such as incentive pilots should be created to animate the market for low-EC products.
- Similar to BD programs which have demonstrated the public benefit of switching fossil fueled appliances to electricity, EC programs need to successfully demonstrate the value-add of reducing carbon emissions in buildings such as improved occupants' health, especially as these benefits are "non-energy" in nature and therefore are not captured in customers' bill savings. The ultimate demonstration of the value of EC programs will be its contribution to achieving the state's net-zero emissions goals, especially as the residual carbon in buildings after operational carbon is removed.
- Further policy actions (e.g., legislation, regulatory policy) should assess how existing EE resources (e.g., codes and standards, incentive programs, emerging technology programs) can be redeployed to support EC concerns alongside other policy priorities including EE, BD, and grid resiliency. CARB has been directed to address EC under multiple AB and SB mandates but might not be in the best position to leverage current work and coordinate these efforts.
- Addressing the reduction of EC in buildings should have a policy priority given the increasing share of emissions impacts in buildings as EE and BD programs successfully reduce the operational impacts of emissions in their programs over time. If the EC pathway into EE is not selected, another program framework to address EC emissions needs to be developed, lest they be trapped in buildings over their eventual lifetimes.
- A number of activities aimed at addressing EC are happening at the local, state, and federal levels simultaneously. Many potential benefits exist between these efforts and agencies and should not be overlooked. For example, the ENERGY STAR® embodied energy and an EC labeling program could eventually be leveraged for incentive program design. A successful MT requires a coordinated effort across statewide, federal, and local efforts to create further momentum for broader EC interest and support. In a similar fashion, TECH Clean California leveraged work started at the grassroots level by local communities and programs to accelerate HP adoption. This paper argues for a similar collective and holistic approach to drive market awareness, demand, and knowledge of EC to create lasting and successful market change.

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