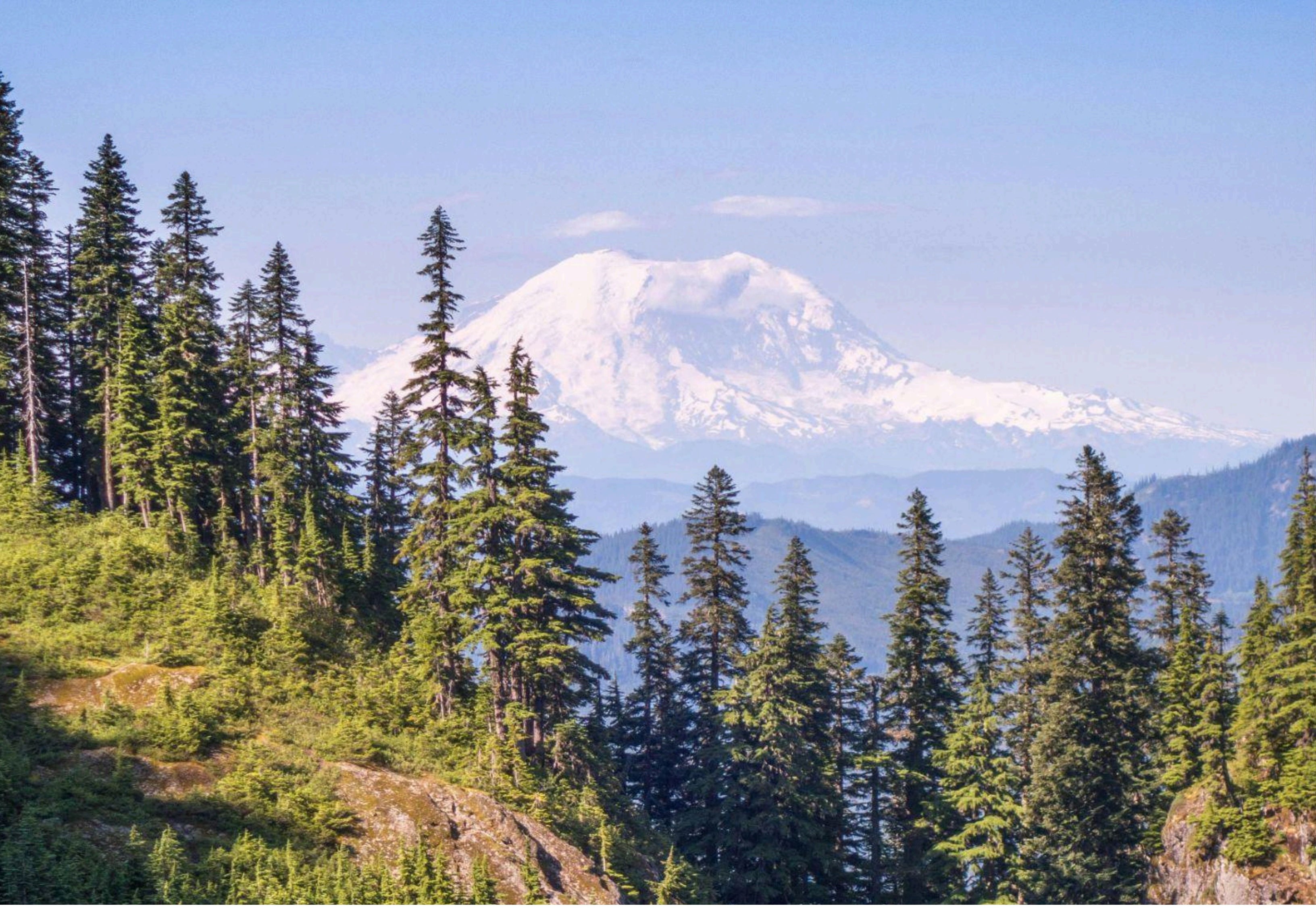


Recommendations for Washington State Embodied Carbon Code Language

A study commissioned by the State of Washington 68th Legislature for potential adoption by code council

NOVEMBER 2024

Carbon Leadership Forum
RMI
nbi new buildings institute
College of Built Environments, University of Washington

About the Carbon Leadership Forum

The Carbon Leadership Forum is a nonprofit dedicated to accelerating the transformation of the building sector to radically reduce the greenhouse gas emissions attributed to materials (also known as embodied carbon) used in buildings and infrastructure. We research, educate, and foster cross-collaboration to bring the embodied carbon of buildings and infrastructure down to zero.

About the New Buildings Institute (NBI)

New Buildings Institute (NBI) is a nonprofit organization that has been working throughout its 26-year history to advance best practices, building and energy codes, and policies through market leadership, research, and technical advocacy for a built environment that is better for people, communities, and the planet. NBI's mission focuses on reducing energy costs, cutting emissions that fuel climate change, and delivering improved health, safety, and resiliency for everyone.

About RMI

RMI is an independent nonprofit, founded in 1982 as Rocky Mountain Institute, that transforms global energy systems through market-driven solutions to align with a 1.5°C future and secure a clean, prosperous, zero-carbon future for all. We work in the world's most critical geographies and engage businesses, policymakers, communities, and NGOs to identify and scale energy system interventions that will cut climate pollution by at least 50 percent by 2030. RMI has offices in Basalt and Boulder, Colorado; New York City; Oakland, California; Washington, D.C.; Abuja, Nigeria; and Beijing.

About the University of Washington (UW) Life Cycle Lab

The Life Cycle Lab at UW's College of Built Environments leads research to advance life cycle assessment (LCA) data, methods, and approaches to enable the optimization of materials, buildings, and infrastructure. Our work is structured to inform impactful policies and practices that support global decarbonization efforts. We envision a transformed, decarbonized building industry – better buildings for a better planet.

Authors

The individuals from the **Carbon Leadership Forum** who worked on this report are:

- Aurora Jensen, Senior Manager Low Carbon Buildings
- Meghan Lewis, Program Director

The individuals from **NBI** who worked on this report are:

- Adriana Colón Adorno, Project Manager, Codes & Policy
- Amie Lewis, Associate Director, Codes & Policy
- Ariel Brenner, Project Analyst, Codes & Policy
- Jim Edelson, Senior Climate Advisor

The individuals from **RMI** who worked on this report are:

- Aurimas Bukauskas, Senior Associate, Carbon-Free Buildings
- Rebecca Esau, Manager, Carbon-Free Buildings

The individuals from the **UW Life Cycle Lab** who worked on this report are:

- Jordan Palmeri, Senior Researcher, UW Life Cycle Lab

Author contributions: Writing — original draft: A.J., A.C.A., A.L., A.Br., A.Bu., R.E., J.P., M.L.; Writing — review and editing: A.J., A.C.A., A.L., A.Br, R.E., J.P. ,J.E., M.L..; Visualization: A.Bu., A.J., M.L..

Competing interests statement: The Carbon Leadership Forum receives gifts from sponsors, including manufacturers and trade associations, which are listed here: https://carbonleadershipforum. org/our-sponsors/.

Acknowledgments

We would like to thank Vince Martinez and Erin McDade at Architecture 2030 for providing project management support for this project.

Additionally, we would like to thank the individuals who participated in interviews with our project team from ten different firms who work on Washington-based building projects. These interviews informed section 5.6 - Additional Code Options of this report. The interviewees included three architects, two structural engineers, three mechanical, electrical, and plumbing engineering firms, one contractor, and one code consultant.

Cover Image by Roman Pohorecki.

Citation

Jensen, A., Brenner, A., Lewis, A., Colón Adorno, A., Palmeri, J., Bukauskas, A., Esau, R., Edelson, J., and Lewis, M. (2024). *Recommendations for Washington State Embodied Carbon Code Language*. Washington State Code Council and Carbon Leadership Forum.

Contents

Executive Summary

This report titled *Recommendations for Washington State Embodied Carbon Code Language* is a study addressing code language for including embodied carbon in building codes commissioned by the Washington State 68th Legislature in 2024. The Washington State Building Code Council contracted the Carbon Leadership Forum, in collaboration with the New Buildings Institute, RMI, Architecture 2030, and the University of Washington Life Cycle Lab, to complete this study.

Embodied carbon is the greenhouse gas (GHG) emissions generated from the manufacture, transport, installation, maintenance, and disposal/recovery of construction materials. These emissions can be measured (and reduction requirements set) at the scale of a single product or an entire building.

Washington state has started to address embodied carbon through state-led policies like HB1282 (the Buy Clean Buy Fair Washington Act) and complementary actions at the city, county, and regional levels. While these are meaningful steps forward, they are not enough to accelerate action quickly enough to achieve the 2050 target established in RCW 70A.45.020. Code-based policies hold critical potential to address embodied emissions, as they most directly impact decisions in design and construction of new buildings where these materials are being used. Building code has the potential to allow Washington State to reach its legislatively mandated emissions reductions while improving community health and reducing future exposure to climate-related impacts.

Building codes, applicable to new construction projects, provide a key avenue for Washington State to reach its legislatively mandated emissions reductions while improving community health and reducing future exposure to climate-related impacts.

Approaches for addressing embodied carbon in codes

The California Green Building Standards Code (CALGreen), the Vancouver Building By-law, and the Denver Green Code provide examples of existing embodied carbon measures in the building codes of other jurisdictions, in addition to many non-code policies across the United States and abroad.

The three primary approaches to addressing embodied carbon in codes, aligning with the framework established by CALGreen, are:

- rewarding building reuse for projects reusing 45% or more of an existing building's primary structural elements and existing building envelope;
- requiring material carbon caps (emissions limits) for products covered by Buy Clean Buy Fair Washington; and
- requiring performance requirements at the building scale via whole building life cycle assessment (WBLCA).

Implementation considerations

Larger buildings benefit from economies of scale which make the administrative and design burdens associated with embodied carbon reduction less onerous than they might be for smaller buildings. An analysis of the estimated number of new buildings and total floor area impacted annually by embodied carbon measures reveals the total buildings required to comply at 25,000, 50,000, 750,000, and 100,000 square feet thresholds. A 50,000 square foot threshold would impact approximately 156 new commercial buildings and 11 new residential buildings each year in Washington, impacting 46% of commercial floor area and 3.5% of residential floor area.

Modeling of a baseline scenario and sixteen additional scenarios provides estimates of the emissions reduction potential of the reuse, material carbon caps, and WBLCA pathways. The largest estimated reduction potentials identified were from three of the four modeled WBLCA scenarios and a multiple compliance pathway (scenario P.7) that phases out material carbon caps to focus on WBLCA reductions and reuse beginning in 2035.

A social cost of carbon analysis based on these estimated reductions identified potential savings between 500 million to 1.5 billion dollars in social costs over the 2025-2050 period for the highest reduction potential pathways and 400-800 million dollars in social costs over the 2025-2050 period for a multiple compliance pathway that phases in stricter reduction requirements over time. In addition to these savings, economic considerations include (1) costs for analysis and (2) costs and savings for reduction measures.

Last, Washington agencies can support successful implementation of embodied carbon measures through: training sessions for designers, builders, and code enforcement officials; detailed reporting forms, ideally collected in a central reporting database; pathway-specific supplementary guidance.

Recommended language

We recommend a multiple compliance pathway approach to building code implementation over the short term, with more stringent requirements for reducing emissions phasing in over time. This recommendation balances environmental and economic savings with feasibility, allowing additional time for education and training. The recommended approach (Scenario P.7) would offer a 16% reduction in embodied carbon for new construction in Washington State from business-as-usual offer, or 5.7 million mtCO_2e of embodied carbon savings over the 2025-2050 period (a savings of ~770 million dollars in social costs). This estimated carbon savings is in the same order of magnitude as the estimated 8.1 million mtCO_2e of savings from the lauded commercial electrification code passed in Washington state in 2022 (Kocher & Gruenwald, 2022). With even more stringent target setting beyond a 30% WBLCA reduction, even greater savings could be realized than what was shown in this report.

Conclusions

The incorporation of embodied carbon into building codes via the use of a multiple compliance pathway as outlined in this report pairs real market transformation across the value chain with flexibility and capacity-building in the short term. Given Washington state's ambitious push towards a zero-carbon future in 2050, regulating embodied carbon from new buildings using building codes is a critical component to achieving this outcome.

1. Introduction

In 2024, members of the Washington State 68th Legislature allocated $250,000 of the climate commitment account to the state building code council to conduct a study reviewing existing language addressing embodied carbon used in the building codes of other jurisdictions and providing recommendations for language addressing embodied carbon for potential adoption by the council.

1.1 Legislative mandate

Senate Bill 5950 Sec. 151 (15), effective March 29, 2024, requires that the state building code council conduct a study, submitted in a report to the appropriate committees of the legislature by December 1, 2024, that includes:

> (i) A review of the language addressing embodied carbon used in the building codes of other jurisdictions, including but not limited to the California Green Building Standards Code and the Vancouver Building By-law; and
>
> (ii) The development of recommendations for language addressing embodied carbon for potential adoption by the council.

- (b) The study must consider subject areas including, but not limited to, the applicability to buildings greater than 50,000 square feet; multiple compliance pathways phased in over time; including whole building life cycle assessments (WBLCA); reuse of existing buildings; and compliance with material carbon caps.
- (c) In conducting the study, the council must provide opportunities for comment from design, construction, and building industry stakeholders.

1.2 Study execution

In the fall of 2024, the Washington State Building Code Council (SBCC) contracted the Carbon Leadership Forum, in collaboration with the New Buildings Institute, RMI, Architecture 2030, and the University of Washington Life Cycle Lab, to complete this study. This study builds off of research and best practices on available strategies for measuring and reducing embodied emissions, a review of existing embodied carbon requirements and supporting programs for successfully implementing building codes and related policies in Washington and other jurisdictions, interviews with architecture, engineering, and construction firms, and Washington State specific analyses to inform our recommendations based on emissions reductions and economic impacts.

This study references policy precedents from other types of policies but only provides recommendations on opportunities to introduce embodied carbon requirements into codes. Additional policy pathways – such as state and municipal requirements, zoning, incentives, or other measures – are also used in the US and internationally and would complement the recommendations in this document.

1.3 Embodied carbon voluntary and regulatory activities in Washington

Embodied carbon is not a new topic in Washington State policy. HB1282 (the Buy Clean Buy Fair Washington Act) was signed into law in March 2024 to reduce embodied carbon in the built environment, improve human and environmental health, grow economic competitiveness, and promote high labor standards in manufacturing by introducing new procurement processes for public buildings.

Embodied carbon was also identified as a critical goal in the Washington state 2021 energy strategy to meet the state's greenhouse gas emission limits, as well as in Inslee's Executive Order 20-01 and the Pacific Coast Collaborative Low Carbon Construction Taskforce and Action Plan. Most recently, Washington state was awarded a $3.5M environmental product declaration (EPD) technical assistance grant from the EPA in collaboration with Oregon and the International Code Council.

Complementary actions are also occurring at the city, county, and regional level, such as the City of Seattle Green Building Incentive Programs, Kirkland's High Performance Green Buildings Embodied Carbon Criteria, Sound Transit Authority's concrete EPD requirements, and King County's Strategic Climate Action Plan. King County was also recently awarded EPA Funding through the Climate Pollution Reduction Grants (CPRG) funding to pursue embodied carbon reductions.

While these are exciting programs, they are not enough to accelerate action quickly enough to achieve the 2050 target established in RCW 70A.45.020.

Code-based policies thus hold critical potential to address these emissions, as they most directly impact decisions in design and construction where these materials are being used. Building code has the potential to allow Washington State to reach its legislatively mandated emissions reductions while improving community health and reducing future exposure to climate-related impacts.

1.3.1 Climate Commitment Act

The Washington State (2021) *Climate Commitment Act* caps and reduces greenhouse gasses from 75% of the state's greenhouse gas emitters, towards a goal of 95% reduction by 2050. The law implemented a cap and invest program allowing emissions trading among industries and driving down overall state emissions over time. In September of 2024, California, Quebec, and Washington signaled they would begin discussions to link their carbon markets together for greater cooperation towards shared goals.

While not directly discussing embodied emissions, the Climate Commitment Act regulates many of the same parties who participate as actors along the supply chains of buildings, from extraction and transportation to manufacturing and construction. Embodied carbon measures in building code would serve to provide an activating framework to help building developers, owners, design teams, contractors, and suppliers to identify where their emissions are coming from and how they can work towards decarbonizing in line with the state's goals.

In its most recent greenhouse gas inventory, Washington State Department of Ecology (2022) estimates emissions from 2019 to be 102.1 MMT CO_2e. Washington State also established statutory limits on statewide carbon emissions between 2020 and 2050, including the following emissions limits and estimated absolute targets by year:

- 2020: Reduce to 1990 levels (approximately 93.5 million $mtCO_2e$)
- 2030: 45% below 1990 (approximately 51.4 million $mtCO_2e$)
- 2040: 70% below 1990 (approximately 28.0 million $mtCO_2e$)
- 2050: 95% below 1990 and achieve net-zero emissions (approximately 4.7 million $mtCO_2e$)

Figure 1-1 documents the emissions by sector from 1990-2019, with the contribution to embodied carbon emissions in multiple sectors - transportation, industrial process, waste management, and the industrial component of "Res/Com/Ind." Refrigerants for conditioning and refrigeration were excluded.

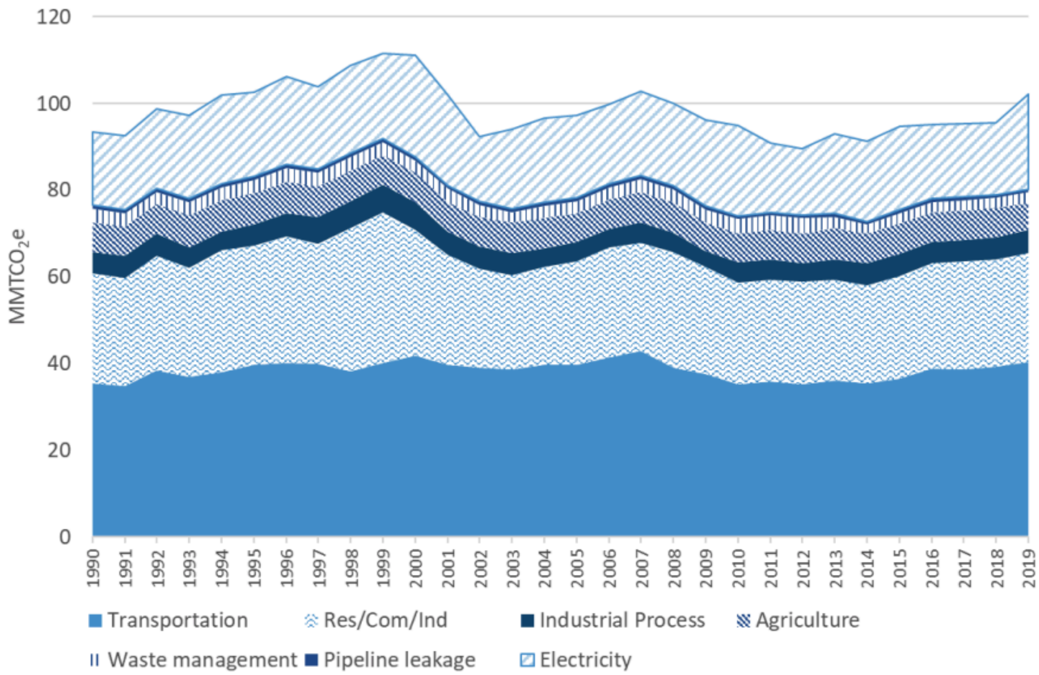


Figure 1-1. Washington's total GHG emissions 1990-2019 in MMT CO_2e. Source: *State of Washington, Department of Ecology (2022). [Washington State Greenhouse Gas Emissions Inventory 1990–2019.]*

2. Embodied carbon emissions

2.1 Embodied emissions, climate, and health

Greenhouse gas (GHG) emissions attributed to buildings can be broadly divided into operational carbon - the emissions associated with energy used to operate a building - and embodied carbon - the emissions associated with the manufacturing, transportation, installation, maintenance, and disposal of construction materials across the building's life cycle. Reducing both operational and embodied emissions is required to support healthy communities and reach global climate targets.

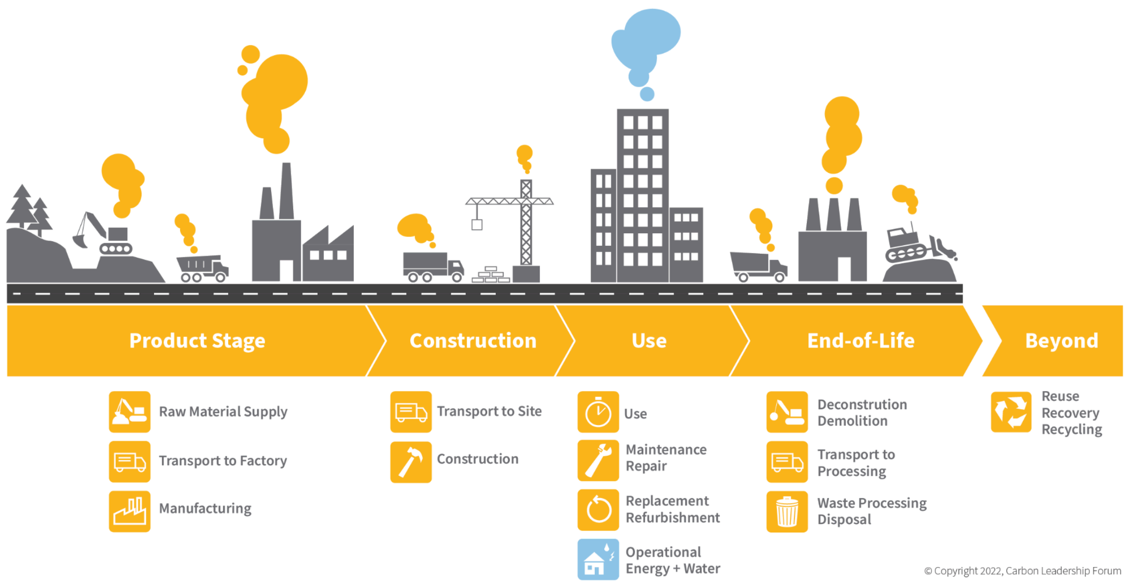


Figure 2-1. Embodied carbon (yellow) and operational carbon (blue) across the life cycle stage of a building. Source: Carbon Leadership Forum (2024) *Embodied Carbon 101*.

Building materials also have a direct local impact on ecological and human health. Communities adjacent to manufacturing facilities can be unjustly burdened by industrial pollution, and workers can bear dangerous working conditions or unfair labor practices.

Embodied carbon is inherently connected to climate justice and issues of public health and equity. Its impact can be seen locally in fenceline communities - those adjacent to construction supply chains - and globally in frontline communities - those that experience the impacts of climate change "first and worst."

High embodied carbon emissions typically correlate to fossil fuel-intensive manufacturing processes that cause additional environmental burdens in the form of air and water pollution. Increasing transparency of reporting for embodied carbon can illuminate environmental hot spots, and reducing embodied carbon can have co-benefits by reducing other environmental harms.

Figure 2-2. Ecological impacts (orange) and human impacts (gray) related to embodied carbon across the life cycle stages of a building. *Source: Carbon Leadership Forum (2024) Embodied Carbon 101*.

Materials used in the construction of buildings represent about 7% of total global greenhouse gas emissions (see Figure 2-3). Raw material use is predicted to double by 2060 – with steel, concrete, and cement already major contributors to greenhouse gas emissions – further increasing these emissions (IEA, 2023).

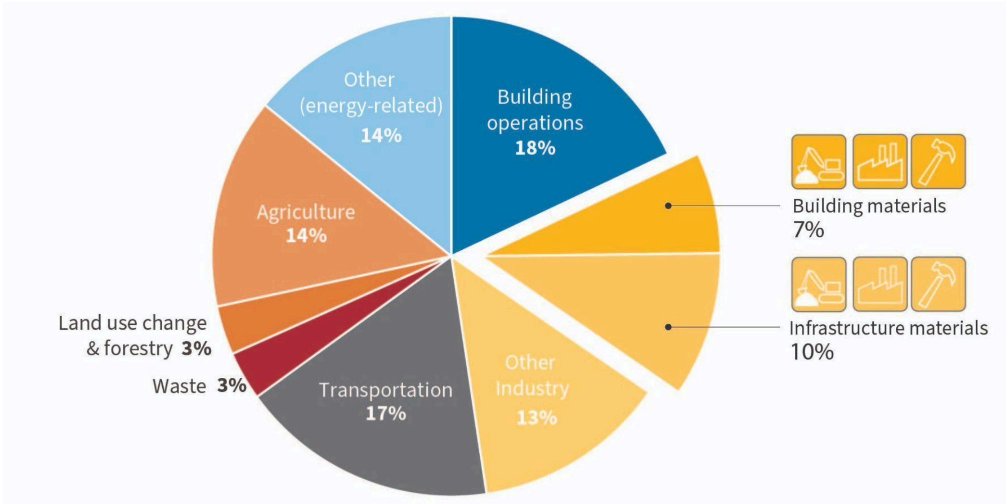


Figure 2-3. Global end-use greenhouse gas emissions breakdown by sector in 2019. Emissions from building and infrastructure materials comprise approximately 17% of global greenhouse gas emissions. *Source: Carbon Leadership Forum (2024)* Embodied Carbon 101.

The Carbon Leadership Forum published a study in 2024 focused on the timing and magnitude of operational and embodied emissions from a set of 30 buildings in California. This study found that for newly constructed buildings in California, embodied emissions would contribute approximately 80% of total buildings-related emissions between 2024 and 2030 and approximately 70% of buildings-related emissions between 2024 and 2045 (see Figure 2-4).

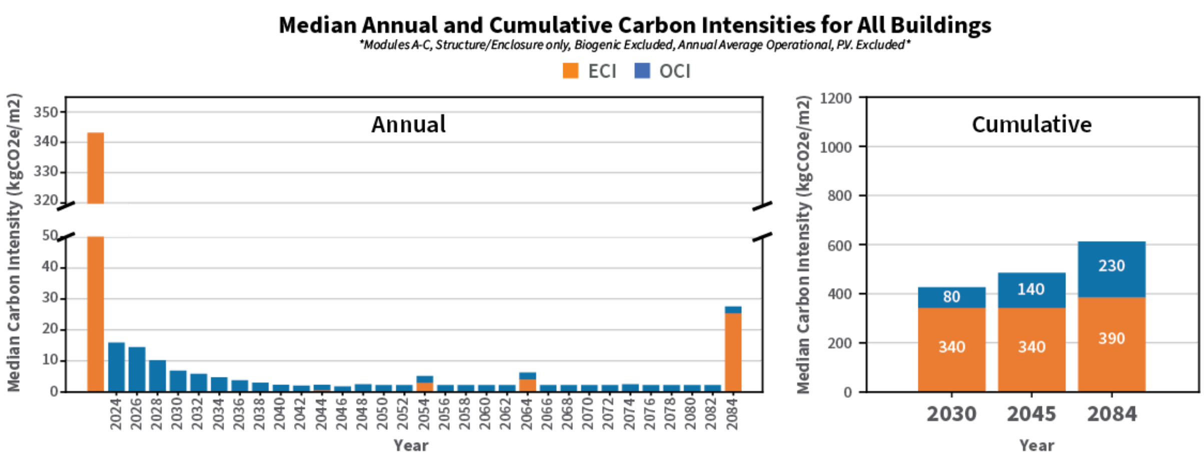


Figure 2-4. Median annual and cumulative embodied carbon intensities (ECIs) and operational carbon intensities (OCIs). Note that the y-axis for annual impacts (above) is shown with a break between 50 and 320 kg CO_2e/m^2). Source: Benke, B., Roberts, M., Lewis, M., Shen, Y., Carlisle, S., Chafart, M., and Simonen, K. (2024). *The California Carbon Report: Six Key Takeaways for Policymakers*. Carbon Leadership Forum, University of Washington. Seattle, WA. Modeling based on the embodied and operational emissions from life cycle modules A-C for the structure and enclosure of buildings in California

Due to Washington's clean electricity grid and electrification efforts, this trend is likely similar in the Washington state context, where embodied emissions are the dominant contributor to buildings-related emissions between now and 2050. Since refrigerants were excluded from this study, the true contribution of embodied carbon is likely to be even greater than what is captured in this analysis.

Emissions released now are more critical than emissions released later, because emissions will accumulate in the atmosphere, and there is limited time remaining before the tipping point of the climate crisis. This means that for new construction in the near term, reducing embodied carbon is as important as—or more important than—addressing operational carbon. This urgency to reduce emissions that will happen in the short term between now and 2030 or 2050 is sometimes referred to as "the time value of carbon."

2.2 Measuring embodied carbon

Embodied carbon is measured using a method called life cycle assessment (LCA) at the level of a single product or material or for a whole building. LCA provides an estimate of greenhouse gas emissions over the building's entire life cycle – reported as global warming potential (GWP) – as well as other environmental and human health impacts, such as acidification, eutrophication, and smog formation. GWP is the metric used to report embodied carbon and is measured in units of kilograms of carbon dioxide equivalents ($kgCO_2e$).

Life cycle stages (Product, Construction, Use, End-of-life) and modules (A1, A2, etc.) subcategorize the life cycle of a building and help communicate when environmental impacts occur. Figure 2-5 summarizes the life cycle stages that are important for capturing the emissions of a product or building over its life cycle.

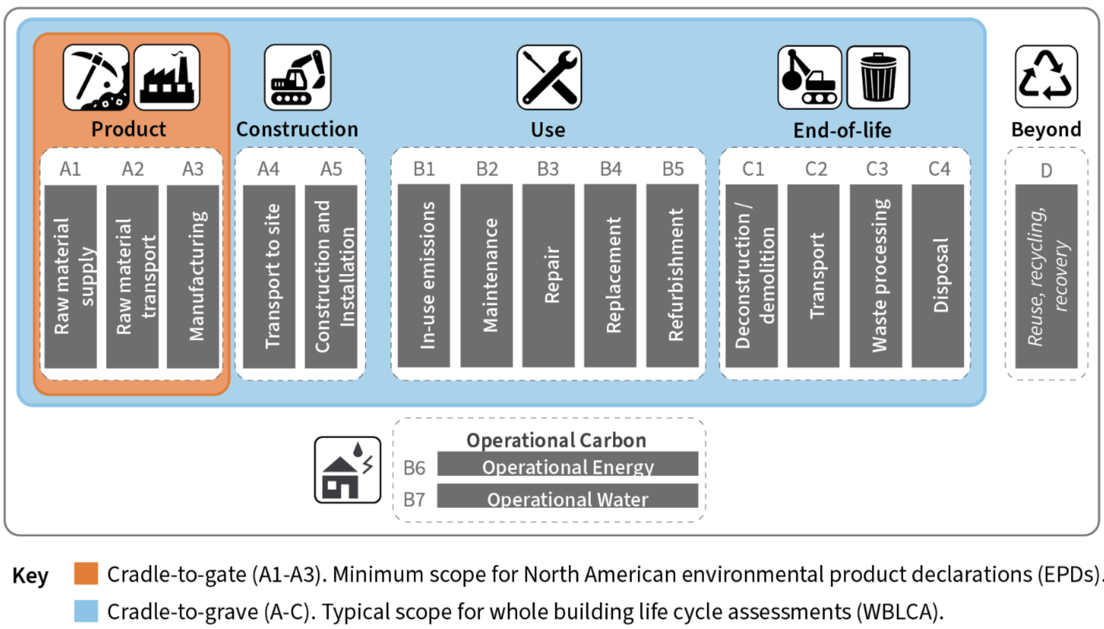


Figure 2-5. Life cycle stages and modules subcategorize the full life cycle of a building. Life cycle stages and modules help communicate the scope of an assessment, when environmental impacts occur, and help communicate what parts of the life cycle are included in an assessment. In North America, EPDs are generally cradle-to-gate (A1-A3) in scope and WBLCA are cradle-to-grave (A-C). *Source: CLF, based on international standards for EPDs and WBLCA.*

LCA can be done at multiple scales. The most common scales used in the building sector are:

1. **Material/product-level LCAs** that focus on quantifying the extraction and manufacturing impacts of a specific product. An environmental product declaration (EPD) is a standardized, third-party-verified document that reports the environmental impacts of a product based on a product LCA.
2. **Building-level LCAs** focus on quantifying the impacts of the materials and processes used to construct a building. A whole building LCA (WBLCA) is a cradle-to-grave (A-C) assessment that evaluates the environmental impacts of a building or portion of a building across its life.

2.2.1 Material-level reporting: Environmental Product Declarations (EPDs)

Material-level reporting requires manufacturers to create and share EPDs. EPDs are independently verified documents that report the environmental impacts of a product based on a product LCA completed in accordance with international standards.

EPDs are often referred to as "nutrition labels" for building products, because they report a variety of life-cycle impacts, including GWP (the metric used for embodied carbon). EPDs can include additional manufacturer and product data, such as materials, manufacturing processes and locations, and resource use. EPDs are intended to be published for business-to-business communication and business-to-consumers for use in their material selection process. EPDs are typically valid for up to five years.

Independent third parties impartially review EPDs before their publication. These parties ensure the accuracy and reliability of the EPD and evaluate them for compliance with international standards that dictate the development of EPDs.

The International Standards Organization (ISO) identifies three types of environmental claims; when it comes to the embodied carbon of building products, policies will consistently call for Type III EPDs:

- Type I: third-party verified labels based on criteria set by a third party; governed by ISO 14024
- Type II: self-declarations made by manufacturers and retailers; governed by ISO 14021
- Type III: third-party verified product information based on life cycle impacts; governed by ISO 14025

EPDs are governed by product category rules (PCRs), which dictate how practitioners perform the LCA to develop an EPD in that category. PCRs lay out methodologies for generating EPDs, describing aspects such as:

- Description of the product
- Goal and scope of assessment including system boundary, description of data and its quality, inputs, and outputs to be considered
- Data aspects such as methods of collection, calculation, and classification of material and energy flows
- Environmental impacts to be considered
- Presentation in the final report.

Examples of PCR-governed product categories include concrete, steel construction products, and building envelope thermal insulation. Program operators develop PCRs with a committee in an open process that allows industry stakeholders to review and comment. Committee participants typically include manufacturers, material suppliers, and trade associations, and sometimes include nongovernmental organizations, public agencies, LCA practitioners, and consumers. The public comment process is open to all stakeholders.

EPDs are the predominant mechanism for GWP disclosure in the building and construction industry. Building professionals use EPDs to evaluate the environmental impacts of a product and to compare data between functionally equivalent products. Manufacturers use product LCAs and EPDs to identify hot spots in their manufacturing processes and supply chains and guide future improvements.

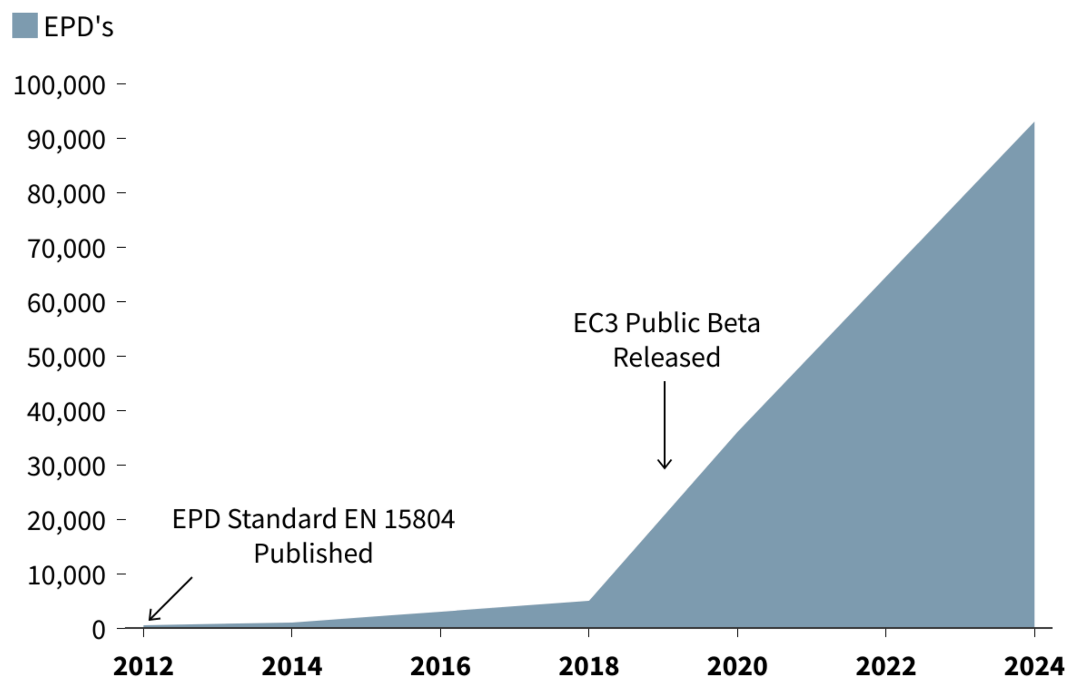
EPDs are created at different resolutions. The level of product and manufacturing specificity define the EPD type. Product-specific EPDs are the most common and can be measured at the facility scale, manufacturer scale, or across an entire industry. Industry-wide EPDs represent multiple manufacturers within an industry and report values as averages of the industry as a whole. These EPDs are particularly helpful for benchmarking national and regional environmental impacts of particular product types.

Product-specific EPDs represent single products and can be combined with various levels of manufacturing specificity, including:

- **Product and facility-specific EPD:** An EPD that covers a single product, a single manufacturer, and a single facility.
- **Product-specific and manufacturer-average EPD:** An EPD that covers a single product from a single manufacturer, and that reports environmental impacts based on an average of data from multiple facility locations for the last facilities in the production chain.
- **Product-specific and Industry-average EPD:** An EPD that reports the impacts of a product which is an average of data provided by multiple manufacturers in a clearly defined sector and/or geographical area. (often called Industry-wide EPDs)

Additionally, the Buy Clean Buy Fair Washington Act defines supply-chain-specific EPDs as EPDs that include supply-chain-specific data for production processes that contribute 70 percent or more of a product's cradle-to-gate global warming potential and report the overall percentage of supply chain specific data included.

Over the last decade, the number of manufacturers producing EPDs for their products has grown exponentially worldwide and in the US. Figure 2-6 below shows the global growth in EPDs from 2012 through 2024.



Global EPD publication count after 2018 estimated using number of EPD's reported in the EC3 database.

Figure 2-6: Estimated growth in the number of EPDs between 2012 and 2024. Based on data from Andersen et al (2019) and the EC3 tool. Note that not all EPDs are published to EC3**.** *Source: Graphic generated by RMI using data from Andersen et al (2016) and Building Transparency.*

Online databases like Building Transparency's Embodied Carbon in Construction Calculator (EC3) and Transparency Catalog from Sustainable Minds help project teams identify and compare EPD data between products and competing manufacturers. Previous to these databases, project designers would reach out to individual manufacturers to request these documents, or they would be posted for download on manufacturers' websites. Since the launch of the EC3 tool in 2019, a free online database of construction material EPDs, there have been over 93,000 EPDs added to its database, with over 81,000 EPDs belonging to US manufacturers (Building Transparency, 2024).

Several current factors will serve to increase the number of EPDs on the market across all material categories. The federal Inflation Reduction Act of 2022 allocates $250,000,000 towards an EPD assistance program supporting projects that improve the transparency and disclosure of embodied carbon emissions data in the US across all construction materials (US EPA, 2024a). In July of 2024, the EPA announced 38 grant recipients to various manufacturers, industry associations, and universities with projects that improve EPD data, develop tools and resources that generate EPDs faster and more cost-effectively and provide financial assistance to manufacturers in producing EPDs.

Among the winning proposals, $3,500,000 is granted to the International Code Council in partnership with the Washington state Department of Commerce and Oregon Department of Environmental Quality (US EPAb, 2024). The funding will go towards Pacific Northwest manufacturers to generate EPDs for concrete, asphalt, steel, wood, and products with very few or no EPDs such as salvaged wood, tile, paint, windows, and roofing.

Another stream of funding through the Inflation Reduction Act allocates $100,000,000 to the EPA to develop an eco-label for low embodied carbon construction materials to help purchasers easily identify low embodied carbon products from their competitors. The draft program includes a tiered labeling format based on embodied carbon intensity data from EPDs and a central registry of certified products to help facilitate procurement. The label program aims to improve the comparability of emissions impacts between products and increase the value proposition for manufacturers to produce EPDs. The program is currently focused on four key priority materials: concrete, steel, asphalt, and glass.

2.2.1 Building-level reporting: whole building life cycle assessments (WBLCA)

A WBLCA is a cradle-to-grave assessment covering life cycle stages A-C as defined by ISO 21931-1 or similarly robust standard that evaluates the environmental impacts of a building, including, at minimum, GWP. A whole life carbon assessment (WLCA) includes similar modeling but is limited to GWP (rather than also including other environmental impacts measured in a WBLCA) and often includes both embodied and operational carbon, therefore accounting for all building-related carbon emissions and allowing for an evaluation of the tradeoffs between operational and embodied reductions.

2.2.1.1 Standards and guidance

Standards establish mandatory uniform technical criteria, methods, processes, and requirements for LCA. They are typically produced by third-party standards organizations and require the formal consensus of technical experts before publication. When available, referring to these standards in codes and policies is critical for increasing the consistency and comparability of results (Lewis et al, 2023).

ISO provides the primary global LCA standards. ISO standards (and similar to the European Standards (EN)) are developed through a multi-stakeholder process, where a technical committee comprising global experts from industry, academia, NGOs, and government uses a consensus-based approach to create the scope and content of the standard. The creation and updating of these standards can happen at any time (i.e., there is no set interval for updates) based on industry needs.

ISO 14040: 2006 and ISO 14044: 2006 are general standards that provide an overall LCA framework, with intentionally broad aspects that are open to interpretation.

- *ISO 14040:2006 Environmental management — Life cycle assessment — Principles and framework* describes the principles and framework for LCA, including: goal and scope definition, life cycle inventory, life cycle impact assessment, interpretation, reporting, limitations, and conditions of use. This standard is quite broad in that it applies to all types of products and services (not just construction-related) and relates to product- and building-scale assessments.

- *ISO 14044:2006 Environmental management — Life cycle assessment — Requirements and guidelines* builds upon the foundational principles and framework of ISO 14040 to provide the normative requirements for guidelines for conducting an LCA. This document provides a discussion of the basic components and terminology of LCA (e.g., phases of the study, data quality requirements, allocation methods, impact assessment).

There are several international standards for WBLCA that build upon ISO 14040 and 14044 standards to provide an LCA framework for buildings specifically. ISO 21931-1:2022 is used in North America. These include:

- *ISO 21931-1:2022 Sustainability in buildings and civil engineering works — Framework for methods of assessment of the environmental, social and economic performance of construction works as a basis for sustainability assessment — Part 1: Buildings* (or “ISO 21931 Part 1”) provides a framework for sustainability assessment of the social, economic, and environmental performance of whole buildings. Significant topics include system boundary, life cycle stages, environmental impacts, social/economic impacts, methods for quantification, and reporting requirements. The standard provides comprehensive requirements on what to include in WBLCA, but limited guidance on how it should be implemented by LCA practitioners.
- *EN 15978:2011 Sustainability of construction works — Assessment of environmental performance of buildings* is the primary European WBLCA standard that provides calculation rules for assessing the environmental performance of new and refurbished buildings. EN 15978 is similar to ISO 21931-1 in scope but is generally more detailed and descriptive, providing specific requirements and examples for the physical scope and system boundary, use of EPDs within a WBLCA, specific scenarios for construction, use, and end of life by module, and many other components of WBLCA.
- *ASTM E2921-22 Practice for Minimum Criteria for Comparing Whole-Building Life Cycle Assessments for Use with Building Codes, Standards, and Rating Systems* mostly directs users to ISO 14025, ISO 14040, ISO 14044, and ISO 21930 for general methodologies and processes of LCA while filling in a few gaps that ISO leaves open to interpretation. The primary use of the standard is as a reference for defining a reference building and final building for comparison.

In addition to the standards described above, several standards are set to be published in the next year that aim to fill a gap in detailed, enforceable quantification language for measuring the embodied emissions of a building:

- *Proposed ASHRAE/ICC Standard 240P — Evaluating Greenhouse Gas (GHG) and Carbon Emissions in Building Design, Construction, and Operation* will provide a quantification method for evaluating and reporting GHG emissions of a building over its full life cycle. The standard will establish minimum modeling standards, including consistent procedures, data, and reporting formats that can be referenced by policies, codes, and other standards that address new and existing building performance. The standard will cover both embodied and operational emissions.
- *Proposed Prestandard for Assessing the Embodied Carbon of Structural Systems for Buildings (Draft 2024)* developed by the Structural Engineering Institute (SEI) of the American Society of Civil Engineers presents a recommended calculation methodology for assessing the embodied emissions of structural systems. Three embodied carbon assessment tiers are defined to support different user goals.

2.2.1.2 WBLCA process and data

LCA is an iterative process. In order to be used to identify and reduce embodied carbon, WBLCA may be repeated throughout the design process. This report references a ***Design WBLCA*** and an ***As-Built WBLCA***:

1) A Design WBLCA would motivate designers to engage LCA early in the process and explore design and optimization strategies that might offer easier pathways to compliance.
2) An As-Built WBLCA would provide the most accurate quantification of a project's embodied carbon, helping Washington understand the impacts of their policies.

WBLCA models draw from a variety of both generic and project-specific data sources. Most of the data used in these models is accessible through building LCA tools, except for material quantities, which must be specific to the project (and therefore provided by the project team).

WBLCA practitioners select the available material data source that best matches their building. As the building is closer to being complete, data can be more specific to the project. During earlier phases, average or regional data is used. As data resolution increases, the potential to make decisions with a large reduction impact decreases, so while 'as-built' estimates are most accurate, they are least likely to facilitate embodied carbon reductions.

Table 2-1. WBLCA data overview. *Source: Adapted from Lewis et al (2024) Building LCA 101: Embodied Carbon Accounting,*

Data Type	Data Sources	Design WBLCA	As-Built WBCLA
Material Quantities	Type and quantity of each material used. Typically collected from BIM software during design (or from contractors after construction).	Design Revit models or takeoffs	Actual purchased quantities
Transportation	Distances and vehicles used to deliver materials along the supply chain, such as manufacturer to construction site and demolition site to landfill.	Typical transit scenarios (available in LCA tools)	Actual transit distances and modes, as available
Construction	Construction data, such as site electricity use, water use, equipment, and fuel usage for excavation, demolition, and construction can be collected by contractors and used in LCA. Some tools and LCA standards include default estimates for these impacts.	Default construction scenarios	Actual fuel and utility data from the site
Use and End-of-Life Scenarios	Data on how and when materials will be used and how long they will last, helping calculate landfill emissions and other impacts.	Default replacement and end-of-life scenarios	Default replacement and end-of-life scenarios
Emissions factors	Emissions factors quantify a material or process' life cycle environmental impact per unit. These come from other LCA studies, public datasets (like the U.S. Life Cycle Inventory database), private LCA software and databases, or EPDs.	Best available data, preferring product-specific EPDs if evidenced in specifications	Best available data, product specific EPDs for installed products

2.2.1.3 WBLCA Tools

Software and tools are a critical piece of complying with WBLCA requirements. In addition to being the primary source for data used in an assessment, some WBLCA tools help users convert assemblies into lists of material quantities for analysis (e.g., converting a curtain wall assembly into disaggregated quantities of glass, metal trim, gaskets and sealants, metal panel, insulation, vapor barriers, and coatings). WBLCA tools also contain data on construction, use, and end-of-life scenarios that are omitted from most product EPDs.

Codes can require software to meet standards, such as those described in 2.2.1.1, to ensure more consistent and comparable modeling practices. The most widely used software tools in North America specifically developed to support WBLCA include:

- **Athena Impact Estimator for Buildings** is a freestanding software package developed in Canada that can be used to complete WBLCA or to compare building assemblies and materials. It includes most standard materials for structure and enclosure and some finish materials. Emissions factors are based on Athena's database and do not include EPDs.
- **One Click LCA** is a suite of tools that allow input of building material quantity data manually or via integrations with other software. It includes a database of product EPDs, industry-average EPDs, and regionalized generic data. Which tool in the suite is being used determines which inputs are available, default modeling assumptions, and outputs.
- **tallyLCA** is a plug-in for Revit (BIM software) that performs iterative WBLCA natively within a design and documentation model. The tool simplifies the process of quantifying materials to compare building design options and assemblies and reports total embodied carbon and other environmental impacts during design for a wide range of materials. As of November 2024, tallyLCA's background database is built on GaBi data and includes only a small number of EPDs.

In addition to these WBLCA software tools, there is a wide range of tools developed for other purposes, such as helping designers identify hot spots early in design based on generic building data. These are helpful tools for educating design teams and reducing embodied carbon but are not appropriate for demonstrating compliance with whole building LCA requirements.

2.3 Reducing embodied carbon

There is no one-size-fits-all strategy for reducing the embodied carbon of buildings. Strategies for reducing the embodied carbon of buildings generally fall into four broad categories:

1. Build less and reuse more, by reducing the floor area of new construction, extending the life of existing buildings, and salvaging and reusing materials.
2. Build lighter and smarter by using less of a material to perform the same function.
3. Substitute high-carbon materials and assemblies with lower-carbon alternatives.
4. Procure low-carbon products by comparing different products or manufacturers with the same function and selecting the lower carbon option.

Each of the pathways described in this study takes advantage of all or a subset of these strategies. For example, the building reuse pathway encourages projects to use less new material, retaining substantial portions of existing structures and envelopes. The material carbon caps pathways encourage projects to procure lower-carbon products, and the whole building LCA performance-based pathway allows projects to use a combination of any of these strategies to achieve reductions.

3. Washington State Code Considerations

3.1 Requirements for building code proposals

Building code proposals in Washington are submitted through the Washington State Building Code Council (SBCC)'s Statewide Code Change Form. The Proposed Rule-Making Order, also named CR-102, is the notice used to publish the text of a proposed change to the Washington State International Building Code (IBC), which will be listed as a proposed rule change in a public hearing (Washington State Department of Social and Health Services). All proposals for statewide amendments to the Building Code must comply with both WAC 51-04-020 *Rules for the consideration of proposed statewide amendments* and WAC 51-04-025 *Procedure for submittal of proposed statewide amendments*.

The Washington SBCC and Technical Advisory Groups (TAGs) review and adopt the new model codes every three years, along with any proposed changes to the new model code editions (WA SBCC, 2022a). The SBCC formally requests code change proposal submissions for the model code and amendments for a set submittal window. The SBCC then reviews all statewide code change proposals for completeness and forwards qualifying proposals to the applicable TAG. The TAG then reviews each proposal, determining whether they will recommend support of the proposal, recommend modifying the proposal, or recommend disapproval of the proposal to the appropriate Council standing committee, which is made entirely of SBCC members. After a final round of public comment, the SBCC standing council responsible for reviewing the code change proposal votes on approval, modification, or disapproval. The Council must make the final decision on adoption by December 1 for all codes, except the Washington State Energy Code-Commercial (WA SBCC, 2022b).

3.2 Criteria used to evaluate new building code proposals

As detailed by WAC 51-04-025, statewide amendments to the Building Code must be based on one of five listed criteria, with the proposed Embodied Carbon Building Code most likely falling under:

> (c) The amendment is necessary for consistency with state or federal laws and regulations; and
>
> (d) The amendment corrects errors and omissions.

As detailed by WAC 51-04-020, the SBCC will accept and consider petitions for statewide amendment to the Building Code if at least one of three listed criteria is met, with the proposed Embodied Carbon Building Code most likely falling under:

> (a) The amendment is directed by the legislature; and
>
> (c) The council determines that the amendment would serve a critical public interest and requires immediate/accelerated action.

Through RCW 70A.45.020, Washington is mandated to achieve net zero greenhouse gas emissions by 2050. The Washington State Building Code is a valuable and legitimate mechanism through which these carbon reductions, including both operational and embodied carbon, can be achieved.

Through the required Statewide Code Change Form, building code proposals are evaluated on their ability to effectively demonstrate the purpose of and need for the code language provided. The problem that the code proposal addresses must also be illustrated, along with the benefits of addressing that problem weighed against any potential costs to the state, to residents, and private entities. Demonstrating alignment of the proposed changes with existing state legislation is also conducive to the proposal evaluation process. Ultimately, a successful code change proposal must explain the unique opportunity that exists to address the presented problem specifically through the State Building Code.

3.3 Lessons from ongoing and previous Washington State embodied carbon proposals

Embodied carbon measures have been proposed in past and current Washington State Building Code revision cycles. Opponents – primarily industry stakeholders such as concrete and steel manufacturers and building developers – made several arguments against these proposals. The following table summarizes the main points raised against the inclusion of embodied carbon in building codes, and potential considerations for how this can be addressed. These considerations are integrated in the pathways considered in sections 5 and 7 of this report.

Table 3-1: Areas of potential pushback based on previous code proposals and considerations for addressing concerns

Potential Pushback	Considerations for addressing concerns
Embodied carbon should only be addressed in stretch and green codes and be excluded from the base code because they are new requirements and/or do not relate to health and safety.	"Safety, public and general welfare" and "safety and other hazards attributed to the built environment" apply to the significant and present impacts and risks of global warming. Mitigating embodied carbon emissions aims to address these public health and safety risks. Additionally, embodied carbon measures are already required in the State of Washington, due to Buy Clean and similar policies, and are not a new measure.
The code should ensure that no construction materials are treated preferentially.	This talking point relates to earlier proposals with different requirements for different materials and is not relevant to the 2024 IBC proposal or the measures included in this study. Additionally, a WBLCA pathway (see section 5.3) permits a performance-based approach that allows all building types and material systems a pathway to compliance. This approach would be applied to all buildings consistently, regardless of their structural system, similar to Washington state's Buy Clean Buy Fair policies.
Washington code officials have concerns about the cost burden on future building project teams.	The legislature has mandated through HB 1282 that the embodied carbon associated with building materials be addressed and through RCW 70A.45.020 that Washington state's greenhouse gas emissions must be addressed; this study and any subsequent code update would carry out that mandate. A robust measure of economic impact therefore resides with the legislature. However, it is anticipated that the economic impact of the proposed embodied carbon code provisions will be insignificant. An economic analysis of measures is provided in section 6.3.
Washington code officials have concerns about feasible enforcement.	There is little to no impact on AHJ enforcement. The only new requirement for code enforcement officials is to confirm that the design professional of record has signed off that measures are complete.
Concern over inclusion of adaptive reuse pathway in IBC, because many projects will use IEBC.	While many renovation projects will not reference IBC and instead will use IEBC, for any major adaptive reuse projects that do reference IBC for any reason this code permits an easier path to compliance for those projects.

Concern that some reference standards (e.g. ISO, EN) are not currently adopted in the codes.	Yes, these reference standards would need to be omitted from the language or adopted into the codes overall.
Preference for inclusion into IECC instead of IBC.	Embodied carbon addresses the life cycle emissions from construction materials and systems. The IBC covers building materials and systems and general building requirements, which are most relevant to embodied carbon.

3.4 Options for placement of new embodied carbon provisions in code

This section highlights options for placement of new embodied carbon requirements in the Washington State Building Code. Any of these options would also require a reference to the new provisions in Chapter 1 on Scope and Administration.

1. *Chapter 4 – Special Detailed Requirements Based on Occupancy and Use.*
   This chapter deals with the unique characteristics of particular occupancies and uses, such as covered malls, high-rise buildings, special amusement areas, and others.

   Some sections do not focus directly on use or occupancy but rather address the risks and benefits that come with certain materials, both with storage – such as in Section 413 on Combustible Storage, 414 on Hazardous Materials, and 430 on Recycled Materials – as well as with installation – such as in 416 on Spray Application of Flammable Finishes, 418 on Organic Coatings, and 419 on Artificial Decorative Vegetation. Some of these sections, as well as others, notably apply to all new construction.

   Adding a new “Section 430” would extend this logic of covering the impacts associated with the installation of building materials. Including a section in this chapter would also draw the clear connection to the purpose of these new code measures – to safeguard the public from the hazards associated with the creation and installation of building materials. The IBC has been in place and used by the design and construction industry to ensure that materials in the built environment preserve public health and safety. This new section would naturally expand the impact of Chapter 4 to further safeguard the public from the hazards associated with the creation of building materials by encouraging extraction, manufacturing, and transportation practices that improve air quality and public health in communities located near industrial centers and manufacturing facilities.

2. *Chapter 13 – Energy Efficiency.*

   This is a short chapter that directs projects adhering to the IBC to comply with the International Energy Conservation Code (IECC). The scope addresses “the design and construction of buildings for energy efficiency.” Incorporating embodied carbon into this chapter would encourage project teams to consider both operational and embodied carbon in tandem, as they both represent substantial opportunities to improve buildings’ impacts on the climate and related impacts on health and safety.

   However, the IECC focuses on the efficiency related to operational energy and does not explicitly address emissions. An embodied carbon addition to this chapter would require an expansion in scope to address emissions – rather than energy – and require a whole life carbon evaluation for energy efficiency and other operational energy measures in addition to embodied emissions.

Balancing consideration of operational and embodied emissions requires a careful evaluation of tradeoffs: how emissions savings made in one area will or will not offset additional emissions in another. For example, strategies to improve buildings' operational energy efficiency, such as improving building envelope thermal performance, will trade off with an increased amount of insulation, which is high in embodied carbon. Applying a whole-life perspective to buildings would make the realization of high-performing buildings with low embodied carbon possible.

3. *(New Chapter) Chapter 36 – Embodied Carbon.*

   An addition of a new chapter on embodied carbon would be the cleanest incorporation of the topic. In addition, this option would not require changes in chapter scopes that might be required of other options listed above. However, to date, adding a new chapter to the IBC is unprecedented in Washington and may face challenging administrative barriers.

Other options that were considered include incorporating requirements into a new appendix to the building code or into a new Green Construction Code, but these are not recommended as these are less likely to reach enough projects that would sufficiently move the state towards realizing its legislation-mandated emissions reductions. Additionally, the existing proposal to IBC focused on embodied carbon measures may already be adopted as an appendix.

4. Review of Existing Embodied Carbon Code Measures outside Washington State

This section provides a review of the language addressing embodied carbon used in the building codes of other jurisdictions, including the California Green Building Standards Code, the Vancouver Building By-law, and the Denver Green Code.

4.1. Embodied Carbon Requirements in the California Green Building Standards Code

In August 2023, California became the first U.S. state to mandate requirements on embodied carbon for building projects covered under its mandatory statewide Green Building Standards Code (CALGreen). Effective July 2024, new construction, alterations, and additions to commercial buildings over 100,000 square feet and school buildings over 50,000 square feet are required to comply with one of three pathways:

1. Prescriptive Pathway: Requires the submission of EPDs for steel, glass, mineral wool, and concrete materials that are on average lower than a specified threshold of global warming potential (GWP);
2. Performance Pathway: Requires the submission of a whole building life cycle assessment (WBLCA) demonstrating a 10% reduction in embodied carbon emissions compared to a baseline; or
3. Building Reuse: Reuse at least 45% of an existing building's structure and exterior elements.

These measures, outlined in Table 4-1, build upon pre-existing voluntary requirements in CALGreen, and the 2017 Buy Clean California Act. The CALGreen provisions also include more ambitious "Tier 1" and "Tier 2" requirements that can be voluntarily adopted by local jurisdictions within the State.

Table 4-1: CALGreen's pre-existing and new mandatory, Tier 1, and Tier 2 requirements for embodied carbon.

CALGreen Pathway	**Pre-existing Voluntary Requirements**	**Mandatory Requirements** for >100,000 sq ft commercial; >50,000 sq ft schools[1]	**Tier 1 Requirements**	**Tier 2 Requirements**
Product GWP compliance (Material carbon caps)	--	No greater than 175% of the GWP value disclosed in Industry-Wide EPDs	No greater than 150% of the GWP value disclosed in Industry-Wide EPDs	No greater than the GWP value disclosed in Industry-Wide EPDs
WBLCA	10% reduction from baseline	10% reduction from baseline	15% reduction from baseline	20% reduction from baseline
Building Reuse	75% of the existing building's structure and enclosure to be maintained	45% of the existing building's structure and enclosure to be maintained	75% of the existing building's structure and enclosure to be maintained	75% of the existing building's structure and enclosure AND 30% of the interior non-structural elements to be maintained

[1] In 2026, the square footage threshold for commercial buildings will drop to 50,000 square feet. Hospital and public housing projects are exempt from the provisions.

Newly constructed commercial buildings greater than 100,000 square feet and schools greater than 50,000 square feet are required to comply with either the product GWP compliance or the whole building life cycle assessment pathway. The project team determines which of the two compliance pathways they will use. Building projects that are alterations and additions to existing buildings are required to comply with any of the three pathways listed in Table 4-1 above. If a building reuse project cannot meet the requirements for the building reuse pathway, the project must comply with either the product GWP compliance or the whole building life cycle assessment pathway.

4.1.1. Overview of Product GWP Compliance (Material Carbon Caps) Path

This pathway intends to encourage the use of products and materials with lower embodied carbon impacts, demonstrated through product or facility-specific EPDs. The pathway provides a prescriptive option for project teams to specify lower carbon materials based on product purchasing and procurement during construction through several materials limited to structural steel, glass, insulation, and concrete (California Building Standards Commission, 2024).

This pathway is described in the official code language from the 2022 California Green Building Standards Code, Title 24, Part 11 (CALGreen) with July 2024 Supplement as:

> ***5.409.3 Product GWP compliance- prescriptive path.*** *Each product that is permanently installed and listed in Table 5.409.3 shall have a Type III environmental product declaration (EPD), either product-specific or factory-specific.*
>
> and
>
> ***5.409.3.1*** *Products shall not exceed the maximum GWP value specified in Table 5.409.3.*

Table 4-2 is a reproduction of Table 5.409.3, which references the maximum acceptable GWP values for each material category required in the code.

Table 4-2: Maximum acceptable Global Warming Potential (GWP) limits for products listed in CALGreen. *Source: 2022 California Green Building Standards Code, Title 24, Part 11 (CALGreen) with July 2024 Supplement, Chapter 5 Nonresidential Mandatory Measures, Table 5.409.3*

Material product category		**Maximum acceptable GWP value**	**Unit of value**
Steel	Hot-rolled steel sections	1.77	MT CO_2e/MT
	Hollow structural sections	3.00	MT CO_2e/MT
	Steel plate	2.61	MT CO_2e/MT
	Reinforcing steel bar	1.56	MT CO_2e/MT
Glass	Flat glass	2.50	kg CO_2e/MT
Insulation	Light-density mineral wool board insulation	5.83	kg CO_2e/1 m^2
	Heavy-density mineral wool board insulation	14.28	kg CO_2e/1 m^2

Ready-Mix Concrete	Up to 2499 psi	450	kg CO_2e/1 m^3
	2500-3499 psi	489	kg CO_2e/1 m^3
	3500-4499 psi	566	kg CO_2e/1 m^3
	4500-5499 psi	661	kg CO_2e/1 m^3
	5500-6499 psi	701	kg CO_2e/1 m^3
	6500 psi and greater	799	kg CO_2e/1 m^3
Lightweight ready-mix concrete	Up to 2499 psi	875	kg CO_2e/1 m^3
	2500-3499 psi	956	kg CO_2e/1 m^3
	3500-4499 psi	1039	kg CO_2e/1 m^3

The GWP values of the products listed in Table 4-2 are based on 175 percent of Buy Clean California Act (BCCA) GWP values, except for concrete products, which are currently not included in the BCCA. The BCCA GWP values are derived from the GWP values listed in industry-average EPDs for each product category. For concrete products, the GWP values in the table represent 175 percent of the National Ready Mixed Concrete Association (NRMCA) 2022 regional benchmark values for the Pacific Southwest (Athena Sustainable Materials Institute, 2022). Not represented in the table are GWP values for more ambitious Tier 1 and Tier 2 compliance, which require 150 percent of and no greater than the BCCA GWP values and NRMCA regional benchmark values respectively.

CALGreen outlines an alternative path for ready-mix concrete products that allows project teams to offset high GWP concrete with low GWP concrete used in the project. For this path, the weighted average of the maximum GWP for all concrete mixes installed in the project must be less than the weighted average of the maximum acceptable GWP value listed in the compliance table above. Project teams choosing this approach must use the equation provided in the code language and perform the calculation with consistent units. This provision acknowledges that due to regional differences in ready-mix concrete ingredients, some regions in California may not be able to comply with prescriptive maximum acceptable GWP values for each strength category (psi) outlined in Table 4-2.

To demonstrate compliance, project teams compile documentation that indicates what materials have been evaluated, what the allowable GWP limits for those materials are, and what the GWP values are for the materials indicated in the construction documents. Project teams submit Type III EPDs for each product required to comply with the regulation, a worksheet outlined in the California's Building Standards Commission (2024) Supplement Update Guide, and the weighted average calculation for concrete if used. At the close of construction, the design professional of record is required to conduct an on-site verification that documents the final products installed on the project and any deviations from the original evaluation.

4.1.2. Overview of Whole Building Life Cycle Assessment Path

This pathway intends to reduce embodied carbon emissions through a flexible, performance-based approach that allows project teams to optimize embodied carbon performance through strategies of their choice, including design efficiency, alternative material selection, and procurement of low-carbon building products (California Building Standards Commission, 2024).

This pathway is described in the official code language from the 2022 California Green Building Standards Code, Title 24, Part 11 (CALGreen) with July 2024 Supplement as:

5.409.2 Whole building life cycle assessment. *Projects shall conduct a cradle-to-grave whole building life cycle assessment performed in accordance with ISO 14040 and ISO 14044, excluding operating energy, and demonstrating a minimum 10 percent reduction in global warming potential (GWP) as compared to a reference baseline building of similar size, function, complexity, type of construction, material specification, and location that meets the requirements of the California Energy Code currently in effect. Software used to conduct the whole building life cycle assessment, including reference baseline building, shall have a data set compliant with ISO 14044, and ISO 21930 or EN 15804, and the software shall conform to ISO 21931 and/or EN 15978. The software tools and data sets shall be the same for the evaluation of both the baseline building and the proposed building.*

Table 4-3 below outlines the required parameters for project teams conducting a WBLCA for compliance. Detailed guidance on conducting the WBLCA, including recommendations on model resolution, building components to be included, acceptable assumptions for creating a project-specific baseline model, and clarification on biogenic carbon storage are outlined in the Supplement Update Guide.

Table 4-3: Summary of CALGreen WBLCA parameters. *Source: 2022 California Green Building Standards Code, Title 24, Part 11 (CALGreen) with July 2024 Supplement, Chapter 5 Nonresidential Mandatory Measures, Section 5.409.2.*

CALGreen WBLCA parameters	
Life cycle scope	Cradle-to-grave (A-C), excluding B6 (operational energy)
Reference Study Period	60 years
Physical Scope	Structure (defined as footings and foundations, structural columns, beams, walls, roofs, and floors) AND Enclosure (defined as glazing assemblies, insulation, and exterior finishes)
Approved Software	Athena Impact Estimator, OneClick LCA-Planetary & OneClick LCA, Sphera GaBi Solutions, SimaPro, Tally for Revit

To demonstrate compliance, project teams submit a summary of the GWP analysis from the software used to conduct the WBLCA and a worksheet provided in the Supplement Update Guide. These documents are signed by the design professional of record and provided in the construction documents as part of the permitting submission.

4.1.3. Overview of Building Reuse Pathway

This pathway intends to incentivize the reuse of existing building infrastructure. Studies have shown building reuse is associated with significant reductions in embodied carbon emissions when compared with new construction through the avoidance of landfill deposits, consumption of natural resources, and generation of GHG emissions related to energy and water-intensive industrial processes to create new construction materials (California Building Standards Commission, 2024). The regulation does not require the reuse of existing buildings but offers a direct and simple pathway to comply with the embodied carbon reduction regulations. By preserving at least 45% of an existing building's primary structure and enclosure when conducting alterations or additions, projects pursuing this compliance pathway are relieved from the performance and prescriptive requirements to submit a WBLCA or EPDs.

The building reuse pathway is described in the official code language from the 2022 California Green Building Standards Code, Title 24, Part 11 (CALGreen) with July 2024 Supplement as:

> ***5.105.2 Reuse of existing building.*** *An alteration or addition to an existing building shall maintain at a minimum 45 percent combined of the existing building's primary structural elements (foundations; columns, beams, walls, and floors; and lateral elements) and existing building enclosure (roof framing, wall framing, and exterior finishes). Window assemblies, insulation, portions of buildings deemed structurally unsound or hazardous, and hazardous materials that are remediated as part of the project shall not be included in the calculation.*

This provision includes an exception where, if the floor area of an addition to an existing building is two times the area or more of the existing building, the project is not eligible to meet compliance.

To demonstrate compliance, project teams identify elements of the existing building that can be reused on a demolition, site, or building plan, and calculate the percentage of existing elements that are retained using a simple area analysis. More complex projects may need to provide a more detailed area analysis of individual structural members to be maintained. The Supplement Update Guide provides worksheets that may be used to assist in documenting compliance.

4.2. Embodied Carbon Requirements in Vancouver's Building By-Law

To support achievement of the 40% reduction in construction-related embodied carbon by 2030 established in Vancouver, Canada's *Climate Emergency Action Plan*, Vancouver's Building By-law (VBBL) mandates the reporting and eventual reduction of embodied carbon for most new construction projects (Bantock, 2024). Effective October 2023, new "Part 3" building projects defined as all buildings over three stories in height or over 600 m^2 (approximately 6,458 sq ft), excluding 1-3 story residential buildings (Government of British Columbia, 2015), are required to:

1. Conduct a WBLCA and report the embodied carbon emissions in kg CO_2e/m^2
2. The embodied carbon emissions must be less than 200% of a standardized baseline.

Beginning in January 2025, new "Part 3" buildings, except projects with a floor area under 1,800 m^2 (19,375 sq ft), will be required to (City of Vancouver, 2022):

1. Conduct a WBLCA and report the embodied carbon emissions in kg CO_2e/m^2
2. Reduce the embodied carbon emissions of the building by 10% or 20% depending on the building type or comply with optional responsible material sourcing credits.

The 2025 exemption for projects with a floor area under 1,800 m2 (19,375 sq ft) was intended to reduce the regulatory burden on smaller-scale developments and streamline compliance efforts (City of Vancouver, 2022).

VBBL is the only existing North American policy that gives project teams the choice to demonstrate whole-building embodied carbon reductions through *either* a percent value or by meeting an absolute cap (referred to as a building carbon budget in section 5.3 of this study). Through the absolute path, projects must meet a maximum GWP value; through the baseline path, projects must demonstrate a percent reduction from a baseline scenario. An overview of these paths for current and 2025 requirements is outlined in Table 4-4.

Table 4-4: Vancouver Building By-Law mandatory requirements for new "Part 3" buildings seeking building permit approval. *Source: RMI*

	2023 Mandatory Requirements	2025 Mandatory Requirements (proposed)
WBLCA Absolute Path (Building carbon budget)	Project cannot exceed 800 kg/CO2e/m2 (double the benchmark intensity of 400 kgCO2e/m2)	Projects up to 6-stories cannot exceed 320 kgCO2e/m2 All other buildings cannot exceed 360 kgCO2e/m2
WBLCA Baseline (% reduction) Path	Projects define a project-specific, functionally equivalent baseline, and cannot be more than double the baseline.	Projects up to 6-stories must achieve a 20% reduction from a baseline All other buildings must achieve a 10% reduction from a baseline
Optional Responsible Material Sourcing Criteria Credits	--	Projects can achieve up to 5% of the total 10% reduction requirements through pursuing optional prescriptive credits

4.2.1. Overview of WBLCA Pathways

In terms of the absolute path (building carbon budget path), the City of Vancouver determined its benchmark value of 400 kg CO_2e/m^2 (4,306 kg CO_2e/sq ft) for all projects by collecting data on local rezoning projects since 2017. In the current provisions of the code, projects must not exceed a maximum GWP of 800 kg CO_2e/m^2 (8,611 kg CO_2e/sq ft)-- double the baseline. By January 2025, building projects up to 6 stories must not exceed 320 kg CO_2e/m^2 (or a 20% reduction from the benchmark value), while all other building projects must not exceed 360 kg CO_2e/m^2 (or a 10% reduction from the benchmark value). These thresholds are the equivalent to 3,445 kg CO_2e/sq ft and 3,875 kg CO_2e/sq ft respectively.

Through the baseline (percent-reduction) pathway, project teams would determine the building's functionally equivalent baseline by following the calculation methodology in the Vancouver's (2023) *Embodied Carbon Guidelines, v1.0.* The Guidelines lay out default baseline assumptions that projects may use in their calculations. Current project teams using this pathway must demonstrate that the building does not exceed more than double the GWP intensity of the baseline building. Starting in 2025, it is anticipated that building projects up to 6-stories must achieve a 20% reduction from the baseline, and all other types a 10% reduction from the baseline.

Table 4-5: Summary of Vancouver Building By-Law WBLA parameters. *Source: City of Vancouver (2023)* Embodied Carbon Guidelines Version 1.0.

Vancouver Building By-Law WBLCA parameters	
Life cycle scope	Cradle-to-grave (A-C), excluding B6 (operational energy) and B7 (operational water use).
Reference Study Period	60 years
Physical Scope	Structure (defined as foundations, subgrade enclosures (below grade exterior walls), slabs-on-grade) AND Shell (defined as floors, columns and beams, shear walls, stairs, balconies, roof structure, canopies; exterior walls, windows and doors; roofing, roof windows, and skylights)
Approved Software	Athena Impact Estimator, OneClick LCA-Planetary & OneClick LCA, Tally for Revit

4.2.2. Overview of Responsible Material Sourcing Credits

In 2025, responsible material sourcing criteria will become optional embodied carbon reduction credits, referred to as Industry Leadership Credits (City of Vancouver, 2022). Project teams can achieve up to 5% of the total 10% or 20% reduction requirements through these credits, which include:

- Reporting embodied carbon of optional building elements such as MEP, interior, and site work;
- Reporting project-specific embodied carbon estimates for life cycle stages beyond production (including construction site emissions and building element's lifespan);
- Using products with sustainability, transparency, or health certifications; and
- Using circularity practices such as material salvage and design for deconstruction.

These optional credits aim to introduce and enhance industry capacity for prescriptive and prescriptive-like compliance paths. Full details of the credits and submission requirements have not yet been published.

4.2.3. Overview of Enforcement

At the time of building permit application, project teams must submit an embodied carbon design report outlining general project information and WBLCA results, exported raw data from the software tool containing both the embodied carbon emissions breakdown and the bill of materials, and any results and justifications for manual calculations that have been conducted outside the software tool. Resubmission of these documents is not required at the Occupancy Permitting phase (City of Vancouver, 2023).

4.3. Embodied Carbon Requirements in Denver's Green Code

The City of Denver, Colorado's Green Building Code applies to all new commercial and multifamily buildings and major renovations. Mandatory requirements are flexible to allow project teams to choose a small number of provisions from each of the six key areas of impact: site sustainability, water use, energy, indoor environmental quality, materials and resources, and construction and plans for operation (City of Denver, 2024).

In 2021, new embodied carbon standards that aim to reduce the life cycle impacts of concrete and steel were added as optional compliance credits within the Materials and Resources category.

4.3.1. Overview of Concrete Requirements

Denver Green Code's concrete requirements intend to reduce the embodied carbon impact of the material by applying carbon dioxide equivalent (CO_2e) limits (i.e. material carbon caps) to concrete products specified in the project. The requirements apply to ready-mix concrete of standard, high-early strength, and lightweight compressive strength (psi) categories.

Projects must comply with one of two compliance options (International Code Council, 2023):

1. **A CO_2e Mixture Limit,** where the total CO_2e value of mixes must not exceed a maximum value, assigned according to compressive strength, and must come with a product-specific type III EPD to verify products.
2. **A CO_2e Project Total Limit,** where the total CO_2e for all of the concrete in a project does not exceed a limit determined by an equation provided in the code. This allows project teams to offset high GWP concrete with low GWP concrete used in the project.

Projects where no concrete suppliers with product-specific EPDs for concrete are located within 100 miles of the project site are allowed to use industry-wide EPDs for compliance. Projects where the total use of new concrete is less than 50 cubic yards are exempt (International Code Council, 2023).

4.3.2. Overview of Steel Requirements

Denver Green Code's steel requirements intend to increase the number of EPDs) for steel products by requiring disclosure of carbon dioxide equivalent (CO2e) content for structural steel and rebar products specified in the project. The requirements also aim to reduce the embodied carbon impact of steel materials.

Projects must comply with two provisions (International Code Council, 2023):

1. **Product-specific Type III EPDs** must be submitted for a minimum of 75% of steel products, based on cost or weight.
2. These products must be produced in **facilities that comply** with at least one of the following:
   a. minimum of 75% of steel products (based on cost or weight) does not exceed total CO_2e values based on product type (maximum values prescribed in the code);
   b. the facility is a Green Power Partner in the US EPA Green Power Partnership program (or equivalent outside the US); or
   c. at least 50% of the energy used for production is renewable.

Acceptable renewable energy resources include on-site renewable energy, off-site renewable energy owned by the production facility owner, community renewable energy, and physical or financial renewable energy power purchase agreements (International Code Council, 2023).

5. Language for addressing embodied carbon in Washington State Code

5.1 Reuse of existing buildings

This section describes the components of a building reuse pathway if included in the code, including:

- Description of building reuse (5.1.1);
- Potential code pathways (5.1.2);
- Enforcement and compliance considerations, including guidance on defining rules to calculate the percentage of building reused (5.1.3); and
- Model language (5.1.4).

5.1.1 Description of Building Reuse

Building reuse can realize a substantial amount of embodied carbon reductions by avoiding emissions associated with demolition and more substantially – the emissions associated with producing building materials for new construction.

A 2011 study by Preservation Green Lab, Skanska, Green Building Services, and others found that reuse of a variety of building types could realize between 4 and 46 percent embodied carbon savings compared to new construction operating at an equivalent energy performance level. Moreover, it can take between 10 and 80 years for new buildings designed with energy efficiency features to overcome the environmental impacts associated with the construction process (Frey et al., 2011). Scaling the practice of reuse across a state or city's building stock can realize significant reductions. A study of reuse in the city of Portland Oregon, for example, found that retrofitting and reusing all single-family homes and commercial office buildings instead of demolishing them over the next 10 years could realize carbon reductions reaching around 231,000 metric tons of CO_2e to about 15% of the county's total reduction target (Frey et al., 2011).

Building reuse therefore offers a simple solution to the urgency of curbing emissions immediately to meet global and state climate targets. Many other co-benefits are associated with building reuse. Avoiding demolition improves air quality by mitigating toxins being released into the surrounding neighborhood (Minner et al., 2024). Reducing construction and demolition waste, which represents the single largest component in US landfills, avoids further harm to the surrounding soil, surface water, and groundwater at landfill locations (Minner et al., 2024).

Opportunities to address building reuse in the code are limited. It is not within the authority of the building code to mandate building reuse – this is best achieved through other legislative actions and policy programs. However, strategies can be employed in the code to encourage adaptive reuse or, at minimum, make it easier for applicants seeking to reuse rather than rebuild. The prevailing example is found in CALGreen, which encourages reuse by providing optionality via compliance paths for reducing embodied carbon in buildings (see section 4.1.3). By preserving at least 45% of an existing building's primary structure and enclosure when conducting alterations or additions, certain projects in California are relieved from the WBLCA and material carbon caps requirements.

5.1.2 Building Reuse Potential Code Pathways

The building code cannot mandate building reuse. Rather, the code can incentivize project teams that choose to pursue adaptive reuse over new construction by exempting these projects from the material carbon caps and the WBLCA embodied carbon provisions.

Compliance pathways for building reuse include the variables described below:

- **Amount of building reused:** Projects must maintain a percentage of the existing building's applicable elements. A percent threshold is consistent with CALGreen provisions.
- **Building elements included:** This could include elements within a building's structural system and/or enclosure/envelope.
- **Project size:** Apply the code provision to substantial building projects above a certain square footage threshold. This threshold should be consistent with the WBLCA and material carbon caps provisions described in sections 5.2 and 5.3. Projects where addition(s) to the existing building(s) are two times the area or more of the existing building(s) are typically not eligible to pursue the building reuse compliance option to prevent projects from gaining compliance by addressing embodied carbon in only a small portion of the overall project.

Recommendations for Washington are outlined in Table 5-1.

Table 5-1: Recommendations for Washington for a code compliance pathway that promotes building reuse. *Source: RMI*

Variable	Compliance recommendation for Washington
Amount of building reuse	Projects shall maintain **at least 45 percent** (consistent with CALGreen) of the existing building's **primary structure and enclosure**.
Building elements included	The **primary structure is defined as** foundations; columns, beams, structural walls and floor framing; and lateral elements. **Enclosure is defined as** roof framing, wall framing, and exterior finishes. **Exemptions include** window assemblies, insulation, portions of buildings deemed structurally unsound or hazardous, and hazardous materials that are remediated as part of the project.
Project size threshold	Apply provisions to substantial improvement projects **above 50,000 square feet** in size and **where the combined addition(s) to the existing building(s) is less than two times the area of the existing building.** Substantial Improvement is defined in the 2021 Washington State Building Code, Chapter 2, as "any repair, reconstruction, rehabilitation, alteration, addition or other improvement of a building or structure, the cost of which equals or exceeds 50 percent of the market value of the structure before the improvement or repair is started."

5.1.3 Building Reuse Enforcement and Compliance Strategies

California Building Standards Commission (2024) *Supplement Update Guide to the 2022 California Green Building Standards Code (CALGreen) - Nonresidential* provides a helpful precedent for documenting compliance, and the recommendations in this section align with California's guidance.

Projects that include an existing building where the total gross square foot of existing and new construction is greater than 50,000 square feet are eligible to comply with one of the three embodied carbon requirements laid out in this study. For building reuse, reporting should occur at the permitting phase and focus on quantifying the percentage of a building that is preserved. Guidance on performing and documenting these calculations is described in detail in section 5.1.2.2 below.

Project teams that choose to pursue the building reuse compliance pathway must show that the combined area of addition(s) (if applicable) is less than two times the area of the existing building(s). Two examples are provided below to illustrate how project compliance would work generally.

Example 1: *An office building of 40,000 sq ft is planned for the following scope of work:*

1. *Additions of 25,000 sq ft*
2. *Alterations to 15,000 sq ft of the existing building*

The total area of the addition and the existing building equals 65,000 sq ft. The area of the addition is less than two times the area of the existing building. This project is therefore required to comply with either the material carbon caps, WBLCA, or building reuse requirement.

Example 2: *A commercial building of 10,000 sq ft is proposed to have two additions: one of 15,000 sq ft and one of 25,000 sq ft.*

The total area of the additions and existing building equals 50,000 square feet, but the total area of the additions (40,000 sq ft) is more than twice that of the existing building (10,000 sq ft). Therefore, this project is *not* eligible to comply with the building reuse pathway and must comply with either the material carbon caps or the WBLCA compliance pathway.

Washington should also include guidance for calculating the area of each structural and building enclosure element, similar to what is required for CALGreen. Supplementing the table, project teams must submit a spreadsheet listing all primary structural and enclosure elements within the existing building prior to construction or renovation, and indicate any elements that are to be removed or altered.

Regarding inspection-phase enforcement, verification of the accuracy of submitted area calculations for each project should be a key step for obtaining a Certificate of Occupancy. CALGreen refers responsibility to each enforcing authority, which “may require inspection… during and at the completion of construction to demonstrate substantial conformance” (California Building Standards Commission, 2024).

In cases where projects fail verification, remediation requirements are unsuitable for enforcement. For one, it is infeasible to ask that structural and enclosure elements from an existing building that should have been maintained be brought back to the construction site and re-installed. Additionally, most of the upfront embodied carbon associated with new building components would already be spent by the time of inspection. Instead of requirements for remediation, retroactive fines could be instituted to deter project teams from non-compliance.

5.1.3.1 Guidance on Defining Rules to Calculate the Percent of Building Reused

The building reuse pathway intends to incentivize eligible projects to pursue building reuse over demolition. To avoid deterring project teams with onerous reporting, it is recommended that compliance documentation allow for a simplified gross floor area analysis (see Table 5-2) for projects that comfortably meet the compliance threshold. Projects that are within a closer range of the compliance threshold will need to conduct a more detailed analysis (see Table 5-3) to verify that the project meets the reuse requirements.

All project teams pursuing the building reuse pathway should start by conducting a simple gross floor area analysis. This type of analysis should take project teams less than an hour to complete. If the results of the gross floor area analysis show that the percentage of retained building(s) is greater than 60%, the analysis should be sufficient to demonstrate compliance. Project teams should submit the gross area analysis along with a building plan that graphically indicates the area of the existing building, the area of any new additions (if applicable), and the areas of the existing building to be removed or altered.

Table 5-2: Recommended table for gross floor area analysis, for projects that retain >60% of structure and enclosure elements. *Source: California Building Standards Commission, Supplement Update Guide to the 2022 California Green Building Standards Code (CALGreen)-Nonresidential, July 1, 2024*

Area of Existing Building(s):		_____ sq ft	
Area of Aggregate Addition(s) (if applicable):		_____ sq ft	
	Existing Total Area (A)	Retained Total Area (B)	% of Retained Building (B)/(A)
Gross floor area of Existing Building	_____ sq ft	_____ sq ft	__%

If the results of the gross floor area analysis show that the percentage of retained building(s) is between 45% and 60%, then project teams must complete a more detailed component-area analysis. These projects are likely to alter significant portions of the existing building and thus warrant a robust assessment of the work planned for the building. Table 5-3 describes this component-area analysis, which aligns with the California Building Standards Commission Worksheet WS-3 “Documentation of Compliance of Existing Building Reuse” and is similar to reporting requirements for LEED Green Building Certification credits for building reuse.

The component-area analysis should, at minimum, include the following:

1. A site, demolition, or building plan(s) that graphically identifies areas of the existing building, areas of additions (if applicable), and areas of the existing building that will be retained, and
2. A table with area calculations demonstrating a minimum of 45% of the existing building's primary structural elements and enclosure will be maintained. The percentage will be determined by dividing the square footage of the total retained materials area by the square footage of the total existing materials area. The table shall include the following information:
    a. Area of the existing building(s) in square feet;
    b. Area of the aggregate addition(s) in square feet (if applicable);
    c. Existing total area and retained total area of primary structural elements (foundations, columns, beams, structural wall framing, floors framing, lateral elements) of the existing building(s) in square feet;
    d. Existing total area and retained total area of the building enclosure (wall framing and exterior finish, roof framing) of the existing building(s) in square feet; and,
3. A spreadsheet listing the area of each existing primary structural element and existing building envelope element, and indicating if the element will be retained, altered, or removed.

Table 5-3: Recommended table for component-area analysis, for projects that retain 45%-60% or more of structure and enclosure elements. *Source: California Building Standards Commission, Supplement Update Guide to the 2022 California Green Building Standards Code (CALGreen)-Nonresidential, July 1, 2024*

Area of Existing Building(s):		_____ sq ft	
Area of Aggregate Addition(s) (if applicable):		_____ sq ft	
	Existing Total Area (A)	**Retained Total Area (B)**	**% of Retained Building (B)/(A)**
Primary Structural Elements of Existing Building(s) (foundations, columns, beams, structural wall framing, floor framing, lateral elements)	_____ sq ft	_____ sq ft	__%
Building Enclosure of Existing Building(s) (exterior wall framing and finish, roof framing)	_____ sq ft	_____ sq ft	__%
Total % reuse of required elements:		__%	

Guidance on how to calculate primary structural elements and building envelope elements should also be provided (see Table 5-4). The building official can request additional detail in any case where the percentage area being retained is not clear.

Table 5-4: Recommended guidance on how to calculate primary structural and building envelope elements for the component-area analysis.

Component	Guidance for Area Calculations
Foundations	Total area
Columns	Surface area of longitudinal face
Beams	Surface area of longitudinal face
Structural wall framing	Surface area (one side)
Floor framing	Surface area (one side)
Lateral elements	Surface area of longitudinal face
Exterior wall framing and exterior finish	Surface area (one side)
Roof Framing	Surface area (one side)

5.1.4 Reuse Model Language

This section provides sample language that may be incorporated into Washington's building code. A discussion of where to locate this in the IBC code is provided in section 3.4. Full recommended code language – including new definitions, referenced standards, compliance requirements, and the applicability threshold – are provided in the full code language in section 7.1.

This provision would apply to substantial improvement projects above a defined square footage threshold. If a project cannot meet the requirements for building reuse, it must meet the requirements for either the material carbon caps or WBLCA provisions.

Add new text as follows:

X01 Documentation of building reuse. A *substantial improvement*- where the total project area, including existing floor area, is 50,000 gross square feet or larger of occupied or conditioned space, and where any combined *addition(s)* to the existing building(s) is less than two times the area of the existing building(s)- shall submit documentation that demonstrates the preservation of at least 45 percent combined of the *existing building's* primary structural elements and existing building envelope. Window assemblies, insulation, portions of buildings deemed structurally unsound or hazardous, and hazardous materials that are remediated as part of the project shall not be included in the calculation.

> **X01.1 Compliance forms for building reuse.** *Construction documents* shall clearly distinguish the measurements for existing and new elements. At a minimum, forms documenting building reuse shall include the information listed in items (a) through (d) below:
>
> (a) Area of the *existing building*(s) in square feet;
> (b) Area of the aggregate addition(s) in square feet (if applicable);
> (c) Total gross floor area of the *existing building*(s) before construction or alteration in square feet; OR existing total area and retained total area of primary structural elements of the *existing building*(s) in square feet; and
> (d) Total gross floor area of the *existing building*(s) to be retained in square feet; OR existing total area and retained total area of the building envelope of the *existing building*(s) in square feet.

5.2 Material Carbon Caps (Product GWP Limits)

This section describes the material carbon caps assessment pathway, including:

- An overview of material carbon caps and existing policies (5.2.1);
- Overview of code pathways (5.2.2);
- Enforcement and compliance strategies (5.2.3); and
- Model language options (5.2.4).

For a detailed discussion of material-level reporting, standards, and environmental product declarations (EPDs), see section 2.2.1.

5.2.1 Material Carbon Caps Overview and Feasibility

One method to reduce embodied carbon in the building sector is to establish global warming potential (GWP) limits for specific building materials to which all new construction and major renovation projects over a certain size threshold must comply. Material-specific code approaches are often referred to as prescriptive, because they establish a specific set of materials and a carbon cap for each. Caps can also be set at the project level for each material, allowing higher performance (lower carbon) materials to balance out higher carbon materials used on the project.

A focus on materials selection and procurement can realize significant embodied carbon reductions at little to no additional up-front cost to building owners. Reductions are achieved through specifying and substituting lower-carbon alternatives for certain materials with lower embodied carbon during the design and specification process and through identifying the lowest carbon option during procurement. For this pathway, only products that are functionally equivalent are compared to identify and achieve reductions.

5.2.1.1 Existing Policies

Policies targeting the reduction of carbon emissions associated with building products require the disclosure and verification of GWP data via EPDs. Government procurement policies, known as Buy Clean, are the most common example of policies that require EPD reporting to disclose the GWP impacts of specific products. Many of these policies also set GWP limits and some establish incentives for lower carbon products as well. In the United States, various forms of Buy Clean policy exist for the states of Washington, Oregon, California, Colorado, New York, New Jersey, Maryland, and Minnesota. Additionally, the US General Services Administration (GSA), the City of Portland, Oregon, the Port Authority of New York New Jersey, and the Sound Transit Authority in Washington state all have Buy Clean policies. Most states that set GWP limits are required to revisit those limits regularly to adjust the GWP thresholds to become increasingly stringent over time. Policymakers often require the submission of product- or facility-specific EPDs and reference data from industry-wide EPDs to set GWP thresholds or allow a specific state agency to establish GWP thresholds based on the best available information (Waldman et al, 2024). In the CALGreen and Denver Green Code, GWP thresholds, which are established per unit of material, are set as maximum embodied carbon intensities based on a percentage of industry or regional averages.

Washington's Buy Clean Buy Fair Act establishes facility-specific EPD and material quantity reporting requirements for structural concrete (ready mix, shotcrete, precast, CMU), reinforcing steel (rebar, PT tendons), structural steel (hot rolled, hollow, metal deck, plate), and engineered wood products (CLT, glulam, LVL, PSL, DLT, NLT, GLT, joists, panels, solid sawn, composite). Reporting begins in July of 2025 for newly constructed state buildings over 100,000 square feet and for buildings over 50,000 square feet starting in July 2027. The law also requires a database for tracking EPDs and material quantities, establishes a technical advisory committee, and allows reporting of a supplier code of conduct for fair labor practices among other provisions.

The GSA's (2024) P100 Facilities Standards for the Public Buildings Service now requires that new construction and major renovations target a 20% reduction in their embodied carbon, compared to a project-specific baseline, and has separate materials-specific requirements for concrete and asphalt: GWP limits for concrete based on strength class, manufacturing techniques for asphalt, and a requirement for type III EPDs for both materials. GSA also has incentive-based limits for projects receiving funding from the 2022 Inflation Reduction Act (IRA). These projects must adhere to additional material requirements for concrete and cement, asphalt, steel, and glass.

Government of Canada's (2022) *Standard on Embodied Carbon in Construction* also provides a schedule of requirements for carbon footprint reductions and disclosures for concrete, requiring the use of the highest-resolution EPDs available or, in the absence of available EPDs, robust data derived using LCA methods. The total project GWP from ready-mix concrete must be at least 10% less than that of the baseline mix in the Regional Industry Average EPD for each strength class.

As of November 2024, California has a suite of five policies that together work on reducing the embodied carbon of building materials, with a strong focus on concrete. First, Buy Clean California sets material carbon caps for steel, mineral wool, and glass used on state-funded projects. Second, CALGreen includes a product GWP compliance option that requires EPD submission for steel, glass, mineral wool, and concrete to demonstrate a lower GWP compared to regional averages (see section 4.1.1 above). Third, California Assembly Bill (AB) 2446 requires the California Air Resources Board (CARB) to develop a framework for measuring and reducing the carbon intensity of building materials in new buildings. Senate Bill (SB) 596 builds on this by requiring CARB to develop a strategy for the cement sector to reach net zero emissions by 2045. And finally, AB 43 authorizes the establishment of an embodied carbon trading system, which would inform the framework for measuring the average carbon intensity of materials.

Other notable North American policies with material carbon caps include:

- The Portland Low Carbon Concrete Initiative requires city-procured concrete to meet a GWP threshold per strength class.
- Marin, CA was the first county in the United States to adopt a Low Carbon Concrete Code, under which new local building projects must choose from two pathways to comply: a total cement limit or a GWP limit met for each concrete mix in a distinct strength category.
- Santa Monica, CA has recently followed suit by adopting its own Low Embodied Carbon Concrete Requirements.
- The Denver Green Code requires projects to meet specific GWP limits for concrete and steel products. For concrete, the total CO_2e value of mixes must not exceed a certain maximum value and must have a product-specific type III EPD. For steel, type III EPDs submitted for a minimum of 75% of steel products, based on cost or weight, must be provided. See section 4.3 for additional discussion.
- Under Toronto's Waterfront Green Building Requirements, buildings can choose to use 50% recycled metal in steel and rebar, low-carbon concrete (with 25% Supplementary Cementitious Materials), or timber products certified by the Forest Stewardship Council.
- The Vermont Building Energy Code has an optional credit for GWP reporting of insulation materials.

5.2.2 Material Carbon Caps Potential Code Pathways

This proposed pathway is a material-focused approach, requiring submission of EPDs to document a reduction in GWP across 90% of covered materials by 10% compared to industry average values.

5.2.2.1 Options for EPD Requirements

Some policies require that EPDs be submitted for a specific list of materials – commonly, materials found in buildings' structure and enclosure. Other policies are agnostic on material types, only requiring that a certain portion of a total project be represented by submitted EPDs. These are explored in options 1 and 2 below.

Additionally, some policies give priority to EPDs that provide greater levels of detail compared to industry-wide EPDs: these may include product and facility-specific, or supply chain-specific EPDs (see section 2.2.1 for EPD types). The IgCC and LEEDv4.1, for example, give priority to product-specific type III EPDs, because they provide a greater level of specificity compared to industry-wide EPDs. Under the IgCC, product-specific EPDs are counted as one product for compliance, while regional- and industry-wide EPDs are counted as one-half. LEEDv4.1 counts product-level critically reviewed life cycle assessments, product-specific EPDs that are internally reviewed, and industry-wide EPDs as one product; product-specific EPDs with third-party certification are counted as 1.5.

Option 1: EPD Requirements for Certain Materials

Most material-focused embodied carbon measures require that EPDs be submitted for specific materials - typically ones that are incorporated into the building's structure and enclosure including concrete, steel, aluminum, wood, glass, and insulation. Together, these materials account for a significant portion of a building's total greenhouse gas emissions in the extraction and manufacturing phases.

Table 5-5 captures the materials that are covered by major prescriptive codes and policies, including Buy Clean. Policies focused purely on concrete have been omitted. The policies listed in Table 5-5 notably include provisions for reporting and a reduction in GWP, which is addressed in more detail in Section 5.2.2.2 on Options for Setting GWP Limits. For a more complete list of Buy Clean policies, including the material scope and GWP limits established, CLF published a Buy Clean Overview Factsheet providing a snapshot of all Buy Clean policies as of April 2024 (Waldman et al, 2024).

Table 5-5. Materials covered by major prescriptive codes and policies. Source: Ariel Brenner, Rebecca Esau, et al., *Findings and Recommendations on the Use of Lower Carbon Materials in the Statewide Building Code and Other Means for Reducing Greenhouse Gas Emissions Attributable to Building Materials*, NBI and RMI, 2024.

	Buy Clean Buy Fair WA	CALGreen & Buy Clean California	Buy Clean Colorado	Buy Clean Buy Fair MN	Buy Clean Oregon	Denver Green Code	GSA Interim IRA Guides
Asphalt			√	√	√		√
Concrete / Cement	√	√	√	√	√	√	√
Steel	√	√	√	√	√	√	√
Glass		√	√				√
Board / Foam Insulation		√ (Mineral wool board only)					
Structural / Engineered Wood & Composites	√		√				

Some jurisdictions have chosen to focus their embodied carbon code efforts solely on concrete since it is a major contributor to carbon emissions, such as the Low Embodied Carbon Concrete codes in Marin County and Santa Monica, California and procurement policies including the Portland Low Carbon Concrete Initiative, New York State Buy Clean, New York City Executive Order 23, and Austin's Resolution No. 20230420-024 (see 5.2.1.1 for additional discussion of existing policies).

The materials commonly referenced by prescriptive codes and policies are chosen because they are accountable for significant GHG emissions throughout their production phases. Fortunately, reducing the production-phase embodied carbon associated with these major materials is already achievable. Several strategies have been identified for each material to reduce its respective emissions throughout its production: high-impact methods for each material are captured in Table 5-6. It is rare and not recommended for codes to prescribe the particular strategies that embodied carbon be reduced for materials, as this can constrain project teams' abilities to creatively and flexibly identify strategies that work for the specific circumstances of the project. However, understanding what these methods are can help to illustrate how required reductions in code are feasible today.

There is concern that an unintended consequence of omitting some low embodied carbon materials, such as mass timber, from material-specific policies is that these materials may not be considered in schematic design due to a focus on funding the reduction of emissions from included materials, i.e. steel and concrete. This perverse incentive can unintentionally lead building projects to not select materials that are inherently low in embodied carbon, such as mass timber and other bio-based materials.

Table 5-6: High-impact strategies to reduce embodied emissions associated with construction materials. Source: Ariel Brenner, Rebecca Esau, et al., *Findings and Recommendations on the Use of Lower Carbon Materials in the Statewide Building Code and Other Means for Reducing Greenhouse Gas Emissions Attributable to Building Materials*, NBI and RMI, 2024.

Material	Selection of embodied carbon reduction strategies that focus on lower GHG intensity
Concrete / Cement	● Incorporate blended cements including portland-limestone cement (PLC) ● Use supplementary cementitious materials (SCMs) to reduce cement content including fly ash, slag cement, silica fume, ground glass pozzolan, calcined clay, and others. ● Specify water-reducing and internal curing admixtures to reduce cement content. ● Power cement and concrete production with low-carbon energy.
Steel	● Use steel made with scrap content in an electric arc furnace, as opposed to virgin steel made in a basic oxygen furnace. ● Increase recycled content in new steel production ● Power electric arc furnaces with low-carbon energy.
Aluminum	● Source products with >90% recycled content ● Power factories with low-carbon energy
Wood	● Source timber locally and use low-carbon transport methods to reduce transportation emissions. ● Source products from sustainably managed forests. Note that sustainable forestry certification may be cost-prohibitive, especially for small local wood producers, and may not always be associated with meaningfully better forest management practices. ● Design timber for easy disassembly and reuse in future buildings. ● Use timber with bio-based adhesives when possible (Hunt et al, 2022). ● Power wood processing facilities with low-carbon energy.
Glass	● Increase use of recycled cullet to reduce waste, energy, and raw materials ● Use furnaces that utilize Oxy Fuel technology, which reduces natural gas by infusing pure oxygen to produce higher temperatures ● Design burners and nozzles to decrease energy use
Board & Foam Insulation	● Use bio-based alternatives ● Use lower-GWP blowing agents ● Mineral wool: increase renewable energy at furnace

Option 2: Material-Neutral Policy

Instead of requiring EPDs for certain specified products, policies might require that a minimum amount of EPDs be submitted, regardless of the material they represent. This may be formulated as a set number of EPDs per square foot of construction, or set as a threshold, such as a percentage relative to the total project cost, weight, or volume.

The IgCC is one major precedent that remains agnostic to material types. Chapter 9 on Materials and Resources contains requirements for all projects to submit EPDs that represent all of the following:

- at least 25% of the total estimated cost of building products
- at least 30 EPDs in total
- at least 10 different manufacturers
- at least 20 different building products
- all building products that exceed 5% of the total cost of the project.

LEED v4.1 contains similar provisions, requiring the use of EPDs representing at least 20 different products from at least 5 different manufacturers. However, the public review draft of the upcoming version 5 of LEED notably veered from this strategy and includes EPD and GWP limits for many of the materials listed under Option 1.

The Minnesota Sustainable Building Guidelines (B3) also require that EPDs representing at least 5 different products from at least 5 different manufacturers be submitted in addition to a WBLCA (University of Minnesota, 2024). The Guidelines specify that this strategy be used only when a project has a dominant structure and enclosure type that represents at least 60% of the building's structural volume and exterior area, and when the project utilizes material categories that are well accounted for by the B3 LCA Material Selection Calculator. The Guidelines also note that this strategy is best used for evaluating material substitutions but is less suitable for considering broader-level GWP reduction strategies: this is something a WBLCA or assembly-level assessment would better address. For this reason, projects are also required to submit WBLCA models at the end of the design phase.

5.2.2.2. Options for Setting GWP Limits

Reporting is an important first step for collecting information on materials and their environmental impacts, and for getting product teams into the practice of considering these attributes when they make design decisions. However, reporting itself will not result in reductions in embodied carbon: this is where GWP limits play a role.

There are two options for setting GWP limits for specific materials: setting caps at the product or project level. Setting compliance at the project level can allow project teams the flexibility to implement carbon reductions where they are most cost-effective. For example, ultra-low carbon material procurement in one category can offset higher emissions in another product category that may not have lower carbon materials readily available.

The LEEDv4.1 pilot credit for procuring low carbon construction materials demonstrates this project-level approach (USGBC, 2019a). Certain materials – including concrete, steel, aluminum, wood and composites, insulation, cladding, and finishes – must be reported in terms of their GWP and total material quantity. The sum of the products of these values ultimately results in one total GWP value reported for the entire project.

Most existing policies, however, take the former approach of setting GWP limits at the product level. GWP limits are typically either explicitly or implicitly based on industry averages (Waldman et all, 2024). For example, New York State Buy Clean Concrete Guidelines sets limits for concrete at 150% of the regional baseline, determined by the National Ready Mix Concrete Association (NRMCA). The GSA IRA Interim Limits for concrete, cement, asphalt, steel, and glass, are hard caps based on the top 20%, 40%, and average of industry values. The Denver Green Code sets its concrete GWP caps based on the 50th percentile of EPDs collected through EC3. Buy Clean

California caps for steel, concrete, glass, and mineral wool board insulation are set at the industry average of facility-specific GWPs for each respective material (State of California, 2024). Buy Clean Colorado similarly set initial GWP limits for asphalt, ready-mix concrete, cement, flat glass, steel, and structural wood at the industry average.

Industry-average GWP values for many materials can be easily accessed through online EPD repositories such as Building Transparency's Embodied Carbon in Construction Calculator (EC3) tool. In this tool, users can select specific material categories and find industry-average values for varying scales ranging from local to global.

Additionally, the Carbon Leadership Forum's North American Baseline reports provide baseline embodied carbon per unit of product values for a wide range of building materials. The baselines represent industry average production practices in North America based on the best publicly available EPD data. The most recent (2023) Material Baselines Report also included region-specific values for concrete products and appendices with summary statistics for major materials (e.g. 20th, 40th, 60th, and 80th percentiles and min, max, mean, and median values) to better demonstrate the range of emissions intensities per product type (Waldman et al., 2023).

5.2.2.3 Phasing in Updates over Time

Inherent in basing GWP limits on industry averages is the expectation that these will decrease over time as manufacturers adjust to new policies and improve their practices to stay competitive in the market. For example, the Department of General Services (DGS) in California is required to review the GWP limits for all covered materials every three years and adjust to reflect industry average; DGS is prohibited from adjusting these limits upward. In Colorado, the Office of the State Architect (OSA) must adjust GWP limits every 4 years at a minimum but is permitted to make updates annually. Portland's Embodied Carbon Thresholds for Concrete Mixes on City Projects similarly calls for an annual review of thresholds through 2028 (City of Portland, 2022).

Section 5.2.4.1 outlines a measure to require a 10% reduction in embodied carbon compared to 2023 industry averages. As embodied carbon becomes more widely addressed in the building sector, the industry averages for various GWPs will continue to decrease. Therefore, the GWP limits set forth by Code Language Option 1 should be updated with regular code update cycles to continue to promote embodied carbon reductions. In addition to improvement across GWP industry averages, the 10% reduction target can also be increased in future revisions to code, for example up to 25%, to proactively meet Washington's decarbonization goals.

Additional materials can also be phased in. The recommendations in this study focus on materials that already have EPD requirements in the Buy Clean Buy Fair Washington Act. Insulation, glass, insulation, interior finishes, aluminum, and masonry should also be considered in the future to capture a larger portion of the building's footprint.

Code officials should also consider phasing in requirements for other building elements including interior finishes and service systems over time. The emissions associated with mechanical, electrical, and plumbing (MEP) systems can be significant, but research and data around these are still in the early stages. Developments associated with ASHRAE 244p, which is a product category rule (PCR) for these materials, should be also tracked for future code updates, with a focus on MEP products and assemblies.

5.2.2.4 Option to Include Other Low-Impact Material Attributes

While prescriptive requirements tend to focus solely on GWP, there are other attributes that materials-based codes may begin to require or incentivize, given further study. Accounting for a broader range of material qualities – such as whether they are recycled, reused, salvaged, or regionally sourced – could highlight the importance of waste avoidance in a way that a pure focus on carbon alone may not be able to achieve. Additional life cycle impact categories that are already reported by most EPDs and WBLCAs – such as acidification, eutrophication, ozone depletion, and smog formation – could also broaden the focus of requirements to include other air, water, and land pollution impacts associated with building materials.

Chapter 9 of the IgCC, focused on materials and resources, includes one optional compliance pathway to utilize reduced impact materials, demonstrating attributes in two of the following four: 10% (based on cost) recycled and salvaged material; 15% (based on cost) regional materials; 5% (based on cost) biobased products; or third-party multi-attribute certification for 5 products. These options are in addition to the requirement of submitting EPDs. Another example is the LEEDv4.1 Building Product Disclosure and Optimization credit, which includes an option for multi-attribute optimization through requiring that projects use third-party certified products demonstrating impact reduction in depletion of nonrenewable energy sources and at least three additional life cycle impact categories.

5.2.3 Material Carbon Caps Enforcement and Compliance Strategies

Existing material carbon caps measures require enforcement at the permitting phase. Compliance is verified through the submission, verification, and review of EPDs, which must demonstrate that the materials meet the established GWP limits. The enforcement strategy includes mandatory reporting, verification via a Registered Design Professional's Declaration Statement, and penalties for non-compliance.

To verify compliance with the set material carbon caps, project teams submit a Registered Design Professional's Declaration Statement confirming adherence to code requirements and committing to the use of specified products during construction. Responsible parties would include the Architect of Record/Designer of Record and the Owner, who would be listed with the permit application.

Building officials verify that the materials meet the GWP limits (through reviewing against the number in an EPD) as part of the overall code compliance review before issuing permits. The declaration of compliance is then signed by the General Contractor and is due in advance of the final building inspection. For all approaches, the Architect of Record/Designer of Record, Owner, and General Contractors should be made aware of these requirements in advance of it becoming a requirement.

5.2.4 Material Carbon Caps Model Language

This section provides sample language that may be incorporated into Washington's building code. A discussion of where to locate this in the IBC code is provided in section 3.4. Full recommended code language – including new definitions, referenced standards, compliance requirements, and the applicability threshold – is provided in the full code language in section 7.1.

5.2.4.1 Code Language Option 1

A prescriptive code that sets requirements for specific materials, which are situated in Chapter 1 of the base code. This structure is suitable for combining these carbon cap requirements with other compliance options, such as whole-building LCA and building reuse.

Add new text as follows:

<u>**X01 Documentation of reduced embodied carbon of covered products.** Project-specific product quantities shall be submitted along with environmental product declarations that demonstrate that the global warming potential of the total mass or volume of the covered products listed in Section X01.1 is no more than 90 percent of the GWP values in Table X01.1 for the same total mass or volume of the covered products.</u>

X01.1 Covered products. Covered products shall include no less than 90 percent of the total mass or volume of the following:
(a) Structural concrete products, including but not limited to ready mix and concrete masonry units;
(b) Reinforcing steel products, specifically rebar;
(c) Structural steel products, specifically hot rolled sections, hollow sections, decking, and plate; and
(d) Structural wood products, including but not limited to laminated veneer lumber, laminated strand lumber, glue laminated timber, wood framing, softwood plywood, and Oriented Strand Board (OSB).

TABLE X01.1 COVERED PRODUCT GWP VALUES

COVERED PRODUCT		GLOBAL WARMING POTENTIAL	UNIT OF MEASUREMENT
Ready mix concrete	Up to 2,499 psi	235	kg CO_2e/m^3
	2,500-3,999 psi	261	kg CO_2e/m^3
	4,000-4,999 psi	316	kg CO_2e/m^3
	5,000-5,999 psi	386	kg CO_2e/m^3
	6,000-7,999 psi	408	kg CO_2e/m^3
	8,000 psi and greater	487	kg CO_2e/m^3
	Lightweight, up to 3,999 psi	518	kg CO_2e/m^3
	Lightweight, 4,000-4,999 psi	575	kg CO_2e/m^3
	Lightweight, 5,000 psi and greater	632	kg CO_2e/m^3
Concrete masonry units	Normal weight, up to 3,249 psi	208	kg CO_2e/m^3
	Normal weight, 3,250-4,499 psi	232	kg CO_2e/m^3
	Normal weight, 4,500 psi and greater	241	kg CO_2e/m^3
	Medium weight, up to 3,249 psi	360	kg CO_2e/m^3
	Medium weight, 3,250 psi and greater	244	kg CO_2e/m^3
	Lightweight, up to 3,249 psi	395	kg CO_2e/m^3
	Lightweight, 3,250 psi and greater	286	kg CO_2e/m^3
Reinforcing steel	Rebar – unfabricated	753	kg CO_2e/metric ton
	Rebar – fabricated	854	kg CO_2e/metric ton
Structural steel	Hot-rolled sections – unfabricated	1,000	kg CO_2e/metric ton

	Hot-rolled sections – fabricated	1,220	kg CO_2e/metric ton
	Hollow structural sections – unfabricated	1,710	kg CO_2e/metric ton
	Hollow structural sections – fabricated	1,990	kg CO_2e/metric ton
	Decking	2,320	kg CO_2e/metric ton
	Plate – unfabricated	1,480	kg CO_2e/metric ton
	Plate – fabricated	1,730	kg CO_2e/metric ton
Structural wood	Laminated veneer lumber	361.45	kg CO_2e/m^3
	Laminated strand lumber	274.9	kg CO_2e/m^3
	Glue laminated timber	137.19	kg CO_2e/m^3
	Wood framing	63.12	kg CO_2e/m^3
	Softwood plywood	219.32	kg CO_2e/m^3
	Oriented Strand Board (OSB)	242.58	kg CO_2e/m^3

5.2.4.2 Code Language Option 2

A prescriptive code that sets requirements for specific materials can integrate new embodied carbon requirements into the materials-focused chapters that populate the base code. One example for concrete is provided below. This structure is most suitable for a scenario in which the code only takes a prescriptive approach to addressing embodied carbon, without integrating other compliance options.

Add new text as follows:

X01 Embodied CO2e in Concrete Products. The CO2e of ready-mix and precast concrete shall meet the requirements in this section, and products used for compliance shall have a *product-specific Type III EPD*. Documentation of the product's kgCO2e/unit and EPDs shall be verified by a *registered design professional* on the project, and a summary shall be made available to the *code official* that includes a list of each product and associated kgCO2e/unit, per the EPD.

X01.1 Embodied CO2e in Ready-mix Concrete Products. 90% of all ready-mix *concrete* mixes used in the *building's primary structural frame*, *secondary members*, *seismic force-resisting system*, and foundations shall not exceed the project limit (CO2Emax) determined by 90% of industry-wide EPDs (IW-EPDs) kgCO2e/y3.

Exceptions:

1. Precast, shotcrete, or auger cast concrete.
2. Buildings less than 50,000 *gross floor area*.
3. Buildings where the total volume of *concrete* is less than 50 cubic yards.

Other sections of the Washington State Building code that may incorporate new language on submitting EPDs and meeting GWP caps include:

- 720.1.1: Embodied CO2e of Insulation Products
- 802.8: Embodied CO2e of Interior Finishes
- 1401.2: Embodied CO2e of Exterior Walls, Wall Coverings, Windows and Doors
- 1501.2: Embodied CO2e of Rooftop Assemblies and Rooftop Structures Products
- 1901.8: Embodied CO2e in Concrete Products
- 2001.2: Embodied CO2e in Aluminum Products
- 2103.1.2: Embodied CO2e in Masonry Construction Products
- 2201.2: Embodied CO2e in Steel Products
- 2303.8: Embodied CO2e of Wood Products
- 2403.6: Embodied CO2e of Glass and Glazing Products
- 2501.3: Embodied CO2e of Gypsum Products
- 2603.14: Embodied CO2e of Foam Plastic Insulation Products

5.3 Whole building life cycle assessments and building-level requirements

This section describes the components of a whole building life cycle assessment (WBLCA) pathway if included in code, including:

- Overview of WBLCA pathway (5.3.1);
- Overview of code options (5.3.2);
- Enforcement and compliance strategies, including guidance on defining the baseline building (5.3.3); and
- Model language (5.3.4).

5.3.1 WBLCA Overview

To comply with a building-level requirement in codes and policies, projects must report a building's GWP (in the form of CO_2e) using a WBLCA or WLCA (see section 2.2.1 to learn more about WBLCA standards and data). Similar to an energy model, WBLCA can be used to demonstrate a GWP percentage reduction requirement from a modeled baseline or to compare a proposed design to a maximum CO_2e limit per floor area (like an energy use intensity target used for operational energy), referred to in this report as a Building Carbon Budget.

Requiring projects to assess the embodied carbon of their building via a WBLCA and achieve reductions engages design and construction teams to design more material-efficient and lower-carbon buildings and to specify lower-carbon products. When WBLCA is used throughout the design process, architects and engineers can coordinate to maximize the reduction potential by coordinating early in the design and construction process, ensuring that changes make it to the specifications, and educating clients and contractors on potential changes.

WBLCA as a reporting method is the most flexible approach, unlocking a large range of possible strategies to reducing embodied carbon:

- **Material Efficiency:** Building the same function and strength with less volume of materials, such as using voided slab systems, post-tensioned slabs, or composite design braced frames instead of moment frames

(Webster, 2020). In addition to requiring building-level requirements and WBLCA, codes can require material efficiency by allowing advanced framing methods or other materially efficient design techniques.

- **Circularity**: Minimizing new construction and reusing existing buildings or components, which can include reusing entire foundations or enclosures to individual salvaged materials. Codes can also reward building reuse by using the approach described in section 5.1 and by rewarding using salvaged materials, as described in section 5.4.
- **Material & Assemblies Substitution**: Evaluating the environmental trade-offs between different components of a building, such as carbon-storing materials (climate-smart wood, hempcrete, bio-based insulation, etc.) or other alternatives in place of conventional materials.
- **Low-carbon products:** Comparing different products or manufacturers with the same function and selecting the lower carbon option. Codes can also require this type of approach through material-specific GWP limits, as described in section 5.2.
- **Durability and resilience**: WBLCAs look at replacement of materials over the lifetime of a project, allowing for evaluation of the tradeoffs of using longer-life materials.
- **Life cycle impacts beyond manufacturing**: Transportation to site, construction impacts, and use phase impacts can be really important for some products like wood, installation, and products using refrigerants and are included in a WBLCA.

5.3.1.1 Existing policies

Existing policies and codes requiring reporting of a WBLCA use reduction targets and/or building carbon budgets to set building embodied carbon performance requirements. The benefits and challenges of each of these approaches are described in the following section.

Option 1: Percentage Reduction Targets

Projects must reduce the building's embodied carbon by a certain percentage compared to a building-specific baseline. This is typically user-modeled. Examples of this approach include the CALGreen WBLCA Pathway (see section 4.1.2), LEEDv4.1 Building Life Cycle Impact Reduction Credit (USGBC, 2019a), and GSA's (2024) P100 Facilities Standards Section 1.9.3.4 Decarbonization. For this option, guidance on how to model the baseline building should be provided, as described in 5.3.3.3.

Option 2: Building Carbon Budgets

Projects must demonstrate that the embodied carbon intensity per floor area (kg CO_2e/m^2) of their project is below a maximum value. This is similar to the material carbon caps described in section 5.2, but for the entire building (per unit of floor area) instead of per material (per unit of product). This approach can also be broken down by scope, requiring compliance with limits for structure and enclosure or other scopes separately, or summed together.

Examples of policies and certifications using this approach include the International Living Future Institute's Living Building Challenge and Zero Carbon Certifications, the Canadian Green Building Council's Zero Carbon Building – Design Standard™ v4, and the Toronto Green Standard (TGS) v4. The TGS is a City of Toronto program that has been required for new planning applications in the City of Toronto since 2010. The TGS sets performance requirements for city-owned buildings and new mid to high-rise residential and non-residential developments. Version 4 came into effect on May 1, 2022, and includes GWP limits for embodied carbon.

Option 3: Combined Approach

Projects can comply with either option 1 or 2 above. This is similar to the City of Vancouver requirements described in section 4.2. Beginning in 2025, the City of Vancouver will require projects (based on building type and height) to reduce 10-20% from either (a) a 400 kg CO_2e/m^2 limit or (b) a baseline building modeled according to Vancouver's requirements.

5.3.2 WBLCA Potential Code Pathways

In this section, we introduce three potential approaches to integrating WBLCA requirements into the code, building on the policy approaches described in the prior section:

A. Percent Reduction: The Global Warming Potential of the Proposed Design WBLCA shall not exceed 90% of the total Global Warming Potential of the Baseline Design WBLCA.

B. Building Carbon Budget (BCB): The Embodied Carbon Intensity of the Proposed Design WBLCA shall not exceed the applicable Building Carbon Budget.

C. Combined: Projects may follow either option A OR option B

Model code language is provided in section 5.3.4, with the pros and cons of the four options described in Table 5-7. Definitions for all terms are provided in section 7.1.

Table 5-7. Pros and Cons of WBLCA Policy Options for WA State. *Adapted from CLF (2024) Building-Scale Embodied Carbon Performance Requirements.*

Option	PROs	CONS
A *(% reduction)*	• Approach has already been successfully incorporated into code (CALGreen WBLCA pathway) • Enables flexibility for higher intensity carbon projects, allowing this method to be more easily used across many building types and seismic requirements • Approach is largely consistent with common building certification approaches to WBLCA (i.e., LEED)	• Requires detailed guidance to support development of fair baseline models that limit "gaming" • More effort required for project teams who need to generate both Baseline and Proposed WBLCAs • Approach rewards relative carbon reduction rather than absolute reductions
B *(building carbon budget)*	• Does not require a Baseline Model, reducing work on design teams and reducing guidance • Approach rewards actual absolute overall carbon reduction more so than flexible baseline method	• Specific benchmarking studies for the Washington region are unavailable, so the limits would be estimated based on current best practice • Could be considered inflexible for higher intensity projects - What can be done when a project just can't meet the metric? Likely, some process for exceptions would need to be made
C *(A or B)*	• Enables flexibility for teams to choose the approach (baseline or GWP limits) that reduces effort • Permits a compliance pathway feasible for all projects, limiting need for exceptions	• Requires detailed guidance to support development of fair baseline models that limit "gaming" • More complex to explain to new audiences

Sample language is provided for all three pathways in section 5.3.4. However, based on the analysis above, Option C is recommended in section 7, because this option:

- Includes a baseline pathway that allows a flexible compliance pathway for any and all project types through a method familiar to current LCA practitioners. This option can also point to CALGreen as an example of a similar code option that is being implemented across California non-residential projects.
- Also introduces a building carbon budget. This pathway simplifies compliance for buildings that easily meet this intensity budget because they will not have to develop a baseline model. In addition, this pathway could offer a more straightforward pathway to updates in line with Washington's state's decarbonization goals.

5.3.3. WBLCA Enforcement and Compliance Strategies

5.3.3.1 WBLCA Submissions

WBLCA reporting may include multiple rounds of modeling submissions:

1) **Design WBLCA Submission** [Required at issued for permit set]

   The first submission at the Issued for Permit stage serves to motivate design intervention and investigation into embodied carbon reductions.

   If a Percentage Reduction approach is pursued, this pathway should require the submission of a Baseline Design WBLCA and a Proposed Design WBLCA model for comparison at the end of the design process. To successfully show a reduction from baseline at this stage, the design team will need to have considered and documented two functionally equivalent models incorporating targeted reduction strategies to achieve the required reduction from the Baseline Design WBLCA's total GWP.

   If a Building Carbon Budget approach is pursued, this pathway should require submission of a Proposed Design WBLCA at the end of the design process, showing that the Embodied Carbon Intensity (ECI) of the project is below the relevant Building Carbon Budget.

2) **As-Built WBLCA Submission** [Required at substantial completion]

   The second submission at the point of Substantial Completion serves to document the project outcomes and actual embodied carbon of the final constructed project. There are no required performance indicators or reductions at this stage, it is a disclosure only.

To comply with the WBLCA pathways, project teams must either identify an existing design team member with the experience to run the WBLCA analysis, or hire a qualified consultant to perform the analysis. The timing and complexity of the WBLCA modeling required will depend on which option is selected:

- In the percent reduction option (option A), two Design WBLCAs must be performed to constitute a comparison.
- In the Building Carbon Budget scenario (option B), one Design WBLCA must be performed to show Carbon Budget compliance.
- All buildings will also be required to submit an As-Built LCA at the end of the project's construction to demonstrate the final impacts of the building.

Table 5-8. Summary of reporting. *Source: CLF.*

Submission	Project Milestone	Description
WBLCA Submission for Percentage Reduction Approach	Construction Documents or Issued for Permit set	A summary report of the Comparative Design WBLCA with a demonstrated 10% reduction must be provided in the Construction Documents or Issued for Permit sets as documentation of compliance. This documentation must include evidence that the analysis was produced by a compliant software, and document that the scope boundary is consistent with the code requirements. The documentation must also include a table that describes the key changes between baseline and proposed that are responsible for the demonstrated 10% reduction. Any reduction strategies that rely on the procurement of specific materials must include an appendix to the report documenting how the specification language shows a mechanism to support the anticipated 10% reduction.
WBLCA Submission for Building Carbon Budget Approach	Construction Documents or Issued for Permit set	A summary report of the Proposed Design WBLCA with an Embodied Carbon Intensity (ECI) of less than the Building Carbon Budget must be provided in the Construction Documents or Issued for Permit sets as documentation of compliance. This documentation must include evidence that the analysis was produced by a compliant software, and document that the scope boundary is consistent with the code requirements.
As-Built WBLCA Submission	Substantial Completion	This documentation must include evidence that the analysis was produced by a compliant software, and document that the scope boundary is consistent with the code requirements. The submission must document the estimated GWP of the final project as constructed and include a narrative that describes the reasons for the differences between the GWP and embodied carbon intensity (ECI) of the Proposed Design WBLCA and the As-Built WBLCA.

5.3.3.2 Reporting

Detailed reporting can lead to more transparent, useful, and consistent assessments and can reduce the burden on the enforcing authority required to verify results. Results can be reported either in a worksheet or in a reporting database. Washington DES or Commerce could create a reporting template to complement the enforcement strategies described in section 5.5, such as Vancouver, Canada's (2023) *Embodied Carbon Design Report v1* or New York City's (2024) *NYC EO 23 LCA Reporting Template*.

This reporting template could further align with industry alignment initiatives through adopting the recommendations of the Embodied Carbon Harmonization and Optimization (2024) *ECHO Schema V1.0*.

5.3.3.3 Baseline building guidance

Option A (described above) requires projects to compare the results of a WBLCA against a baseline building, also referred to as a "reference building" or "baseline design WBLCA"**.** This reference model represents a typical or average building for the location where the project is being built as if the project had not taken steps to reduce the embodied carbon of the project. The baseline design WBLCA model must be functionally equivalent to the building being permitted, referred to as the “as-designed WBLCA” and must have the same massing, area, function, and thermal criteria. It must be submitted as part of the Design WBLCA Submission.

Providing guidance on what assumptions are appropriate for Washington State would streamline the process for project teams and simplify the review process for any audits performed by Washington State. Examples of existing similar guidance include the City of Vancouver (2023) *Embodied Carbon Guidelines, version 1.0* and National Resource Council Canada’s (2024) *National Whole-building Life Cycle Assessment Practitioner’s Guide: Guidance for Compliance Reporting of Embodied Carbon in Canadian Building Construction.*

The tables below provide examples of the type of guidance that Washington State could provide. Table 5-9 documents the baseline assumptions for key assemblies to be used in constructing a baseline model, such as which insulation type should be assumed in which assembly. Table 5-10 documents the baseline material assumptions by noting the source data that should be referenced to apply industry-standard materials. Finally, Table 5-11 documents the basis for comparison between the baseline and proposed models and what a team can and can’t take credit for in their comparative WBLCA.

Table 5-9. Example Guidance Table: Baseline Assembly Assumptions for Washington State. *Adapted from the City of Vancouver (2023)* Embodied Carbon Guidelines, v1.

Building Elements (per Omniclass Table 21)			**Default Assumptions (if applicable)**
Level 1	**Level 2**	**Level 3**	
Substructure	Foundations, Subgrade Enclosure, Slab on Grade	all	Steel-reinforced concrete Subgrade insulation: XPS
Shell	Superstructure	Floor Construction	Steel-reinforced concrete
		Horizontal/Roof Construction	Typical span: Steel-reinforced concrete Long span: steel trusses
	Exterior Vertical Enclosure	Exterior Walls	Office and Commercial: Aluminum Window wall Residential (7+ stories): Aluminum Window Wall Framing: 6” deep steel framing @ 16” on center Sheathing: Gypsum Board Thermal Cavity Insulation: Mineral Wool Batt Insulation Thermal Cavity Insulation: Heavy Density Mineral Wool Board Cladding: Galvanized Steel
		Exterior Windows	Window frame: Aluminum Insulated Glass Unit: as required to meet thermal performance Window-to-wall ratio: as required to meet thermal performance
	Exterior Horizontal Enclosure	Roofing	Insulation: ● Conventional roof: polyiso ● Inverted roof: XPS ● Interior sheathing: gypsum board ● Membrane: 2-ply SBS

Interiors	Constructions	Interior Partitions	Framing: 6" deep steel framing @ 16" o.c. Sheathing: gypsum board on both sides Acoustic insulation (where required): mineral wool batt
	Finishes	Wall Finishes	Paint
	Finishes	Floor Finishes	Offices: carpet Residential and hotels: vinyl Retail: ceramic tile Industrial: exposed concrete Healthcare: ceramic tiles All building types: ● Hallways: carpet ● Below-grade and service rooms: exposed concrete ● Bathrooms and showers: ceramic tiles
	Finishes	Ceiling Finishes	● Drop ceiling: acoustic tile ● Gypsum board with skim coat and paint

Table 5-10. Example Guidance Table: Baseline Material Assumptions for Washington State. Baseline source data from Waldman et al (2023) *2023 Carbon Leadership Forum Material Baselines Baseline Report v2*.

Material	Baseline Design WBLCA Material Assumptions
Concrete	NRMCA Pacific Northwest Baselines by strength and weight. Baseline strengths by application must match the proposed.
Insulation	Baseline EPDs shall match the closest insulation type in the CLF 2023 Baselines report.
Flat Glass	National Glass Association (2019). Environmental product declaration - Flat glass.
Reinforcement	CRSI. (2022). Environmental product declaration - Steel reinforcement bar.
Steel	For non-rebar steel including Plate Steel, Hollow Structural Section (HSS), Hot-Rolled Sections, Steel Framing, and Open Web Steel Joists, baselines shall reference the relevant industry-wide EPD. Baseline EPDs shall match the closest steel type in the CLF 2023 Baselines report.
Aluminum	Aluminum products shall reference the relevant industry-wide EPD. AEC. (2022). Environmental product declaration - Aluminum extrusions - mill finished, painted, and anodized.
Wood	Wood products shall reference relevant industry-wide EPDs from the American Wood Council (AWC) or other relevant organizations. Baseline EPDs shall match the closest steel type in the CLF 2023 Baselines report.

Table 5-11. Example Guidance Table: Baseline and Proposed Design Modelling Guidance. *Adapted from the City of Vancouver (2023)* Embodied Carbon Guidelines, v1.

Process / Strategy	Baseline Design WBLCA Approach	Proposed Design WBLCA Approach
Demolition	If the proposed design includes partial or complete removal of any existing building or building element on the site, the baseline shall not include the emissions from the demolition or deconstruction of the existing building.	Out of Scope
Reuse/ Salvage	The baseline shall assume entirely new construction for all building areas, even if some portions of the building will be retained and reused in the proposed design.	For materials reused directly in situ, it is permissible to assume the A1-A4 stages carry no impact in the Proposed Design WBLCA to show the benefit of reusing materials, while retaining the A1-A4 estimated impacts for these products for these materials in the Baseline Design WBLCA. For salvaged materials brought to the site, it is permissible to assume the A1-A3 stages carry no impact in the Proposed Design WBLCA to show the benefit of reusing materials, while retaining the A1-A3 estimated impacts for these products for these materials in the Baseline Design WBLCA.
Design for Disassembly	Even if DfD is incorporated in the proposed design, default module C and D assumptions in the software tool shall be used for the baseline. The baseline module C and D data may be modified if the project team can provide more representative project-specific or regional data on these modules.	
Design Lighter and Smarter	The baseline shall assume one of the following options to identify the parkade area of the baseline: Option 1. The minimum parking requirements in code. Option 2. The same as the proposed design.	As per the proposed design
Material Efficiency	The baseline may assume a typical structural design, appropriate to the building and functionally equivalent to the proposed design, as determined by the building structural engineer. Where intentional design choices are made that vary from a typical design and result in embodied carbon reduction, those may be reflected in differences between the baseline and the proposed design. Otherwise, both the baseline and proposed design shall have the same structural design assumptions. Examples of these design choices for the structural elements include: Reducing bay sizing and column and beam spacing; Reducing member cross sections; Avoiding	As per the proposed design

	cantilevers and transfer slabs; Reducing rebar and tendons quantities and concrete volume in structural concrete by using post-tensioned concrete slabs; The knock-on effects of lighter structures, e.g., using void systems, timber structural elements, lighter enclosure and façade systems may result in smaller footings and foundations; Allowing for the preservation of an existing structure; Exposing structural materials where possible to avoid finishing.	
Choose Finishes	If included in the embodied carbon of the proposed design, the baseline may assume typical interior finishes, appropriate to the building and functionally equivalent to the proposed design, as determined by the building architect.	As per the proposed design
Minimize C&D Waste	As per the default scenarios in the software tools for modules A5 and C1-C4. The baseline data may be modified, if the tool allows it, and if the project team can provide more representative project-specific, city-wide, or regional waste management data.	As per the proposed design
Low Carbon Alternatives	The baseline structure and enclosure assemblies and materials shall reflect local typical practice for the building type and application. The project team should use their professional judgment to specify the local common practice for the building archetype and application.	As per the proposed design
Lower Carbon Products	The baseline shall use the industry-wide EPD available for a material or product, using the most recent version of the CLF Baselines Report (See Appendix A.1 (d) (i)). The most local EPD shall be selected, by order of priority: BC, Canada, and North America.	As per the proposed design
Lower Carbon Construction	For transportation to site and construction site emissions, the baseline shall be as per the default scenarios in the software tool for modules A4 and A5. The embodied carbon emissions from construction sites (A5) tend to be underreported in the software tools. If the project team intends to claim embodied carbon reduction from the construction site, the user may replace the default values in the tool for the baseline with more comprehensive data that the project team may have from comparable recent projects.	As per the proposed design
Select Carbon-Storing Materials	If reported for the proposed design, the baseline shall also report biogenic carbon. The results shall be reported separately and shall not be included in the demonstration of compliance.	Out of Scope

5.3.4 WBLCA Model Language

This section provides a preview of the WBLCA language for incorporating into Washington's building code. A discussion of where to locate this in the IBC code is provided in section 3.4. Full recommended code language – including new definitions, referenced standards, compliance requirements, and the applicability threshold – is provided in the full code language in section 7.1.

Add new text as follows:

X01 Whole building life cycle assessment (WBLCA). Whole Building Life Cycle Assessments (WBLCAs) performed in accordance with ISO 14040–2006 and ISO 14044–2006 shall be submitted for a project at the following stages:

3) **Issued for Permit Set:** Design WBLCA Submission
4) **Substantial Completion:** As-Built WBLCA Submission

Add one of the following options as follows:

Option A

X01.1 Design WBLCA Submission. The Design WBLCA Submission shall include the *Proposed Design WBLCA* and the *Baseline Design WBLCA* results. The total *Global Warming Potential* of the *Proposed Design WBLCA* shall not exceed 90% of the total *Global Warming Potential* of the *Baseline Design WBLCA*.

X01.2 As-Built WBLCA Submission. The As-Built WBLCA Submission must document the *As-Built WBLCA* of the final project as constructed to the best of the design and construction team's knowledge. Actual purchased quantities and product data, including *Product-Specific Environmental Product Declarations*, should be used to report the total *Global Warming Potential* and *Embodied Carbon Intensity* of the as-built project.

This option is the most similar to the WBLCA pathway incorporated in the CALGreen code updates.

Option B

X01.1 Design WBLCA Submission. The Design WBLCA Submission shall include the *Proposed Design WBLCA* results. The *Proposed Design WBLCA* shall demonstrate an *Embodied Carbon Intensity* (ECI) that is less than the *Building Carbon Budget* of:

- Multifamily (>50,000 ft^2) : 91 $lbCO_2e/ft^2$ (450 $kgCO_2e/m^2$)
- Nonresidential (50,000-200,000 ft^2): 91 $lbCO_2e/ft^2$ (450 $kgCO_2e/m^2$)
- Nonresidential (>200,000 ft^2): 128 $lbCO_2e/ft^2$ (630 $kgCO_2e/m^2$)

X01.2 As-Built WBLCA Submission. The As-Built WBLCA Submission must document the *As-Built WBLCA* of the final project as constructed to the best of the knowledge of the design and construction team. Actual purchased quantities and product data, including *Product-Specific Environmental Product Declarations*, should be used to report the total *Global Warming Potential* and *Embodied Carbon Intensity* of the as-built project.

This option is more likely to produce actual low carbon buildings by emphasizing Embodied Carbon Intensity values, rather than comparing to a relative baseline.

Option C

X01.1 Design WBLCA Submission. The Design WBLCA Submission shall include the *Proposed Design WBLCA* results and the *Baseline Design WBLCA* results. The total *Global Warming Potential* of the Proposed Design WBLCA shall not exceed 90% of the total Global Warming Potential of the Baseline Design WBLCA, or the *Proposed Design WBLCA* shall demonstrate an *Embodied Carbon Intensity* (ECI) that is less than the *Building Carbon Budget* of:

- Multifamily (>50,000 ft^2) : 91 $lbCO_2e/ft^2$ (450 $kgCO_2e/m^2$)
- Nonresidential (50,000-200,000 ft^2): 91 $lbCO_2e/ft^2$ (450 $kgCO_2e/m^2$)
- Nonresidential (>200,000 ft^2): 128 $lbCO_2e/ft^2$ (630 $kgCO_2e/m^2$)

X01.2 As-Built WBLCA Submission. The As-Built WBLCA Submission must document the *As-Built WBLCA* of the final project as constructed to the best of the knowledge of the design and construction team. Actual purchased quantities and product data, including *Product-Specific Environmental Product Declarations*, should be used to report the total *Global Warming Potential* and *Embodied Carbon Intensity* of the as-built project.

This option is recommended based on the analysis provided in this report. This option offers the baseline pathway which allows for a flexible compliance pathway for any and all project types through a method familiar to current LCA practitioners. It also introduces and socializes the concept of a Building Carbon Budget that could offer future avenues for absolute decarbonization in line with Washington state's goals. In the near term, this will also simplify compliance for buildings that easily meet this intensity budget.

Add new text as follows:

X01.3 Software and data quality. Software used to conduct a Whole Building Life Cycle Assessment shall conform to ISO 21931–-2022 and/or EN 15978–2011 and shall have a data set compliant with ISO 14044–2006 and ISO 21930–2017 and/or EN 15804–2012. The software shall utilize a calculation methodology that is compliant with EN 15978–2011, ISO 21931–-2022, and ISO 21929–-2011. The software tools and datasets shall be the same for the evaluation of both the Baseline Design WBLCA and the Proposed Design WBLCA. For ease of comparison, it is recommended that the same tool used in the Design WBLCA Submission be used for the As-Built LCA Submission, to the extent feasible.

X01.4 Life cycle stages. The whole building life cycle assessments shall include all modules in life cycle stages A, B, and C, as defined by EN 15978–2011, except for operating energy and water stages (B6 and B7).

X01.4.1 Reuse and salvage. Existing and salvaged building components shall be included or excluded at the discretion of the project team. For reused materials, it is permissible to assume the A1-A4 stages carry no impact in the Proposed Design WBLCA to show the benefit of reusing materials, while retaining the A1-A4 estimated impacts for these products for these materials in the Baseline Design WBLCA. For salvaged materials, it is permissible to assume the A1-A3 stages carry no impact in the Proposed Design WBLCA to show the benefit of reusing materials, while retaining the A1-A3 estimated impacts for these products for these materials in the Baseline Design WBLCA.

X01.4.2 Biogenic Carbon. Biogenic carbon and carbon sequestration shall be reported separately from fossil GWP.

X01.5 Building elements. The whole building life cycle assessment shall include all of the following building elements: foundations; *exterior wall envelope*; *primary structural frame*; *secondary structural members*; *roof covering*; *roof deck*; *fenestration*; *load-bearing walls*; *non load-bearing walls*; interior constructions and *interior finishes*.

Exception: A whole building life cycle assessment that includes no less than 95 percent of the total mass or volume of building elements.

Exception: A whole building life cycle assessment submitted for an addition, alteration, repair, or substantial improvement may exclude existing and/or remaining building components.

X01.6 Reference study period. The reference study period shall be 60 years.

5.4 Multiple compliance pathway

In California's CALGreen code, the three code pathways described in sections 5.1, 5.2, and 5.3 are in place in parallel. The code is written such that a project team has the option of choosing one of the three pathways for compliance. As discussed in section 5.1 on Building Reuse, this is required to include a building reuse pathway, whereas sections 5.2 and 5.3 could be adopted in isolation.

The code options in the multiple compliance pathway approach would be written such that a team could pursue one of the following options at their discretion:

- **Reuse Pathway (section 5.1)**. The project must reuse >45% of existing elements.
- **Material Carbon Caps Pathway (section 5.2).** The project must provide EPDs that have GWPs that are no more than 90% of the Covered Product GWP values.
- **WBLCA Pathway (section 5.3).** The Global Warming Potential of the Proposed Design WBLCA shall not exceed 90% of the total Global Warming Potential of the Baseline Design WBLCA, or the Proposed Design WBLCA shall not exceed the Building Carbon Budget as noted.

This combined approach offers the greatest flexibility for project teams to select an option that works for the project. The full recommendation and model code language showing this combined multiple compliance pathway is provided in section 7.

5.5 Enforcement Considerations

The Washington State Building Code Act requires that each local jurisdiction enforce the State Building Code within its jurisdiction. Thus, the responsibility to review plan submittals and perform on-site verifications would fall to each jurisdiction. Plan review comments and adequate construction administration to oversee installation of materials hold the most promise for enforcing embodied carbon measures in code.

5.5.1 Enforcement Strategies at Permitting Phase

Most existing embodied carbon programs practice enforcement at the permitting phase. For all three code-based approaches discussed – reuse of existing buildings, material carbon caps, and WBLCA – enforcement strategies involve reviewing submitted documentation. EPDs play a critical role in the material carbon caps approach and require review by building officials to ensure compliance. For WBLCA, engaging project teams to steward the LCA process is key, with early enforcement methods placing the burden of proof on the registered design professional, and later on phasing in audits by the enforcing agency. For building reuse, enforcement is focused on quantifying the percentage of a building that is preserved.

Documents would be reviewed during permitting. In cases in which plan examiners deem submissions to be out of compliance, they would issue comments prior to permit approval and Responsible Designers (the professional responsible for reviewing and coordinating aspects of the project and determining compliance with the code's submittal requirements) must then respond to the comments and make the requested corrections to the permit set before submitting them again to their building department (California Building Standards Commission, 2024).

5.5.2 Enforcement Strategies at Construction and Inspection Phases

On-site verification during the inspection is limited for embodied carbon measures. Washington could consider allocating responsibility to jurisdictions to perform verifications of compliance with plans that attest to the use of reported material products and check the accuracy of submitted embodied carbon calculations. Submitting these verifications would be a requirement for obtaining a Certificate of Occupancy.

However, few precedents exist where mandatory embodied carbon programs require the verification of product installation of lower embodied carbon projects on-site. One relevant example of note on the residential side is the guidelines for verification outlined by RESNET/ICC 1550, a standard currently under development that will provide a methodology for calculating and reporting embodied carbon of the product life cycle stages of a project. The intent is for Home Energy Rating System (HERS) raters – who conduct energy assessments of buildings on site – to integrate this new embodied carbon assessment into their existing energy rating processes. This will ultimately streamline the verification process. At present, whether these inspections will be required by the standard or provided as a compliance option is yet to be determined.

Existing embodied carbon measures do not include penalties. However, a fine could be included. For example, the City of Seattle's Living Building Pilot Program also utilizes penalties for failure to comply with requirements around gaining incentives related to such elements as Floor Area Ratio (FAR) and height bonuses, which cannot be feasibly undone once construction is completed. The Living Building Pilot Program grants projects additional height and FAR bonuses, as well as exemptions from Seattle Land Use Code provisions, in exchange for adhering to the Living Building Challenge, a green building certification program administered by the International Living Future Institute (Seattle Department of Construction & Inspections, n.d.). Projects that receive these bonuses but fail to comply with ILFI's standards are subject to penalties of up to 5 percent of the construction value of the project (City of Seattle, n.d.). Additionally, failure to submit required reporting can result in fines of $500 per day from when the reporting was due.

In summary, incorporating verification processes into existing inspection visits and other job duties of inspectors and agency staff is an expeditious strategy. Alternatively, if as-built inspections and verification are deemed infeasible, requiring an independent review of submissions could be considered. This would include an assessment of submitted calculations, methodology, and data quality.

Requirements for remediation, while sensible for materials that actively harm the environment post-installation, are less suitable for enforcement focused on embodied carbon. Asking for large materials to be replaced is infeasible due to the high cost, effort, and further would entirely counteract the emissions reductions goals of the embodied carbon measures: most of the upfront embodied carbon associated with their installation would already be spent by the time of inspection. The impacts of removing materials that have already spent the energy and carbon used for their production and construction would be counterproductive, and the reconstruction required could double embodied emissions.

However, a similar system of fines shown by the D.C., Austin, and Seattle examples – which include retroactive fines – could be instituted to deter project teams from non-compliance by changing their reported materials down the line.

5.6 Additional Code Options

Codes indirectly increase or reduce embodied carbon through the construction practices and materials that they allow or ban. For example, the current Washington State building code includes several measures that indirectly reduce embodied carbon in buildings. These measures include but are not limited to:

1. Advanced Framing (Building Code Section 2308.5) - Advanced framing as defined by the Building Code allows for wood stud frame walls to be constructed with 2x6 studs framed on 24-inch centers, rather than the standard 2x4 studs framed on 16-inch centers that is most common in building codes throughout the country. This framing technique can significantly reduce the amount of wood needed to construct the walls of a building, thereby reducing the embodied carbon footprint of construction (APA, n.d.).
2. Material reuse and recycling (2021 WA IBC - Appendix P and 2021 WA IRC Appendix AWY) - These appendices require Washington building owners to complete a salvage assessment on building projects before a permit is issued. Embodied carbon reductions are achieved by increasing the reuse and recycling of construction and demolition materials in new construction, renovation, or demolition projects that are over 750 square feet or valued at greater than $75,000.
3. Allowance of A2L refrigerants (Mechanical Code Section 1103.1) - A2L refrigerants consist mainly of hydrofluoroolefins (HFOs), which significantly reduce the atmospheric lifetime/persistence and GWP of these refrigerants, relative to conventional refrigerants.
4. Allowance of natural refrigerants (Mechanical Code Section 1103.1) - Although natural refrigerants such as CO2 and propane with relatively lower GWP compared to conventional refrigerants are only currently allowed in small amounts (4.5 and 0.56 pounds per 1,000 cubic feet of occupied space, respectively), Washington could increase this limit for greater EC reductions. This topic is covered in greater detail in section 5.6.
5. Allowance of Air Admittance Valves (AAVs) (Residential Code Chapter 31) - AAVs reduce the amount of plumbing pipe runs required in construction and also potentially increase the durability of enclosure materials by creating fewer roof penetrations, potentially reducing the need for replacement materials in the future.

As part of this study, the research team gathered insight from industry members on other embodied carbon strategies that could inform the development of future code approaches as a complement to the measures described in section 5.1, 5.2, and 5.3. This section summarizes interviews conducted with 10 different firms that work on Washington-based building projects. The interviewees included architects, contractors, structural engineers, MEP engineers, and one code consultant. Through these interviews, the research team gained valuable insights into three different categories of actions to reduce embodied carbon in Washington's building codes. These insights were grouped into potential near-term measures, measures requiring additional research, and considerations for a best practice credit system.

5.6.1 Potential near-term measures

These measures, identified through interviews with Washington state construction professionals, are possible in the near-term using available code appendices and/or 2024 code proposals:

1. Adopt Appendix C of the Uniform Plumbing Code directly into the base code.
    a. Single-stack plumbing can reduce vent piping material quantities and thereby reduce the embodied carbon of plumbing systems. The system is currently allowed in WA State Uniform Plumbing Code Appendix C but requires discretionary approval from individual authorities having jurisdiction. Adopting this appendix into the base code would help promote a plumbing design practice that can reduce piping, embodied carbon, and cost.
2. Adopt Appendix M of the Uniform Plumbing Code directly into the base code:
    a. Appendix M (Peak Water Demand Calculator) prescribes a method for sizing water pipes based on the calculated water demand in single and multifamily dwellings with water-conserving plumbing fixtures. Pipe size and service may be downsized based on the prevalence of low-flow fixtures installed in today's newly constructed buildings. The performance-based sizing allowances in this appendix may reduce pipe size due to system design and have the potential to use less material and reduce embodied carbon. The use of this Appendix requires discretionary approval from individual authorities having jurisdiction and adoption into the base code would streamline the use of these practices.
3. Adopt Appendix P of the WA State amendments to the IBC directly into the base code:
    a. Appendix P covers construction and demolition material management and includes provisions for separate containers for non-recyclable material, salvage assessments, and a waste diversion report. All three of these measures help reduce embodied carbon through more efficient recycling, identification of materials that can be reused, and reporting and accountability of waste diversion. The use of this Appendix requires discretionary approval from individual authorities having jurisdiction and adoption into the base code would streamline the use of these practices.
4. Allow the use of larger quantities of A3 natural refrigerants like propane (R-290).
    a. This action would complement the recent Washington Department of Ecology (2024b) phased restrictions on refrigerants with a GWP over 750. US EPA restrictions on refrigerants used in building HVAC equipment have a similar 700 GWP limit and phase-out schedule (US EPA, 2023). Existing regulation in the U.S. only permits 114g (0.3lb) of propane in fixed or non-fixed heat pumps and AC units (including outdoors) (Garry, 2023). ASHRAE has approved an amendment to its 15-2022 Safety Standard for Refrigeration Systems in Residential Applications to allow up to 4.9kg (10.9lbs) of flammable (A3) refrigerants like propane (R290) in outdoor or machinery room heat pumps and air conditioners.
    b. There are numerous pathways to allowing larger quantities of A3 refrigerants in mechanical code. The 2024 WA code proposal "IMC Chapter 11 and ASHRAE 15: A3 and B3 Refrigerants" to the International Mechanical Code (IMC) being considered by the state building code council would use language from ASHRAE 15-2022, which has standards for refrigeration systems to allow for A3 and B3 refrigerants to be installed outdoors or in machinery rooms. Another 2024

proposal "[IMC Chapter 11 and CE Certification]" would allow for products meeting European standard IEC 60335-2-40 for testing to be used in WA State. This would allow A3 heat pump equipment that is already being installed in Europe to be used here.

5.6.2 Measures requiring additional research

These measures, identified through interviews with Washington state construction professionals, require additional research but provide opportunities for embodied carbon reductions in Washington codes:

1. Review the National Electrical Code (NEC) to reduce overbuild. Interviewees reported the high costs of electrification and that many electrical systems are overbuilt. In this case, overbuilt refers to an excess of wiring, conduit, switchgear, and breakers that have contributed to approximately 35% excess capacity on some buildings - contributing to increased embodied carbon and cost. The recommendation is to conduct a more detailed review of the NEC with electrical engineers and contractors to identify areas where fewer materials could be used without sacrificing the performance or reliability of electrical systems. In general, the contribution of electrical systems to a building's embodied carbon is evolving as more data and studies are conducted. However, early studies of MEP systems show that they can contribute significantly to embodied carbon over the lifecycle of a building when repair and replacements are considered (Rodriguez et al, 2020).
2. Performance-based structural design is currently allowed in the WA IBC code but the evaluation against the code intent and equivalency criteria can be cumbersome and vague. More detailed guidelines on how to demonstrate equivalency with the criteria in IBC section 104.2.3.4 would help facilitate performance-based structural designs that reduce embodied carbon.
3. PAE Engineers (2020) conducted a study for the City of Seattle and concluded that refrigerant leakage is primarily associated with field-constructed joints for systems like variable refrigerant flow (VRF) or mini-split heat pumps. These systems have long piping runs that are field assembled and convey significant volumes of refrigerants around the building. Additionally, it can be difficult to identify and repair leaks when extensive refrigerant piping is utilized. The study found that systems that contain refrigerants within packaged units (sealed at the factory) significantly reduce the volume and risk of refrigerant leakage. Typically, these sealed systems are associated with hydronic heating and cooling systems, which are less commonly installed in the Seattle building stock. The study found that compression and flared fitting were more prone to leaking. However, another study found that compression and flare fitting had noticeably lower leak rates compared to press fittings when properly installed and tightened, which shows that installer training is an important factor (Lawrence et al., 2020). Braised fittings are considered the most durable and leak-resistant but also require more training, skill, time, and cost to install. Additionally, as Washington state transitions to lower GWP refrigerants that have higher flammability ratings, preventing leaks becomes even more important. A deeper dive research project could evaluate which (if any) pipe fitting should be restricted in code.
4. HB 2071 (2024) directs the WA SBCC to adopt code amendments to apply the international residential code (IRC) to the construction of up to 6 residential units with shared walls within one structure. The IRC is currently limited to 1-2 single dwelling structures in WA. The bill has the intention of lower housing costs. Some of those costs may be associated with using fewer materials and may deserve further study to determine the embodied carbon savings from this code change. As the SBCC convenes the technical advisory group (TAG) to study this issue later this year, embodied carbon could be added to the evaluation to the scope of the committee work.

5.6.3 Best practice credit system

Existing codes in the United States require a credit-based system for specific measures. For example, the 2021 Washington Energy Code codes for commercial and residential buildings require energy efficiency credits according to building type and/or size. These systems provide a menu of options for pursuing energy efficiency in buildings and allow the permittee to pursue whichever "best practices" they deem most appropriate for their projects. There are also examples of energy codes that provide embodied carbon reduction credits within the menu options for permittees. Specifically, the City of Boulder (2024) *Energy Conservation Code* and the State of Vermont (2023) Commercial Building Energy Standards Amendments both offer a variety of embodied carbon reduction options as voluntary pathways towards credit obligations in the energy code.

The interviews with firms that work on Washington-based buildings revealed a variety of practices to reduce embodied carbon in the design and construction of buildings. Many of these practices are currently allowed by building code but are not frequently utilized or have some barriers to implementation. Grouping practices into a credit-based system in Washington building codes could increase uptake of best practices without requiring analysis or uptake of specific practices, providing an approachable and flexible approach for projects of all types. Best practices could be grouped in individual code sections or collectively in energy code like the examples cited in Colorado and Vermont. In either approach, embodied carbon reduction credits would be incorporated into a menu of credit options to pursue for the permittee.

The practices below were gathered from direct interviews and some supplemental research. In order to group and evaluate the relative embodied carbon reduction of each of these practices, we recommend additional research and evaluation to develop a credit-based system for these best practices. Once evaluated, they could serve as a menu of options for individual codes or collectively through the energy code like other jurisdictions have pursued. Many of these practices would be captured in the reductions reported by a WBLCA, per section 5.3 above. If a credit system is pursued, the practice of conducting a WBLCA could be a credit pathway as well.

Table 5-12. Example practices for a best practice credit system / menu of options approach grouped by code category.
Note: These practices were primarily gathered from direct interviews with WA construction professionals. Additional research is required to evaluate the relative reduction potential of each practice if a credit-based system were developed.

Code	Example practices
Structural (WA IBC)	● Limiting load transfers and cantilevers ● Designing for assembly area live loads only where needed ● Limiting building on poor soils ● Use of high-strength materials (specifically concrete and steel) ● Reuse of 45% or more of the existing foundation and superstructure (as outlined in section 5.1) ● Using lower GWP materials compared to industry-wide GWP (as outlined in section 5.2) ● Conducting a WBLCA (as outlined in section 5.3) ● Use of a single stairwell egress (which is currently being studied by the WA Building Code Council) ● Using advanced wall framing - studs 24 inches on center instead of 16 inches (residential and commercial code) ● Reporting of material quantities
Mechanical (WA IMC)	● Use of hydronic systems instead of VRF systems

	● Use of specific pipe fittings to reduce refrigerant leakage ● Use of refrigerants below XYZ GWP value ● Downsizing mechanical through passive envelope design ● Use of pressure-independent control valves to reduce return piping length ● Use of fabric and gypsum ducting instead of sheet metal ducts ● Use of prefabricated ducting to reduce onsite fabrication waste ● Use of dedicated Outdoor Air Systems (DOAS) ● Use of plenum returns instead of ducted returns ● Use of radiant heating and cooling to reduce material use ● Use of lower GWP piping material where allowed ● Alter the designed “comfort” expectations for the mechanical system ● Reporting of refrigerant volume/building area ● Reporting of material quantities
Electrical (WA NEC)	● Use of wireless controls to reduce wiring ● Use of power over ethernet (POE) lighting and controls to reduce wiring ● Use of DC wiring for buildings to reduce costs, wiring and increase integration of renewables ● Reporting of material quantities
Plumbing (WA UPC)	● Utilize single-stack drainage and venting systems to reduce piping ● Utilize air admittance valves (AAVs) to reduce piping ● Use of lower GWP piping material where allowed ● Downsize piping based on water demand piping size calculations ● Reporting of material quantities
Energy (WA IECC and IRC)	● Window to wall ratio of “XY”. Lower window-to-wall ratio since wall systems are typically lower embodied carbon and more insulative than glazing (this could also be a direct code change measure)
Waste/material/other measures	● Design for disassembly ● Use of XYZ (%/mass/volume) of salvaged materials ● Use of XYZ (%/mass/volume) of carbon-storing materials that have a service life longer than their plant growth cycle ● Small building design below XYZ sqft ● Source separate of onsite construction/demolition waste to facilitate reuse and recycling ● Conduct a deconstruction audit

6. Implementation Considerations

6.1. Analysis of Number of Affected Buildings in Washington

The embodied carbon reduction measures proposed in this study would affect buildings over a given floor area threshold (e.g. 50,000 square feet). Larger buildings benefit from economies of scale which make the administrative and design burdens associated with embodied carbon reduction less onerous than they might be for smaller buildings.

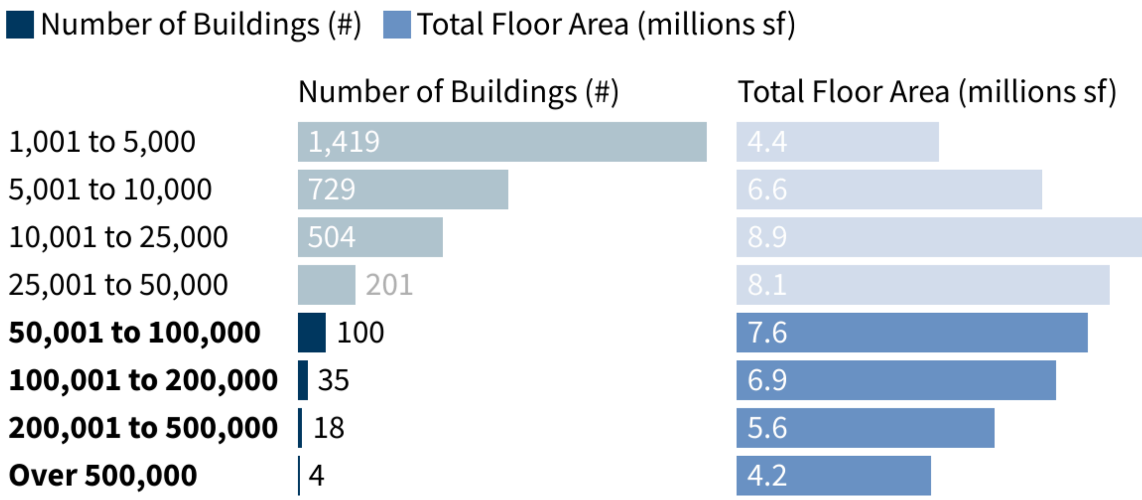
For the commercial building sector, large buildings (over 50,000 sf) make up roughly half of the commercial floor area nationally. Reducing the embodied carbon impact of these buildings is therefore likely to have an outsized embodied carbon reduction impact with minimal administrative and cost burden.

For the residential building sector, the vast majority of floor area in the US is made up of detached single-family homes. However, roughly 3-4 percent of residential floor area is attributed to multifamily buildings over 50,000 square feet. Such buildings make up as little as 0.05% of buildings built annually. Targeting large residential buildings can make a modest impact on total residential embodied carbon with minimal administrative and cost burden. The numbers and total areas of new commercial and residential buildings affected by the proposed code measures are discussed below.

6.1.1. Commercial Buildings

Figure 6-1 illustrates the estimated number of new commercial buildings in Washington state that are likely to be affected by the proposed embodied carbon code measures. A total of roughly 160 buildings and 24 million square feet of commercial floor space are likely to be impacted per year initially. This amounts to roughly 5% of newly constructed buildings, but as much as 45% of newly constructed commercial floor area. This suggests that this floor area threshold can achieve substantial embodied carbon reduction impacts while limiting the number of building projects that will need to alter their design, procurement, and construction practices.

If construction rates increase over time, or if the proportion of large buildings increases, the number of buildings and floor areas impacted by code measures will increase. Future updates to code measures that reduce floor area thresholds will result in more buildings being affected.

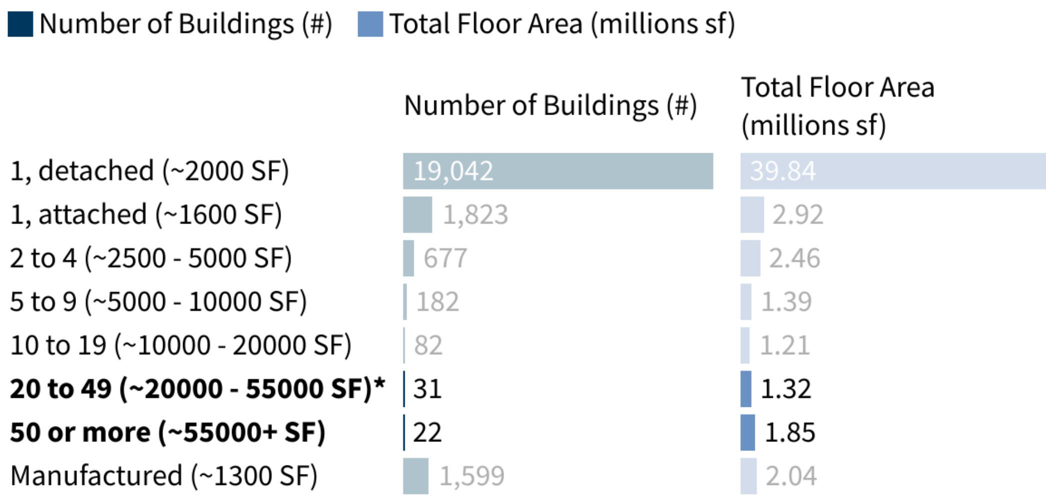


Construction rates for 2025 were estimated using US Energy Information Administration (EIA) Annual Energy Outlook 2023 projections. Number of buildings and floor area breakdowns were estimated using EIA Commercial Building Energy Consumption Survey 2019 data. National and regional quantities were scaled to Washington level on a population basis.

Figure 6-1. Estimated number and size of commercial buildings in Washington state affected by proposed embodied carbon code measures in 2025, grouped by floor area in square feet. Buildings greater than 50,000 square feet are highlighted, as they are proposed to be affected by the code measures recommended in this study. *Source: RMI/CLF Analysis using Energy Information Administration (EIA) data. Spreadsheet with detailed calculations and methodology available upon request.*

6.1.2. Residential Buildings

Figure 6-2 illustrates the number of total floor area of new residential buildings impacted by the proposed embodied carbon measures in 2025. Approximately 26 buildings, with a total estimated floor area of roughly 2 million square feet are likely to be affected. This amounts to roughly 0.1% of new buildings and 3.5% of new building floor area affected. If the proportion of dwelling units built in large multifamily buildings (50 units or more) increases in the future (Zahalak, 2022), more buildings are likely to be subject to the proposed code measures.



*Construction rates for 2025 were estimated using US Energy Information Administration (EIA) Annual Energy Outlook 2023 projections. Number of buildings and floor area breakdowns were estimated using American Housing Survey 2023 data. National and regional quantities were scaled to Washington level on a population basis. *Assuming an even distribution of floor areas within the 20-49 unit category, 14% of buildings in this category have a floor area of greater than 50,000 square feet.*

Figure 6-2. Estimated number and size of new residential buildings in Washington state affected by proposed embodied carbon code measures in 2025, grouped by floor area in square feet. Buildings with more than 50 units are highlighted, as they are likely to be affected by the proposed code measures. Source: RMI/CLF Analysis using EIA and American Housing Survey (AHS) 2023 data. Spreadsheet with detailed calculations and methodology available upon request.

6.1.3. Floor Area Thresholds Sensitivity Analysis

Table 6-1 illustrates the number and floor areas of commercial and residential buildings impacted by the proposed embodied carbon code measures at various floor area thresholds. Increasing the floor area threshold to 100,000 square feet reduces the number of commercial buildings impacted by over a factor of two, while only reducing the commercial floor area affected by about 25%. This suggests that this higher threshold still offers substantial embodied carbon savings while greatly reducing the administrative design burden. Regardless of whether a threshold of 50,000, 75,000, or 100,000 square feet is chosen, at least roughly a third of the commercial floor area will be affected.

The US Census Bureau does not report the distribution of residential building floor areas over 50 units in size. As an estimate, Table 6-1 illustrates the number of buildings and floor area affected by the proposed measures assuming that 50% of new residential buildings with more than 50 units are less than 75,000 square feet, and 75% are less than 100,000 square feet. Regardless of the floor area threshold selected, residential embodied carbon reductions are likely to be modest, given the small proportion of anticipated new US residential building stock which is greater than 50,000 square feet. Concerning code enforcement and administration, the fixed administrative costs associated with reviewing code submittals detailing embodied carbon reduction measures suggest that a threshold of 50,000 square feet would provide greater embodied carbon reductions than higher floor area thresholds while incurring relatively little additional administrative burden.

Table 6-1: Estimated annual number of new buildings and total floor area built (shown for 2025) affected by proposed embodied carbon code measures at 25,000, 50,000, 75,000, and 100,000 square feet thresholds. Percents are of total annual new construction. *Source: RMI analysis.*

Floor Area Threshold (SF)	Number of Commercial Buildings	%	Commercial Floor Area (million SF)	%	Number of Residential Buildings	%	Residential Floor Area (millions SF)	%
25,000	357	11.9%	32.4	62%	49	0.21%	2.98	5.6%
50,000	156	5.2%	24	46%	26	0.09%	2.04	3.5%
75,000	106	3.5%	20	39%	11	0.05%	0.9	1.7%
100,000	56	1.9%	17	32%	5	0.02%	0.4	0.8%

6.2 Emissions Reduction Potential

This section provides emissions reduction estimates of the proposed code pathways introduced in sections 5.1, 5.2, and 5.3. Modeling results are presented first, followed by the modeling scope and approach, as follows:

- Emissions reduction results (section 6.2.1);
- Modeling scope (section 6.2.2); and
- Modeling approach (section 6.2.3).

This section also explores possible outcomes of how the reuse, material carbon caps, and WBLCA code pathways could work in combination, and how phasing in greater stringency in the codes over time might influence the results.

6.2.1 Modeling Results

A baseline scenario and sixteen additional scenarios were modeled to explore the emissions reduction potential of the pathways described in section 5.1, 5.2, and 5.3. Results in this section are reported in terms of cumulative emissions reductions between 2025-2050 in terms of million metric tons of carbon dioxide equivalents (CO_2e).

Table 6-2 summarizes the seventeen modeled scenarios and potential cumulative carbon savings for 2025-2050. The embodied carbon measures with the largest reduction potential (based on analyzed scenarios) are a WBLCA pathway requiring 20% or higher reduction from a baseline (or similar building carbon budget measures) or a multiple compliance pathway (material carbon caps, reuse, and WBLCA) with greater uptake on WBLCA and material carbon caps over time.

Table 6-2: Summary of cumulative carbon savings for 2025-2050 (million mtCO2e) for each modeled scenario. Note that the percent reduction requirements in the “Requirement” columns are larger than the “% reduction from baseline scenario” column because the latter takes into account the portion of affected buildings. *BCB refers to the building carbon budget scenarios outlined in Table 6-4.

Scenario	Description	Requirement	Cumulative Carbon Saved 2020-2050 (million mtCO2e)	Estimated % reduction from baseline scenario
Baseline	Baseline		0	NA
Independent material carbon caps (M) and WBLCA (W) pathway scenarios				
M.1	Material Carbon Cap 1	Industry average	0	0%
M.2	Material Carbon Cap 2	10% reduction	2	5%
M.3	Material Carbon Cap 3	15% reduction	3	8%
M.4	Material Carbon Cap 4	20% reduction	4	10%
M.5	Material Carbon Caps Phasing Over Time	2025 - M.1, 2030 - M.2, 2035 - M.3, 2040 - M.4	2	7%
W.1	WBLCA C1	10% reduction OR BCB.1*	4	10%
W.2	**WBLCA C2**	**20% OR BCB.2***	**7**	**20%**
W.3	**WBLCA C3**	**30% OR BCB.3***	**11**	**30%**
W.4	**WBLCA Over Time**	**2025 - W.1, 2035 - W.2, 2045 - W.3**	**6**	**18%**
Multiple compliance pathways (P) scenarios				
P.1	Equal Uptake	33%-33%-33%	4	10%
P.2	Favoring Material Cap	20%-60%-20%	2	7%
P.3	WB and Caps Dominate	10%-45%-45%	3	7%
P.4	Equal Uptake Over Time	33%-33%-33%	5	13%
P.5	Favoring Material Cap Over Time	20%-60%-20%	3	9%
P.6	WB and Caps Dominate Over Time	10%-45%-45%	4	12%
P.7	**MCP and then WBLCA**	**2025 - MCP Equal Uptake, 2035 -80% W.4, 20% R**	**6**	**16%**

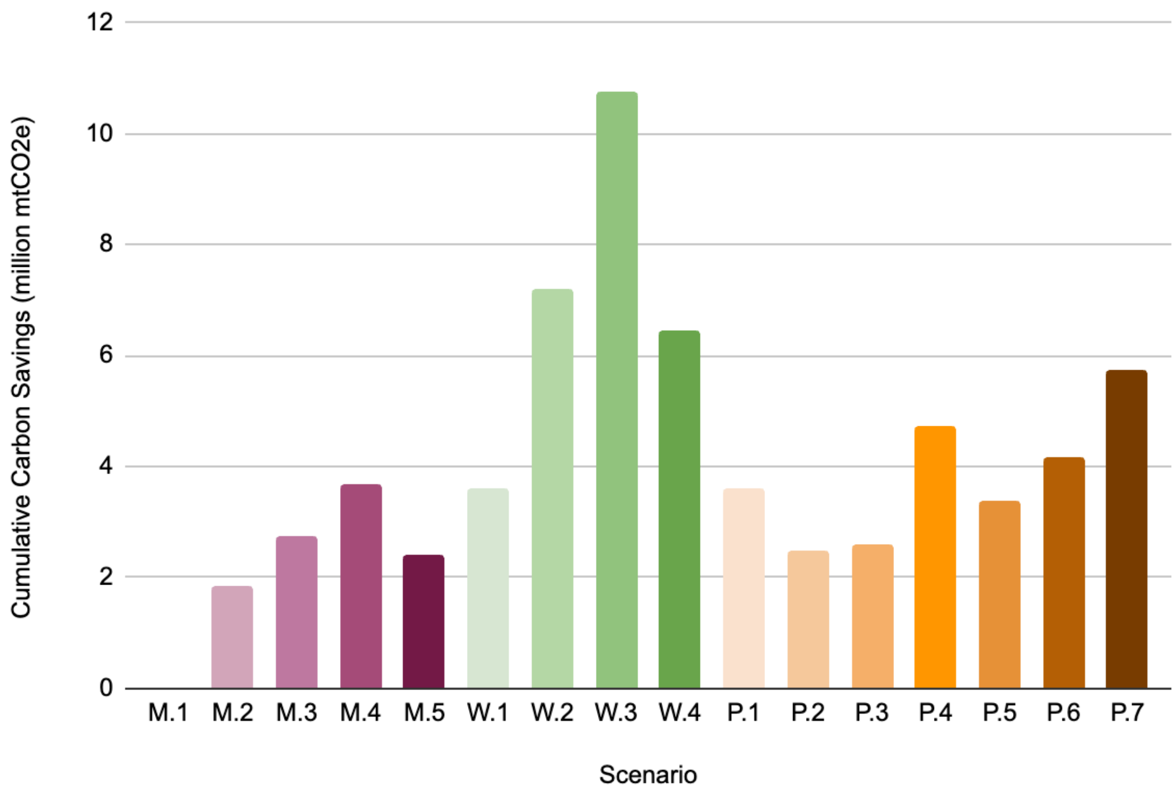


Figure 6-3. Cumulative Emissions Reductions of All Pathways between 2025-2050. The largest reduction potentials are from WBLCA scenarios W.3 (30% reduction or BCB.3) and W.2 (20% reduction or BCB.2) and the multiple compliance pathway scenario P.7, (equal uptake of reuse, phased material carbon caps, and phased WBLCA reductions until 2035, and then 20% reuse and 80% WBLCA uptake 2035-2050).

6.2.1.1 Emissions Reduction Potential of Independent Pathways

Figure 6-4 shows the potential cumulative emissions reductions from the material carbon caps and WBLCA pathways if they were implemented independently between 2025 and 2050.

The options modeled for the material carbon caps pathways are as follows:

- **Scenario M.1 -** GWP of total mass or volume no more than 100% of the equivalent mass or volume of the using the covered product GWP values.
- **Scenario M.2 (PRIMARY) -** GWP of total mass or volume no more than 90% of the equivalent mass or volume of the using the covered product GWP values.
- **Scenario M.3 -** GWP of total mass or volume no more than 85% of the equivalent mass or volume of the using the covered product GWP values.
- **Scenario M.4 -** GWP of total mass or volume no more than 80% of the equivalent mass or volume of the using the covered product GWP values.
- **Scenario M.5** - Material Cap Over Time assumes that the above criteria phase in over time, coming into effect in the following years:
    - 2025 - M.1

   - 2030 - M.2
   - 2035 - M.3
   - 2040 - M.4

The options modeled for the WBLCA pathways are as follows:

- **Scenario W.1 (PRIMARY) -** The Global Warming Potential of the Proposed Design WBLCA shall not exceed 90% of the total Global Warming Potential of the Baseline Design WBLCA, or the Proposed Design WBLCA shall not exceed the applicable Building Carbon Budget (BCB.1).
- **Scenario W.2 -** The Global Warming Potential of the Proposed Design WBLCA shall not exceed 80% of the total Global Warming Potential of the Baseline Design WBLCA, or the Proposed Design WBLCA shall not exceed the applicable Building Carbon Budget (BCB.2).
- **Scenario W.3 -** The Global Warming Potential of the Proposed Design WBLCA shall not exceed 70% of the total Global Warming Potential of the Baseline Design WBLCA, or the Proposed Design WBLCA shall not exceed the applicable Building Carbon Budget (BCB.3).
- **Scenario W.4** - WBLCA Over Time assumes that the above criteria phase in over time, coming into effect in the following years:
  - 2025 - W.1
  - 2035 - W.2
  - 2045 - W.3

Reuse was not modeled independently because that pathway inherently relies on relieving projects from the requirements of the other two pathways in order to be incorporated into code.

The independent pathway that shows the greatest overall reduction potential is the W.3 pathway, a consistent 30% reduction requirement in the covered scope of the building. All the WBLCA pathways yield a larger emissions reduction than the material carbon caps pathways. This is due to the fact that the requirements apply to a larger scope of the building (i.e. all of the structure and enclosure, rather than only a subset of materials). For example, a 10% reduction in GWP across an entire building will naturally result in a larger reduction than a 10% reduction in GWP across only one material within that building.

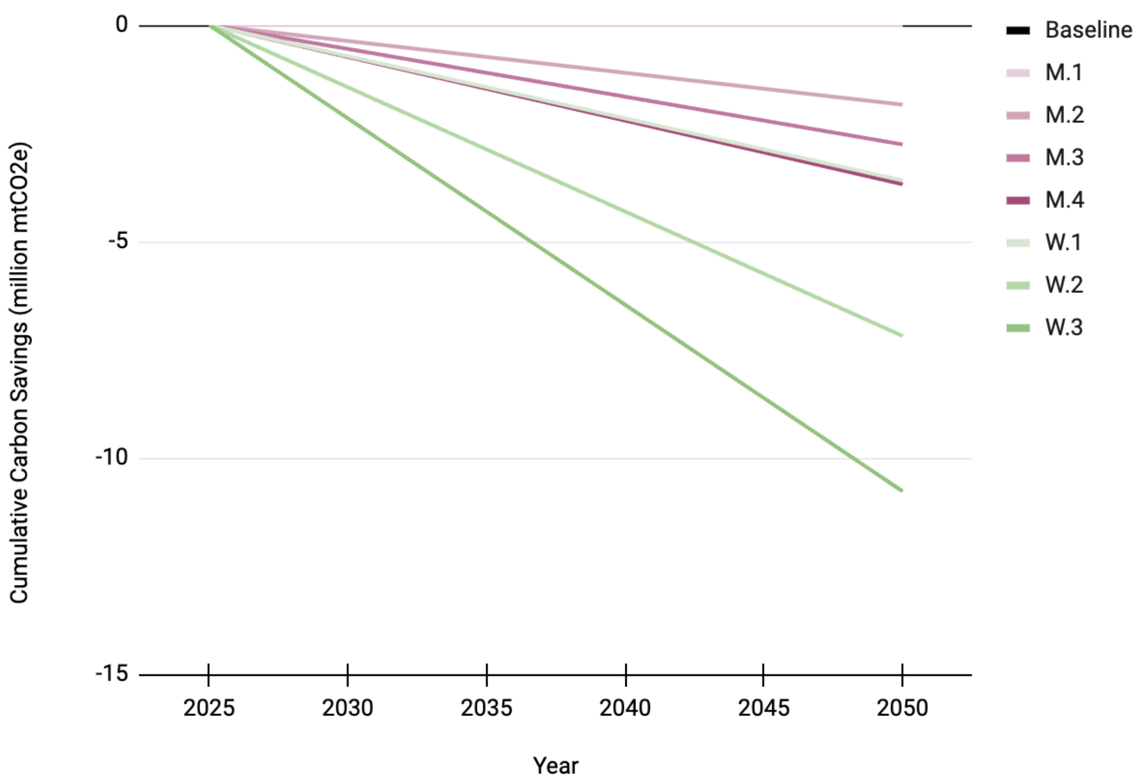


Figure 6-4. Material Carbon Caps and WBLCA Pathways, modeled independently. Material carbon caps scenarios include M.1 (no required reductions - industry average), M.2 (10% reduction from industry average), M.3 (15% reduction), M.4 (20% reduction), and M.5 (phasing in M.1-M.4 over time between 2025 and 20240). WBLCA scenarios include W.1 (10% reduction from a baseline or BCB.1*), W.2 (20% reduction or BCB.2), W.3 (30% reduction or BCB.3), or W.4 (phasing in W.1-W.3 over time from 2025-2045).

6.2.1.2 Emissions reduction potential of multiple compliance pathway

Figure 6-5 shows the potential emissions reductions from the three pathways if they were implemented in parallel as a combined pathway between 2025 and 2050. The three options represent different possible outcomes on uptake of the different primary pathways (M.2, W.1, and reuse depending on uptake proportion):

- Scenario P.1 - Equal uptake: assumes projects pursue each code option equally, with a ratio of 1:1:1 (reuse : material carbon caps : WBLCA).
- Scenario P.2 - Favoring material carbon caps: assumes projects pursue the material carbon caps option most often, with a ratio of 1:3:1.
- Scenario P.3 - WBLCA and material carbon caps dominate: assumes projects pursue the material carbon caps and WBLCA options most often, with a ratio of 10:45:45

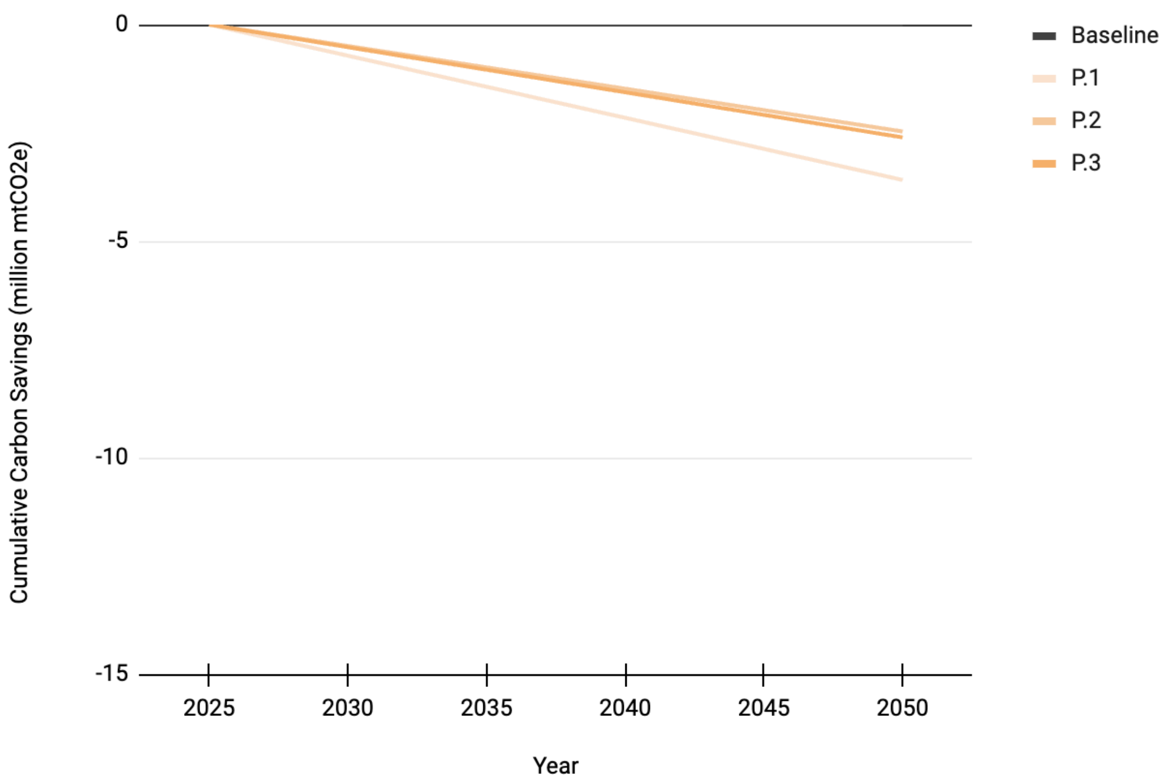


Figure 6-5. Multiple compliance pathways (P.1, P.2, P.3) combining reuse (R), material carbon caps (M), and WBLCA (W). P.3 offers the greatest reduction potential.

6.2.1.3 Emissions Reduction Potential of Change Over Time Pathways

The figure below shows the potential emissions reductions from the three pathways if they were implemented as both independent and combined pathways and ramped up over time between 2025 and 2050. See section 6.2.3 for additional discussion of each scenario.

- Scenario M.5 assumes the material carbon caps ramping up over time, from M.1-M.4 (see 6.2.1.1)
- Scenario W.4 assumes the WBLCA requirements ramping up over time from W.1-W.3 (see 6.2.1.1)
- Scenario P.4 - Equal Uptake: assumes projects pursue each code option equally, with a ratio of 1:1:1
- Scenario P.5 - Favoring Material Cap: assumes projects pursue the material carbon caps option most often, with a ratio of 1:3:1
- Scenario P.6 - WB and Caps Dominate: assumes projects pursue the material carbon caps and WBLCA options most often, with a ratio of 10:45:45
- Scenario P.7 - MCP towards WBLCA: assumes a multiple compliance pathway where all projects pursue all three scenarios (1:1:1) equally until 2035, and then the material carbon caps pathway is omitted, and a ratio of 20:80 (Reuse: WBLCA) is assumed for the rest of the period until 2050

The option that offers the most carbon savings is the WBLCA pathway independently, ramping up over time, followed by the multiple compliance pathway if the WBLCA and material carbon caps dominate the uptake.

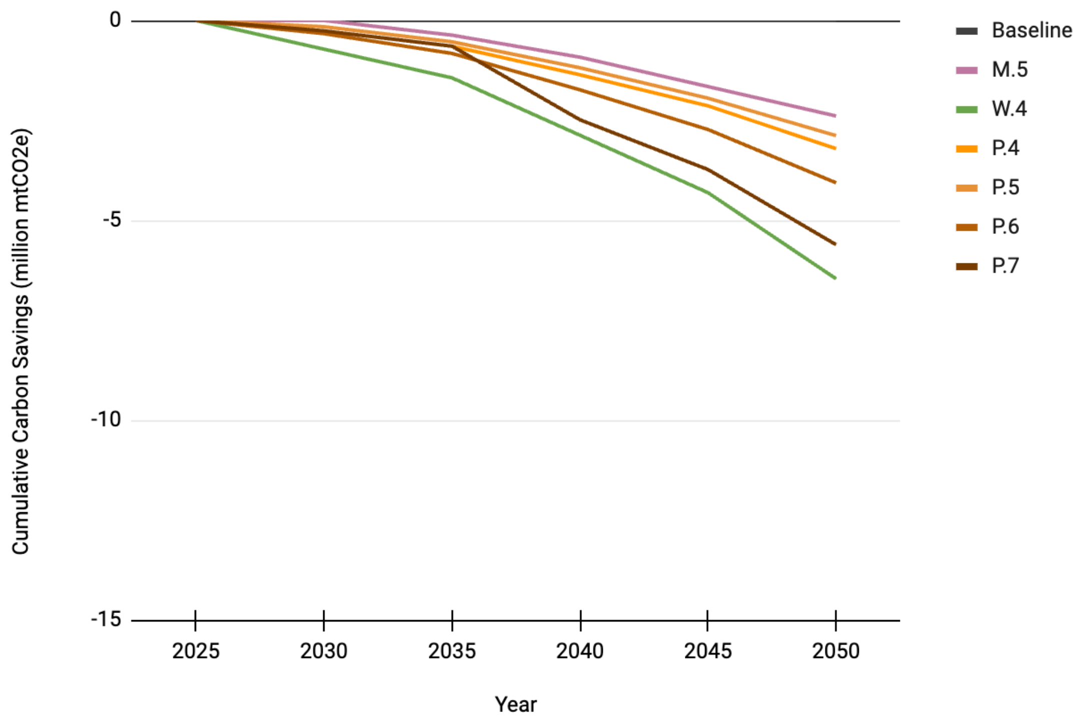


Figure 6-6. Material Cap 4 (M.4), WBLCA 1 (W.4), and multiple compliance pathways (P.4 P.5, P.6) phasing in larger reduction requirements over time. The option that offers the most carbon savings is the WBLCA pathway independently, ramping up over time (W.4), followed by the multiple compliance pathway if the WBLCA and material carbon caps dominate the uptake (P.6).

Based on our analysis, the pathways with the greatest savings include:

1. The independent WBLCA code pathways –from W.1 at 10% to W.3 at 30% – or ramping up over time as in W.4, result in the largest overall carbon reductions, saving between 4-11 million $mtCO_2e$ over the 2025-2050 period.
2. The multiple compliance pathways that are ramped up over time (P.4-P.7) and when the WBLCA pathway gets a greater share of uptake, offer the greatest reductions of the combined options, saving between 3-6 million $mtCO_2e$ over the 2025-2050 period.

6.2.1.4 Relevant Subset of Affected Emissions

Based on the Washington emissions reported in 2019, the total projected emissions over the period between 2025 and 2050 is around 2,550 million $mtCO_2e$. While embodied carbon is not reported separately in the Washington state inventory report, if we use the global figure that embodied carbon is ~11% of GHG emissions, this amounts to about 280 million $mtCO_2e$ of these projected emissions are from embodied carbon-related emissions (Weir et al., 2023).

Within this estimate, the building codes we have outlined have been written to apply to the upfront emissions of large commercial and multifamily buildings. The code language proposed in section 7.1 is not written to apply to single family buildings, smaller commercial projects, roadway and infrastructure projects. The codes also do not influence building project sitework, MEP/AV/IT installations, furniture, transportation (A4), on-site construction activities (A5), and emissions from use or end of life (B and C). Given this, our analysis suggests these codes apply to approximately ~13% of the overall construction spend.

Using this 13% as a proxy for the share of the embodied carbon emissions that this code is influencing, the total emissions that are targeted by these codes is only about ~36-38 million mtCO_2e in this study. Far greater reductions could be achieved by applying embodied carbon policies more broadly across infrastructure and single family home projects, as well as smaller buildings.

6.2.2 Modeling Scope

While many factors contribute to the built environment's impacts, this study was limited in its physical, life cycle, and environmental scope.

6.2.2.1 Physical Scope

The physical scope of the model is limited to buildings—particularly the structure, enclosure, and interiors. The model does not include impacts of other systems such as the mechanical, electrical, and plumbing systems (MEP), nor does it include impacts of infrastructure, such as roadways, parking lots, sewer and water systems, and power distribution networks, which can all contribute to the carbon footprint of cities and significantly affect the results.

6.2.2.2 Life Cycle Scope

The life cycle scope is limited to the product stage of a full life cycle (A1-A3) due to the limitations in available data for use in the model. This means that impacts from construction operations, use and replacement, demolition, and end-of-life are not included. These stages are critical to include in future stages of developing these kinds of models to provide agencies with estimates that include the entire life cycle. The estimates of emissions reductions are therefore conservative, in that they capture reductions from only a portion of the embodied carbon associated growth in Washington State. The actual emissions and savings are likely to be much higher.

6.2.2.3 Environmental Scope

The environmental scope of the model is limited to embodied carbon and a corresponding estimate of the social cost of carbon. They do not include other global environmental impacts such as smog or acidification, nor do they include local impacts such as noise, air pollution, or land use changes.

6.2.3 Modeling Approach

The modeling approach used in this study builds on the CLF's 2022 report "*Developing an Embodied Carbon Policy Reduction Calculator*".

6.2.3.1 Modeling Assumptions

This section summarizes the key modeling assumptions required to estimate the potential of various code options. Table 6-3 covers the projected areas of assumed commercial and residential growth based on area projections from various federal agencies.

Table 6-4 documents baseline embodied carbon intensities (ECIs) used in the baseline scenario, as well as the key assumptions used in modeling the reuse, material carbon caps, and WBLCA pathways, based on the following primary recommended code options:

- **Reuse pathway**. The project must reuse >45% of existing elements.

    - This was modeled as a direct 45% reduction in embodied carbon intensity (ECI) from the baseline.
- **Material carbon caps pathway.** GWP of total mass or volume no more than 90% of the equivalent mass or volume of the using the covered product GWP values.
    - This was modeled using the % of the ECI affected by the material carbon caps, and the 10% reduction was adjusted by the 90% of covered materials that must meet the caps.
- **WBLCA pathway.** The Global Warming Potential of the Proposed Design WBLCA shall not exceed 90% of the total Global Warming Potential of the Baseline Design WBLCA, or the Proposed Design WBLCA shall not exceed the applicable Building Carbon Budget (BCB.1).
    - This was modeled by adjusting the baseline ECIs to reflect the 10% reduction or the BCB limits, which were designed to match an equivalent % reduction for the purposes of this model.

Table 6-3. Area of New Commercial and Residential Growth between 2025-2050

Year	Commercial Growth (>50k buildings) in (SF)	Residential Growth (>50k buildings) in (SF)	Source
2025-2050	628,282,618	43,556,044	Area Projections based on EIA, Census, CBECS, and AHS

Table 6-4. Key Embodied Carbon Intensity Assumptions by Building Type and Size.

Primary Building Use	**Size** (ft^2)	**Baseline ECI*** (kgCO_2e/m^2)	**Reuse ECI** (~45% reduction)	**% of ECI affected by Material carbon caps**	**Limits BCB.1** (~10% reduction)	**Limits BCB.2** (~20% reduction)	**Limits BCB.3** (~40% reduction)
Medium Commercial	> 50,000 - 200,000	500	275	57%	450	400	300
Large Commercial	> 200,000	700	385	57%	630	560	420
Multifamily	> 50,000	500	275	55%	450	400	300

[1] CLF "Multifamily, Commercial, Institutional" (1-7 Stories, > 7 Stories, Low Rise 1-5, Mid Rise 6-10) and "Multifamily, Commercial" (Very Large, High Rise >10)

[2] Arup's Material contribution to BECI based on *Embodied Carbon Reduction Roadmap: Strategies and Policies for the State of California*" and Arup project experience.

6.2.3.2 Modeling of the Reuse Pathway

For the reuse scenario, a baseline scenario was calculated assuming 100% new construction. To do this, the model multiplied the projected area of growth for Washington state for each typology by the corresponding Baseline ECI values. To calculate the reuse scenarios, we assumed a percentage of the total growth to be achieved through adaptive reuse, rather than new construction. The impact of the reused projects was then assumed based on a reduction percentage equivalent to the percent of a building that would be reused in the reuse pathway (45%). This was then added to the remaining impacts of new construction. Based on this approach, the model estimates the projected embodied carbon by 2050 for a baseline scenario (e.g., new construction only), the increased reuse scenario(s), and the total carbon savings potential by 2050.

Within this pathway, we tested variations on the uptake of reuse in the market as a proportion of future new projected construction. We modeled three scenarios: 10% of growth as adaptive reuse, 20% of growth as adaptive reuse, and 33% of growth as adaptive reuse. The reuse pathway is modeled in combination with the other pathways, and the scenario was chosen based on relative uptake (10%, 20% or 33%) in the combined scenarios. For the reuse pathway, the code outcomes are inherently tied to the other two pathways, so the impacts from reuse are not modeled independently in this report. The impacts of the reuse pathway are included only in the multiple compliance pathway, alongside the material carbon caps and WBLCA Pathways.

While not modeled independently, for reference the three reuse scenarios used are as follows:

- Scenario R.1 - 10% of projected total new construction is adaptive reuse
- Scenario R.2 - 20% of projected new construction is adaptive reuse
- Scenario R.3 - 33% of projected new construction is adaptive reuse

6.2.3.3 Modeling of the material carbon caps Pathway

For the material carbon caps pathway, the code outcomes are modeled both independently and in combination with the other pathways in the multiple compliance pathway.

To calculate the material carbon caps scenarios, the model multiplied the baseline ECI values for each building typology with the expected building typology growth projected for Washington State. To calculate the material cap scenarios, the model then uses the baseline ECIs, the percent of the GWP affected by material carbon caps, and the % reduction of those caps from baseline to estimate the embodied carbon associated with the scenarios. Based on this approach, the model estimates the projected embodied carbon by 2050 for a baseline scenario, the projected embodied carbon of the material carbon caps scenarios, and the total carbon savings potential by 2050.

This modeling approach is likely to underestimate the actual carbon savings particularly when the caps are set at baseline GWP, because all materials in the market are likely not currently meeting these industry-average GWPs.

6.2.3.4 Modeling of the WBLCA Pathway

For the WBLCA pathway, the code outcomes are modeled both independently and in the context of the multiple compliance pathway. While section 5.3 introduced four options for the WBLCA Pathway, only option C (allowing for both a percentage reduction from a baseline OR a building carbon budget) is modeled here, as it is the recommended option. However, the options for the WBLCA Pathway follow the same reduction logic from A-D and the differences are more about documentation, so the modeling results for WBLCA pathway options A, B, and D would not have significant differences.

To calculate the baseline scenario, the model multiplied the baseline ECI values for each building typology with the expected building typology growth projected for Washington State. For each scenario, it then applied the percentage reduction or cap specified. After entering this information, the model provides an estimate of projected embodied carbon by 2050 for a baseline scenario and the reduction scenario(s), as well as the total carbon savings potential by 2050.

6.2.3.5 Multiple compliance pathways (and over time)

In addition to the independent scenarios described above, we modeled the three code pathways applied in parallel as a series of options that a design team could pick between to demonstrate compliance, as consistent with our recommendation in 7.1. Scenarios P.1-P.3 all use the primary recommended scenarios (M.2, and W.1) consistent with the model language, and the reuse scenario based on the proportion of uptake, as the basis for the modeling.

Last, we modeled the four code options where there is a multiple compliance pathway and the requirements ramp up their requirements over time. Scenarios P.4-P.7 all use the change-over-time scenarios (M.5, and W.4) as the basis for the modeling and the reuse scenario based on the proportions of uptake.

6.3 Economic Analysis

This section provides an overview of some of some of the economic benefits and costs of the code pathways described in this study, including:

- Social cost of carbon analysis (6.3.1);
- Costs for analysis (6.3.2); and
- Costs and savings for reduction strategies (6.3.2).

6.3.1 Economic Benefits: Social Cost of Carbon Comparison

This section combines all the findings of the previous analyses and translates the findings from the emissions reductions, into a dollar value using Washington state's social cost of carbon for present and future years (Washington Utilities and Transportation Commission, 2022). These calculations use WA social cost of carbon values, applied to emissions reductions from section 6.2 for the appropriate ear, to estimate savings. The trends are therefore same as what is observed for the emissions reductions, with the WBLCA pathways and multiple compliance options with increasing stringency over time, showing the greatest savings:

1. The independent WBLCA code pathways –from W.1 at 10% to W.3 at 30% – or ramping up over time as in W.4, result in the largest overall carbon reductions, saving between 480 million to 1.5 billion dollars in social costs over the 2025-2050 period.
2. The multiple compliance pathways that are ramped up over time (P.4-P.7) and when the WBLCA pathway gets a greater share of uptake, offer the greatest reductions of the combined options, saving between 450-770 million dollars in social costs over the 2025-2050 period.

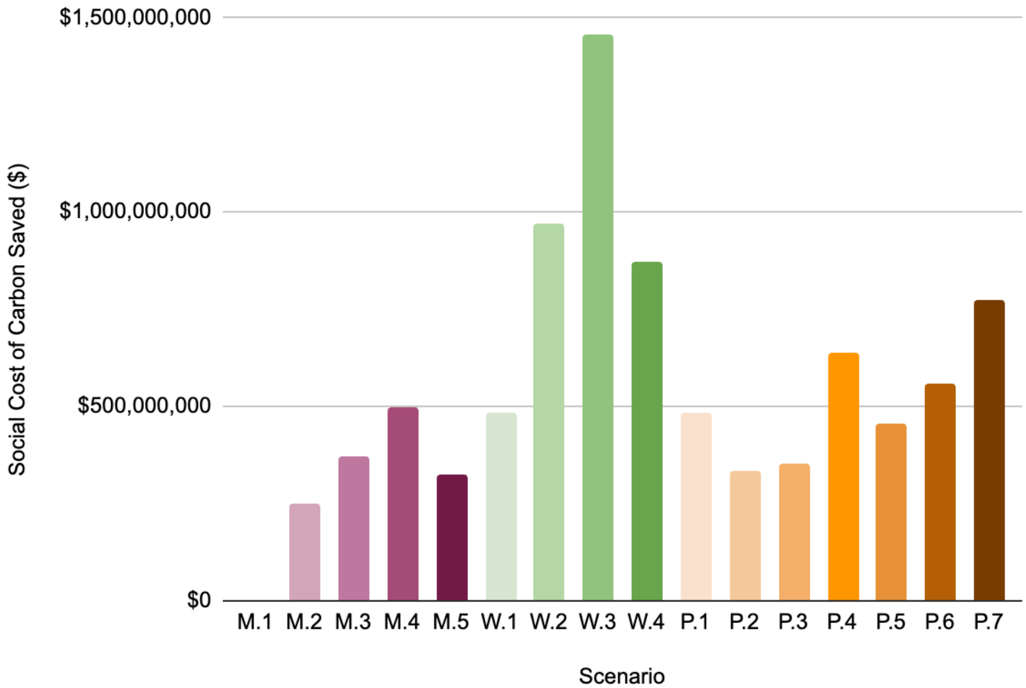


Figure 6-7. Social Cost of Carbon of All Pathways between 2025-2050. Scenarios include material carbon caps (M.1-M.5) WBLCA, (W.1-W.4), and multiple compliance pathways (P.1-P.7). See Table 6-2 for a summary of all scenarios.

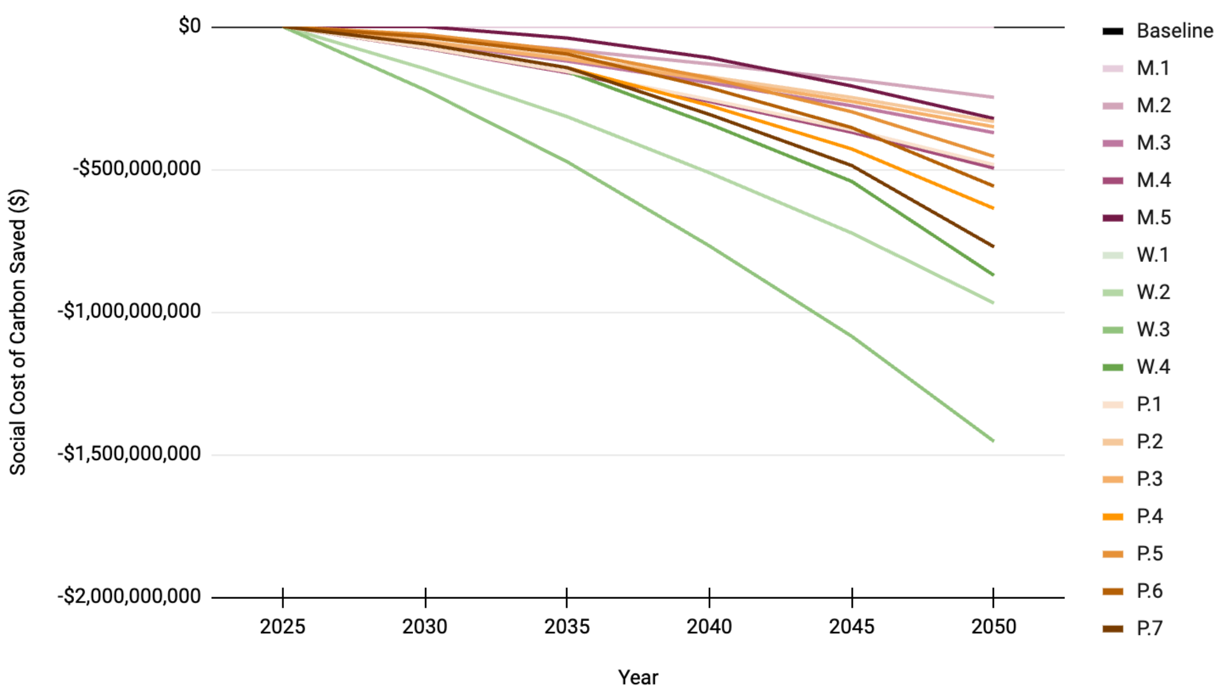


Figure 6-8. Social Cost of Carbon of All Pathways between 2025-2050. Scenarios include material carbon caps (M.1-M.5) WBLCA, (W.1-W.4), and multiple compliance pathways (P.1-P.7). See Table 6-2 for a summary of all scenarios.

6.3.2 Costs and Savings: Analysis and Reductions

Two primary types of costs could be associated with embodied carbon code requirements: (1) costs for analysis and (2) costs and savings for reductions.

Analysis costs

For the building reuse pathway, analysis costs are minimal or nonexistent. The only analysis required to comply is a calculation of floor area and submittal of the relevant worksheet, estimated to be an hour or less (see section 5.1).

The material carbon caps pathway requires manufacturers to pay for an EPD. For most materials, this can be done approximately once every five years for a product line, unless changes are made to the production that should be represented in the EPD. A notable exception is for ready-mixed concrete EPDs, which are often made custom for a project using EPD generator tools due to the wide range of mixes. Due to the success of these EPD generator tools, a significant portion of the EPA's Technical Assistance grants announced in the summer of 2024 are going towards the creation of EPD generator tools to accelerate the production of robust EPDs and reduce costs for manufacturers.

Figure 6-7 shows approximate costs for EPDs in a typical model and an EPD generator model, based on current estimates provided through interviews and correspondence with EPD generator tools staff. These numbers provide an order of magnitude estimate, not an exact cost.

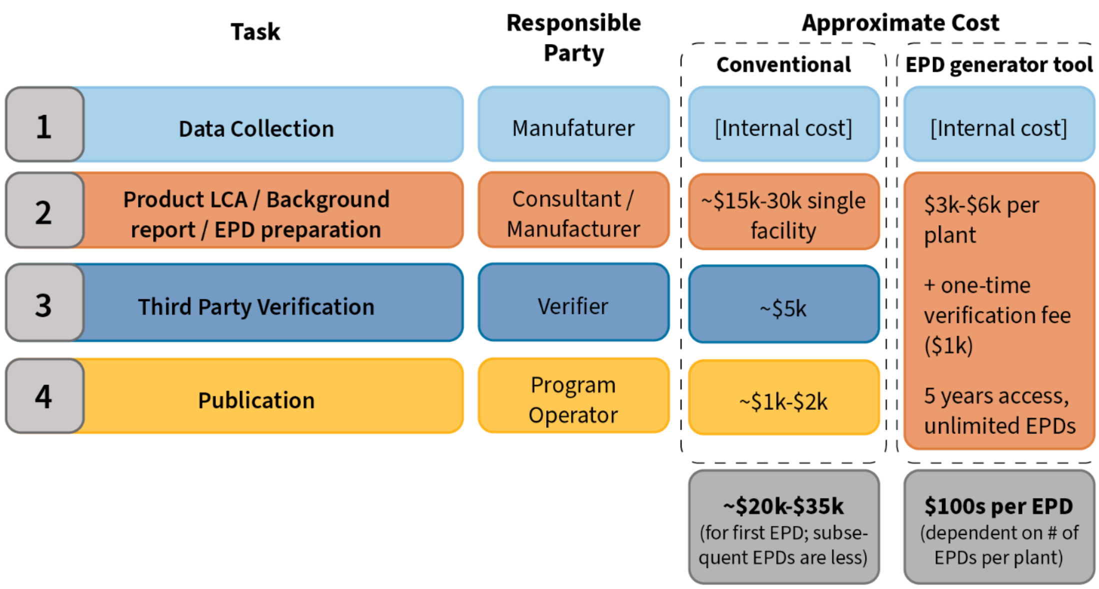


Figure 6-7 Development Costs of EPDs. Source: CLF, based on 2024 estimates provided through interviews and correspondence with EPD generator tools staff. These numbers provide an order of magnitude estimate, not an exact cost.

For AEC professionals, costs associated with additional staff time spent selecting and verifying materials that comply with the code requirements and working with suppliers to ensure that these materials are installed on-site, vary with each project and project team. Average hourly rates (not including overhead) for architecture, and engineering professionals in Washington are $55-65 for architects and engineers in Washington (based on data retrieved from ZipRecruiter.com on November 4, 2024). For each EPD that needs to be verified during construction, it costs the design team conservatively about 1 hour to review and confirm compliance per EPD, with about 50% additional time for overhead and communication. Assuming the following EPD counts for covered categories recommended in this report: Concrete ~ 10 EPDs, CMU ~ 3 EPDs, Rebar ~ 3 EPDs, Steel ~ 8 EPDs, Wood ~ 8 EPDs, we estimate about 32 EPDs will be reviewed on a typical project, with more complex projects approaching 50 EPDs. This amounts to a price range of around $2500 - $5000 for EPD review, not including overhead.

Analysis costs for a whole building life cycle assessment are typically a part of the fee for the architect, engineer, and/or green building consultant on a project. These costs are a minimal part of the overall project cost but are in the range of $15,000 to over $100,000 for the entire project timeline. The range varies widely depending on factors such as:

- Number of analyses performed throughout the design and construction timeline
- Whether a baseline model is also required to be modeled, and
- Size and complexity of the project.

Costs and savings from embodied carbon reduction strategies

A focus on materials selection and procurement can realize significant embodied carbon reductions at little to no additional up-front cost. Case studies in the Pacific Northwest have shown an embodied carbon savings potential of 19%–46% at cost premiums of less than 1%, simply through specifying and substituting lower-carbon alternatives for certain materials during the design and specification process (Esau et al., 2021). These cases demonstrate that there are products and solutions available today that can realize embodied carbon reductions with low to no financial burden.

Embodied carbon code measures can result in additional cost savings in the future through supporting scaling of low embodied carbon materials. For products where a low carbon premium does exist, increased demand for lower carbon materials may help scale production and lower the long-term costs of these products.

To achieve embodied carbon reductions in the WBLCA requirement, building professionals can deploy a broad number of strategies, from selecting lower embodied carbon materials to sourcing local materials, to designing for structural efficiency. Many solutions for lowering embodied carbon inherently lower building material and construction costs, leading to overall project savings that outweigh additional design fees. For example, right-sizing spaces, reducing subgrade construction, maximizing material efficiency, and eliminating unnecessary finishes will reduce the quantity of material required and therefore reduce costs and embodied carbon. For example, project teams in Massachusetts' 2024 Embodied Carbon Reduction Challenge noted cost savings from minimizing below-Grade construction by shifting mechanical systems to the roof, optimizing the structural grid to reduce steel column and beam quantities, and even employing mass timber construction – a material with high cost premiums – due to savings resulting from faster construction and eliminating the need for ceiling and wall finishes by leaving the timber material exposed (Built Environment Plus, 2024).

Reusing an existing building's structural system can avoid spending on new steel, concrete, and other structural materials while saving a significant amount of embodied carbon (Urban Land Institute, 2019). A study published by the California Green Building Standards Commission for CALGreen's 2022 embodied carbon requirements determined that the building reuse compliance option would not have a significant increase in project costs and may have a reduction in costs through material conservation (California Standards Commission, 2023).

Table 6-5. Summary of costs and savings variables for different pathways

Pathway	Analysis costs	Reductions costs and savings
Reuse	No cost for analysis	Varies by project. Retaining structural and enclosure materials in an existing building can avoid costs spent on new materials.
Material carbon caps	Analysis of cost burden on manufacturers	Varies by product and location. Premiums exist for some products, but case studies demonstrate that no cost reductions are possible and the market for available products is expanding due to policy uptake and federal investments.
WBLCA Pathway	Analysis cost burden on building owner (via fee to architect, engineer, or green building consultant)	Varies by strategy. Material efficiency and reuse strategies can reduce material costs. Design changes may be a part of regular design fees depending on the project. Material substitution strategies may come with a cost premium until they are more widely available.

6.4 Training, Reporting, and Supplementary Guidance

If the Washington State Code Council adopts embodied carbon measures, supplementary training and resources will increase the success of implementation, such as:

- Training sessions for designers and builders on the compliance pathways, including a general overview of the process, calculation rules, and required data collection;
- Training sessions for enforcing code officials;
- A detailed reporting form, ideally collected in a central reporting database; and
- Pathway-specific supplementary guidance.

6.4.1 Training sessions

Training sessions build the skills needed to provide the calculations and documentation required for successful compliance. Architects, owners, general contractors, and other stakeholders should be made aware of these requirements and have access to training in advance of the provisions becoming active in the code. Training building officials on how to determine compliance should also be a focus of implementing any new code provision.

Designers and builders

During the year before embodied carbon codes came into effect as part of CALGreen, multiple stakeholders offered training to introduce the code requirements and understand how design teams could implement these codes. The American Institute for Architects (AIA) CA chapter and the Structural Engineers Association of California (SEAOC) partnered to offer a four-part training. The training covered:

1) Overview of embodied carbon and relevant code changes
2) Implementing the WBLCA pathway
3) Implementing the material carbon caps pathway
4) Implementing the building reuse pathway

Code enforcement officials

The concepts in this proposal are generally new to plan review staff. It is critical to build their familiarity with the measures to ensure success in plan review, verification, and enforcement. As the new CALGreen embodied carbon requirements have come into effect in California, key stakeholders have begun providing training to building department staff.

Effective training should include the following:

- A brief introduction to embodied carbon in buildings
- Overview of the requirements and pathways, including submission & documentation requirements
- What to look for in plan review, including sample corrective comments
- Possible mechanisms for ensuring compliance and enforcement

6.4.2 Reporting

Detailed reporting can lead to more transparent, useful, and consistent assessments and can reduce the burden on the enforcing authority required to verify results. Detailed reporting also enables the enforcing authority to observe and report out on the norms across the affected projects, as well as identify outliers that need additional explanation. A reporting framework could enable the enforcing authority to contribute to or lead the development of regionally relevant benchmarks for whole building embodied carbon intensities, and track the policy's impact in carbon reduction terms.

6.4.3 Pathway-specific supplementary guidance

Additional supplementary guidance may support implementation for specific pathways, such as:

- Guidance on defining rules to calculate the percent of building reused (see 5.1.2.2);
- Baseline building guidance for the WBLCA pathway if using reduction targets (see 5.3.3.3); and
- Suggested tools: Providing educational resources on which tools and datasets can be used in the code is helpful for project teams in streamlining compliance. More information is provided in section 2.2.1.3.

7. Recommended Language for Washington State Code Council

Based on the findings of this study, Washington should consider a multiple compliance pathway approach, similar to the three code pathways allowed by CALGreen. The options in the multiple compliance pathway approach would be written such that a team could pursue one of the following options at their discretion:

- **Reuse Pathway (section 5.1)**. The project must reuse >45% of existing elements.
- **Material Carbon Caps Pathway (section 5.2).** The project must provide EPDs that have GWPs that are no more than 90% of the Covered Product GWP values.
- **WBLCA Pathway (section 5.3).** The Global Warming Potential of the Proposed Design WBLCA shall not exceed 90% of the total Global Warming Potential of the Baseline Design WBLCA, or the Proposed Design WBLCA shall not exceed the Building Carbon Budget as noted.

The benefits of a multiple compliance pathway include:

- Offers the greatest flexibility for project teams to select an option that works for the project.
- Spreads the costs of analysis across multiple stakeholders (manufacturers and building owners), and allows for a no-cost analysis pathway when building reuse is feasible.

In 2035, Washington should review the state of practice and consider phasing out the material carbon caps path to focus on WBLCA and reuse, as modeled in the P.7 scenario in section 6.2. This multiple compliance pathway had the largest estimated emissions reduction benefits, while still allowing time for standardization and uptake of WBLCA by more firms and better integration of EPDs into WBLCA to better capture procurement strategies.

7.1 Model language

CHAPTER 2
DEFINITIONS

SECTION 201
GENERAL

Add new definitions as follows:

AS-BUILT WBLCA. An As-Built Whole Building Life Cycle Assessment model represents the final as-constructed project at substantial completion.

BASELINE DESIGN WBLCA. An LCA model that represents a functionally equivalent reference design as described by E2921-22 to the Proposed Design Whole Building Life Cycle Assessment and has the same massing, area, function, and thermal criteria as the Proposed Design WBLCA model and meets equivalent building code.

BUILDING CARBON BUDGET. A building-scale embodied carbon requirement in which a project's Embodied Carbon Intensity expressed in $lbCO_2e/ft^2$ or $kg\ CO_2e/m^2$ must be below a maximum value.

EMBODIED CARBON. The greenhouse gas (GHG) emissions generated by the manufacturing, transportation, installation, maintenance, and disposal of construction materials used in buildings, roads, and other infrastructure, as measured using a life cycle assessment.

EMBODIED CARBON INTENSITY (ECI). A metric, expressed as kg CO_2e/m^2, calculated by taking the total Global Warming Potential from a Whole Building Life Cycle Assessment study and dividing by the project's gross floor area, including parking.

FUNCTIONAL EQUIVALENT. Quantified functional requirements and/or technical requirements for a building for use as a reference basis for comparison.

GLOBAL WARMING POTENTIAL (GWP). The potential climate change impact of a product or process as measured by an LCA. GWP is reported in units of carbon dioxide equivalents (CO_2e) and is the agreed-upon metric for tracking embodied carbon.

GROSS FLOOR AREA (GFA). The floor area within the inside perimeter of the exterior walls of the building under consideration, exclusive of vent shafts and courts, without deduction for corridors, stairways, ramps, closets, the thickness of interior walls, columns, or other features. The floor area of a building, or portion thereof, not provided with surrounding exterior walls shall be the usable area under the horizontal projection of the roof or floor above. The gross floor area shall not include shafts with no openings or interior courts.

LIFE CYCLE ASSESSMENT (LCA). A systematic set of procedures for compiling and evaluating the inputs and outputs of materials and energy, and the associated environmental impacts directly attributable to a product or process throughout its life cycle.

PRODUCT AND FACILITY-SPECIFIC ENVIRONMENTAL PRODUCT DECLARATION. A Type III Environmental Product Declaration that covers a single product, a single manufacturer, and a single facility. The Environmental Product Declaration must be created in accordance with International Organization for Standardization standards 14025 and 21930 or similarly robust life-cycle assessment methods that have uniform standards in data collection, industry acceptance, and integrity.

PROPOSED DESIGN WBLCA. An LCA model that represents the building design at the 100% Construction Documents or permit set stage of development.

REFERENCE STUDY PERIOD (RSP). The period over which the time-dependent characteristics of the building *products and elements are* accounted for in the *whole building LCA* are analyzed.

SUBSTANTIAL COMPLETION. Substantial completion is a critical milestone that signifies the point at which a construction project is considered to be almost finished. While not every minor detail or finishing touch may be in place, substantial completion denotes that the project is functional and can be occupied or utilized for its intended purpose. It indicates that the contractor has fulfilled the major requirements outlined in the contract, allowing the owner to take possession of the premises or facility.

WHOLE BUILDING LIFE CYCLE ASSESSMENT (WBLCA). A cradle-to-grave assessment covering life cycle stages A-C as defined by ISO 21931-1 or similarly robust whole building life cycle assessment or whole life carbon assessment standard that evaluates the environmental impacts of a building, including, at minimum, global warming potential.

CHAPTER 4
SPECIAL DETAILED REQUIREMENTS BASED ON OCCUPANCY AND USE

Add new text as follows:

SECTION 431

EMBODIED CARBON REQUIREMENTS

430.1 Submittal for reduction of embodied CO2e. *Construction documents* submitted for the construction or *substantial improvement* of any building 50,000 gross square feet or larger shall comply with Sections 430.2, 430.3, or 430.4.

430.2 Documentation of building reuse. A *substantial improvement*- where the total project area, including existing floor area, is 50,000 gross square feet or larger of occupied or conditioned space, and where any combined *addition(s)* to an existing building(s) is less than two times the area of the existing building(s)- shall submit documentation that demonstrates the preservation of at least 45 percent combined of the *existing building's* primary structural elements and existing building envelope. Window assemblies, insulation, portions of buildings deemed structurally unsound or hazardous, and hazardous materials that are remediated as part of the project shall not be included in the calculation.

430.2.1 Compliance forms for building reuse. *Construction documents* shall clearly distinguish the measurements for existing and new elements. At a minimum, forms documenting building reuse shall include the information listed in items (a) through (d) below:

(a) Area of the *existing building*(s) in square feet;

(b) Area of the aggregate addition(s) in square feet (if applicable);

(c) Total gross floor area of the *existing building*(s) before construction or alteration in square feet; OR existing total area and retained total area of primary structural elements of the *existing building*(s) in square feet; and

(d) Total gross floor area of the *existing building*(s) to be retained in square feet; OR existing total area and retained total area of the building envelope of the *existing building*(s) in square feet.

430.3 Documentation of reduced embodied carbon of covered products. Project-specific product quantities shall be submitted along with *Product and Facility-specific Environmental Product Declarations* that demonstrate that the global warming potential of the total mass or volume of the covered products listed in Section 430.3.1 is no more than 90 percent of the GWP values in Table 430.1 for the same total mass or volume of the covered products.

430.3.1 Covered products. Covered products shall include no less than 90 percent of the total mass or volume of the following:

(a) Structural concrete products, including but not limited to ready mix and concrete masonry units;

(b) Reinforcing steel products, specifically rebar;

(c) Structural steel products, specifically hot rolled sections, hollow sections, decking, and plate; and

(d) Structural wood products, including but not limited to laminated veneer lumber, laminated strand lumber, glue laminated timber, wood framing, softwood plywood, and Oriented Strand Board (OSB).

TABLE 430.1 COVERED PRODUCT GWP VALUES

COVERED PRODUCT	**GLOBAL WARMING POTENTIAL**	**UNIT OF MEASUREMENT**

Ready mix concrete	Up to 2,499 psi	235	kg CO_2e/m^3
	2,500-3,999 psi	261	kg CO_2e/m^3
	4,000-4,999 psi	316	kg CO_2e/m^3
	5,000-5,999 psi	386	kg CO_2e/m^3
	6,000-7,999 psi	408	kg CO_2e/m^3
	8,000 psi and greater	487	kg CO_2e/m^3
	Lightweight, up to 3,999 psi	518	kg CO_2e/m^3
	Lightweight, 4,000-4,999 psi	575	kg CO_2e/m^3
	Lightweight, 5,000 psi and greater	632	kg CO_2e/m^3
Concrete masonry units	Normal weight, up to 3,249 psi	208	kg CO_2e/m^3
	Normal weight, 3,250-4,499 psi	232	kg CO_2e/m^3
	Normal weight, 4,500 psi and greater	241	kg CO_2e/m^3
	Medium weight, up to 3,249 psi	360	kg CO_2e/m^3
	Medium weight, 3,250 psi and greater	244	kg CO_2e/m^3
	Lightweight, up to 3,249 psi	395	kg CO_2e/m^3
	Lightweight, 3,250 psi and greater	286	kg CO_2e/m^3
Reinforcing steel	Rebar – unfabricated	753	kg CO_2e/metric ton
	Rebar – fabricated	854	kg CO_2e/metric ton
Structural steel	Hot-rolled sections – unfabricated	1,000	kg CO_2e/metric ton
	Hot-rolled sections – fabricated	1,220	kg CO_2e/metric ton
	Hollow structural sections – unfabricated	1,710	kg CO_2e/metric ton
	Hollow structural sections – fabricated	1,990	kg CO_2e/metric ton
	Decking	2,320	kg CO_2e/metric ton
	Plate – unfabricated	1,480	kg CO_2e/metric ton

	Plate – fabricated	1,730	kg CO_2e/metric ton
Structural wood	Laminated veneer lumber	361.45	kg CO_2e/m^3
	Laminated strand lumber	274.9	kg CO_2e/m^3
	Glue laminated timber	137.19	kg CO_2e/m^3
	Wood framing	63.12	kg CO_2e/m^3
	Softwood plywood	219.32	kg CO_2e/m^3
	Oriented Strand Board (OSB)	242.58	kg CO_2e/m^3

430.4 Whole building life cycle assessment (WBLCA). Whole Building Life Cycle Assessments (WBLCAs) performed in accordance with ISO 14040–2006 and ISO 14044:2006 shall be submitted for a project at the following stages:

1. **Issued for Permit Set:** Design WBLCA Submission
2. **Substantial Completion:** As-Built WBLCA Submission

430.4.1 Design WBLCA Submission. The Design WBLCA Submission shall include the *Proposed Design WBLCA* results and the *Baseline Design WBLCA* results. The total *Global Warming Potential* of the Proposed Design WBLCA shall not exceed 90% of the total Global Warming Potential of the Baseline Design WBLCA, or the *Proposed Design WBLCA* shall demonstrate an *Embodied Carbon Intensity* (ECI) that is less than the *Building Carbon Budget* of:

- Multifamily (>50,000 ft^2) : 91 lbCO_2e/ft^2 (450 kgCO_2e/m^2)
- Nonresidential (50,000-200,000 ft^2): 91 lbCO_2e/ft^2 (450 kgCO_2e/m^2)
- Nonresidential (>200,000 ft^2): 128 lbCO_2e/ft^2 (630 kgCO_2e/m^2)

430.4.2 As-Built WBLCA Submission. The As-Built WBLCA Submission must document the *As-Built WBLCA* of the final project as constructed to the best of the knowledge of the design and construction team. Actual purchased quantities and product data, including *Product and Facility-Specific Environmental Product Declarations*, should be used to report the total *Global Warming Potential* and *Embodied Carbon Intensity* of the as-built project.

430.4.3 Software and data quality. Software used to conduct a Whole Building Life Cycle Assessment shall conform to ISO 21931–-2022 and/or EN 15978–2011 and shall have a data set compliant with ISO 14044–2006 and ISO 21930–2017 and/or EN 15804–2012. The software shall utilize a calculation methodology that is compliant with EN 15978–2011, ISO 21931–-2022, and ISO 21929–-2011. The software tools and datasets shall be the same for the evaluation of both the Baseline Design WBLCA and the Proposed Design WBLCA. For ease of comparison, it is recommended that the same tool used in the Design WBLCA Submission be used for the As-Built LCA Submission, to the extent feasible.

430.4.4 Life cycle stages. The whole building life cycle assessments shall include all modules in life cycle stages A, B, and C, as defined by EN 15978–2011, except for operating energy and water stages (B6 and B7).

430.4.4.1 Reuse and salvage. Existing and salvaged building components shall be included or excluded at the discretion of the project team. For reused materials, it is permissible to assume the A1-A4 stages carry no impact in the Proposed Design WBLCA to show the benefit of reusing materials, while retaining the A1-A4 estimated impacts for these products for these materials in the Baseline Design WBLCA. For salvaged materials, it is permissible to assume the A1-A3 stages carry no impact in the Proposed Design WBLCA to show the benefit of reusing materials, while retaining the A1-A3 estimated impacts for these products for these materials in the Baseline Design WBLCA.

430.4.4.2 Biogenic Carbon. Biogenic carbon and carbon sequestration shall be reported separately from fossil GWP.

430.4.5 Building elements. The whole building life cycle assessment shall include all of the following building elements: foundations; *exterior wall envelope*; *primary structural frame*; *secondary structural members*; *roof covering*; *roof deck*; *fenestration*; *load-bearing walls*; *non load-bearing walls*; interior constructions and *interior finishes*.

Exception: A whole building life cycle assessment that includes no less than 95 percent of the total mass or volume of building elements.

Exception: A whole building life cycle assessment submitted for an addition, alteration, repair, or substantial improvement may exclude existing and/or remaining building components.

430.4.5 Reference study period. The reference study period shall be 60 years.

430.5 Verification of compliance. The *registered design professional*, as specified in the construction documents, shall provide a signature verifying compliance with the requirements. The contractor for a building project that submits documentation per Sections 430.2, 430.3, or 430.4 shall update documentation and calculations based on procured products and attest that they are accurate and align with the construction documents to the best of the contractor's knowledge. All calculations shall be verified by the *registered design professional*.

CHAPTER 35
REFERENCED STANDARDS

ASTM

Add new text as follows:

E2921-22	Standard Practice for Minimum Criteria for Comparing Whole Building Life Cycle Assessments for Use with Building Codes, Standards, and Rating Systems

EN

Add new text as follows:

EN 15978–2011	Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method
EN 15804–2012	Sustainability of construction works, Environmental product declarations, Core rules for the product category of construction products

ISO

Add new text as follows:

ISO 14040–2006	Environmental management — Life cycle assessment — Principles and framework
ISO 14044–2006	Environmental management — Life cycle assessment — Requirements and guidelines
ISO 21929–-2011	Sustainability in building construction — Sustainability indicators. Part 1: Framework for the development of indicators and a core set of indicators for buildings
ISO 21931–-2022	Sustainability in buildings and civil engineering works — Framework for methods of assessment of the environmental, social and economic performance of construction works as a basis for sustainability assessment
ISO 21930–2017	Sustainability in buildings and civil engineering works — Core rules for environmental product declarations of construction products and services

8. Conclusion

Washington state has started to address embodied carbon with modest gains in policy and increasing engagement with the topic across municipal levels. The HB1282 (the Buy Clean Buy Fair Washington Act) was signed into law in March 2024 introducing new procurement processes for public buildings. Embodied carbon was identified as a critical goal in the Washington state 2021 energy strategy to meet the state's greenhouse gas emission limits, as well as in Inslee's Executive Order 20-01 and the Pacific Coast Collaborative Low Carbon Construction Taskforce and Action Plan. Washington state was also awarded a $3.5M environmental product declaration (EPD) technical assistance grant from the EPA in collaboration with Oregon and the ICC. Complementary actions are also occurring at the city, county, and regional levels.

While these are meaningful steps forward, they are not enough to accelerate action quickly enough to achieve the 2050 target established in RCW 70A.45.020. These policies begin to move the market by focusing on public buildings and developing EPDs, but they do not provide a pathway to lower the embodied carbon of new construction projects across the state.

Building codes apply to all new construction projects in the state and therefore hold the potential to address critical upfront embodied carbon emissions. Building codes provide a key avenue for Washington State to reach its legislatively mandated emissions reductions while improving community health and reducing future exposure to climate-related impacts.

This report explores three primary approaches to building codes: rewarding reuse of existing buildings, requiring emissions limits at the material scale (material carbon caps), and requiring performance requirements at the building scale via whole building life cycle assessment (WBLCA). The recommendations offered in this report suggest a multiple compliance pathway approach to building code implementation over the short term, with more stringent requirements for reducing emissions phasing in over time. The recommended approach (Scenario P.7) would offer a 16% reduction in embodied carbon for new construction in Washington State from business-as-usual offer, or 5.7 million $mtCO_2e$ of embodied carbon savings over the 2025-2050 period (a savings of ~770 million dollars in social costs). This savings is in the same order of magnitude as the estimated 8.1 million $mtCO_2e$ of savings from the commercial electrification code passed in Washington state in 2022 (Kocher & Gruenwald, 2022). Broader considerations for future code development are also provided in section 5.6 based on interviews with industry practitioners.

The incorporation of embodied carbon into building codes as outlined in this report pairs real market transformation across the value chain with flexibility and capacity-building in the short term. Given Washington state's ambitious push towards a zero-carbon future in 2050, regulating embodied carbon from new buildings using building codes is a critical component to achieving this outcome.

References

Andersen, S. C., Larsen, H. F., Raffnsøe, L., & Melvang, C. (2019). Environmental Product Declarations (EPDs) as a competitive parameter within sustainable buildings and building materials. *IOP Conference Series: Earth and Environmental Science*, *323*(1), 012145. https://doi.org/10.1088/1755-1315/323/1/012145.

APA - The Engineered Wood Association. (n.d.). *Advanced Framing.* https://www.apawood.org/advanced-framing

Athena Sustainable Materials Institute. (2022). *A Cradle-to-Gate Life Cycle Assessment of Ready Mixed Concrete Manufactured by NRMCA Members*, Version 3.2.

Bantock, A. (2024). Embodied Carbon in Vancouver Building By-Law. *Preoptima.* https://www.preoptima.com/the-carbon-source/embodied-carbon-vancouver-building-bylaw.

Built Environment Plus. (2024). *Project Details for the Embodied Carbon Reduction Challenge*. https://builtenvironmentplus.org/embodied-carbon-reduction-challenge-peoples-choice/.

Building Transparency. (2024). Embodied Carbon in Construction Calculator (EC3) Tool. Data retrieved July 24, 2024. https://buildingtransparency.org/ec3.

California Building Standards Commission. (2024). *Supplement Update Guide to the 2022 California Green Building Standards Code (CALGreen)- Nonresidential*. Government of California, Department of General Services.

California Building Standards Commission. (2023). *Economic and Fiscal Impact Statement (Form 399), Attachment C- CCRC regulations 54day, Amend the 2022 California Green Building Standards Code, CCR, Title 24, Part 11.* Government of California, Department of General Services.

City of Boulder and the International Code Council. (2024). *City of Boulder Energy Conservation Code.*

City of Denver. Community Planning and Development. (2024). Denver Green Code. City of Denver. https://denvergov.org/Government/Agencies-Departments-Offices/Agencies-Departments-Offices-Directory/Community-Planning-and-Development/Building-Codes-Policies-and-Guides/Denver-Green-Code

City of Portland. (2022). *Notice of New Requirements for Concrete.* City of Portland.

PAE Engineers. (2020). *City of Seattle Refrigerant Emissions Analysis: GHG Emissions Calculation Methodologies.* City of Seattle.

City of Seattle (n.d.). *City of Seattle Municipal Code, Title 23, Subtitle III, Chapter 23.40, Section 23.40.060 - Living Building Pilot Program.* Seattle, Washington.

City of Vancouver. (2023). *Embodied Carbon Guidelines Version 1.0*. City of Vancouver.

City of Vancouver. Office of the Chief Building Official. (2022). *Public Review, Vancouver Building By-law, Proposed Change to Low Carbon Materials and Construction*. City of Vancouver.

Esau, R., Jungclaus, M., Olgyay, V., & Rempher, A. (2021). *Reducing Embodied Carbon in Buildings: Low-Cost, High-Value Opportunities*. RMI.

Frey, P., Dunn, L., & Cochran, R. (2011). The Greenest Building: Quantifying the Environmental Value of Building *Reuse*. National Trust for Historic Preservation Green Lab. https://www.bostonpreservation.org/resource-item/greenest-building-quantifying-environmental-value-building-reuse

Garry, M. (2023, September 20). EIA Supports ASHRAE Proposal for 4.9kg Propane Charge in Outdoor Heat Pumps in U.S. *Natural Refrigerants.com.* https://naturalrefrigerants.com/eia-supports-ashrae-proposal-for-4-9kg-propane-charge-in-outdoor-heat-pumps-in-u-s/

Government of British Columbia. Office of Housing and Construction Standards. (2015). *Understanding BC's Building Regulatory System.* Office of Housing and Construction Standards.

Government of Canada. (2022). *Standard on Embodied Carbon in Construction.*

Hunt, C. G., & Dunky, M. (2022). Analysis of Future Prospects and Opportunities for Wood Adhesives: A Review*. *Forest Products Journal*, *72*(s2), 14–22. https://doi.org/10.13073/fpj-d-23-00011

International Energy Agency (IEA). (2023). *Energy Technology Perspectives 2023.* IEA, Paris. https://www.iea.org/reports/energy-technology-perspectives-2023.

International Code Council. (2023). *2022 Denver Green Code, Chapter 9 Materials and Resources*. International Code Council Digital Codes. https://codes.iccsafe.org/content/CODGC2022P1/chapter-9-materials-and-resources.

International Code Council. (2024). *2021 Washington State Building Code, Appendix AWY Construction and Demolition Material Management*. International Code Council Digital Codes. https://codes.iccsafe.org/content/WARC2021P2/appendix-awy-construction-and-demolition-material-management

International Code Council. (2023). *2021 Washington State Residential Code, Appendix P Construction and Demolition Material Management*. International Code Council Digital Codes. https://codes.iccsafe.org/content/WABC2021P2/appendix-p-construction-and-demolition-material-management

Kocher, J. & Gruenwald, T. (2022, January 3). Washington State Could Lead the Nation on Building Electrification Codes. *RMI.* https://rmi.org/washington-state-could-lead-the-nation-on-building-electrification-codes/

Lawrence, N., & Elbel, S. (2020). Servicing and installing equipment using flammable refrigerants: Assessment of field-made mechanical joints (ASHRAE RP-1808). *Science and Technology for the Built Environment,* 26(5), 621–630. https://doi.org/10.1080/23744731.2020.1735259

Lewis, M., Waldman, B., Carlisle, S., Benke, B., & Simonen, K. (2023). *Advancing the LCA Ecosystem: A Policy-Focused Roadmap for Reducing Embodied Carbon*. Carbon Leadership Forum, University of Washington. Seattle, WA.

Minner, J., Poe, J., Heisel, F., Kopetzky, A., Porath, M., & Worth, G. (2024). *Embodying Justice in the Built Environment: Circularity in Practice*. Ithaca, NY: Cornell University.

National Research Council (NRC). (2024). National Whole-building Life Cycle Assessment Practitioner's Guide: Guidance for Compliance Reporting of Embodied Carbon in Canadian Building Construction. https://doi.org/10.4224/40003365

Rodriguez, B. X., Huang, M., Lee, H. W., Simonen, K., & Ditto, J. (2020). Mechanical, electrical, plumbing and tenant improvements over the building lifetime: Estimating material quantities and embodied carbon for climate change mitigation. *Energy and Buildings*, *226*, 110324. https://doi.org/10.1016/j.enbuild.2020.110324

Seattle Department of Construction & Inspections. (n.d.). *Living Building Pilot - Overview.* https://www.seattle.gov/sdci/permits/green-building/living-building-pilot-overview

State of California. Department of General Services. (2024). *Buy Clean California Act.* Government of California. https://www.dgs.ca.gov/PD/Resources/Page-Content/Procurement-Division-Resources-List-Folder/Buy-Clean-California-Act

State of Vermont. (2023). *Vermont Commercial Building Energy Standards (CBES) Amendments.*

University of Minnesota. Center for Sustainable Building Research. (2024). *Minnesota B3 Guidelines New Buildings and Major Renovations, Version 3.2 Revision 02, June 2024*. University of Minnesota College of Design, Twin Cities.

United States Environmental Protection Agency (US EPA). (2023). *FACT SHEET: Final Rule - Phasedown of Hydrofluorocarbons: Restrictions on the Use of Certain Hydrofluorocarbons under Subsection (i) of the American Innovation and Manufacturing Act of 2020*. US EPA. Washington, D.C.

US EPA. (2024a). Reducing Embodied Carbon of Construction Materials through the Inflation Reduction Act. https://www.epa.gov/greenerproducts/reducing-embodied-carbon-construction-materials-through-inflation-reduction-act.

US EPA (2024b). *Summaries of the FY 23–24 IRA 60112 Grant Selections: Reducing Embodied Greenhouse Gas Emissions for Construction Materials and Products*.

United States General Services Administration (GSA). (2024). *P100 Facilities Standards for the Public Buildings Service.*

United States Green Building Council (USGBC). (2019a). *LEED BD+C New Construction v4.1.: Procurement of Low Carbon Construction Materials.*

USGBC. (2019b). *LEED BD+C: New Construction v4.1: Building life-cycle impact reduction credit.*

Urban Land Institute: Greenprint. (2019). *Embodied Carbon in Building Materials for Real Estate*. Urban Land Institute.

Waldman, B., Hyatt, A., Carlisle, S., Palmeri, J., & Simonen, K. (2023). *2023 Carbon Leadership Forum Material Baselines Baseline Report v2*. Carbon Leadership Forum.

Waldman, B., Lewis, M., & Palmeri, J. (2024). *Buy Clean Policies: Overview + Implementation*. Carbon Leadership Forum.

Washington State Department of Ecology (2021). *Climate Commitment Act*. Washington State Department of Ecology. https://ecology.wa.gov/Air-Climate/Climate-Commitment-Act.

Washington State Department of Ecology (2022). *Washington State Greenhouse Gas Emissions Inventory 1990–2019.* Washington State Department of Ecology. Olympia, Washington.

Washington State Department of Ecology (2024a, September 23). California, Québec and Washington to begin linkage agreement discussions. Washington State Department of Ecology. https://ecology.wa.gov/about-us/who-we-are/news/2024-news-stories/california-quebec-and-washington-to-begin-linkage-agreement-discussions.

Washington State Department of Ecology (2024b). *Hydrofluorocarbons Adopted Rule Language: Informational Guidebook.* Washington State Department of Ecology. Olympia, Washington.

Washington State Department of Social and Health Services (n.d.). *Proposed Rules and Public Hearings.* State of Washington. https://www.dshs.wa.gov/sesa/rpau/proposed-rules-and-public-hearings.

Washington Utilities and Transportation Commission. (2022). *Social Cost of Carbon.* State of Washington. https://www.utc.wa.gov/regulated-industries/utilities/energy/conservation-and-renewable-energy-overview/clean-energy-transformation-act/social-cost-carbon.

Washington State Building Code Council (WA SBCC). (2022a). “2021 Code Proposals.” State of Washington. https://sbcc.wa.gov/about-sbcc/2021-code-proposals.

WA SBCC. (2022b). *RE: Washington State Building Codes Review and Adoption Process*. State of Washington. https://sbcc.wa.gov/about-sbcc/2021-code-proposals.

Webster, M. (Ed.) (2020). *Achieving Net Zero Embodied Carbon in Structural Materials by 2050.* Structural Engineering Institute’s Sustainability Committee Carbon Working Group. 10.13140/RG.2.2.28440.14085.

Weir, M., Rempher, A. & Esau, R. (2023, March 27). *Embodied Carbon 101: Building Materials.* RMI. https://rmi.org/embodied-carbon-101/

Zahalak, T. (2022, 19 April). *Differences in Identifying Units in Small Multifamily Properties*. Fannie Mae Multifamily. https://multifamily.fanniemae.com/news-insights/multifamily-market-commentary/differences-identifying-units-small-multifamily.