DETERMINING INITIAL ACCEPTABLE GWP LIMITS FOR CEMENT AND CONCRETE

BUY CLEAN MARYLAND ACT OF 2023

MARCH 2025

MARYLAND DEPARTMENT OF GENERAL SERVICES | MARYLAND GREEN BUILDING COUNCIL

US CLIMATE ALLIANCE PROJECT (C-20435) | PREPARED BY GREENPLUMSTREET LLC

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Maryland Buy Clean Technical Assistance c/o US Climate Alliance Project (C-20435)
March 2025
Author: GreenPlum Street LLC for Maryland Department of General Services and Maryland Green Building Council (typ@greenplumstreet.com, ndp@greenplumstreet.com)

SUMMARY
The focus of this study is the analysis of Buy Clean programs which require environmental disclosure and establishment of maximum allowable global warming potential (GWP) values for varying classes of eligible cement and concrete material. The GWP limits are compared to the industry benchmarks. Then, we establish the best pathways for Maryland to establish its own emission limits. The methodology is documented to support the Buy Clean Maryland Act (2023).

Building codes are a well-understood, enforceable vehicle for GWP requirements. California's CalGreen code set embodied carbon limits for various materials with mandatory and "reach" Tiers of performance. Denver, Colorado, amended its Green Code to require all eligible projects to meet specific GWP limits relative to the compressive strength of concrete. Because these limits are minimum values in the building code, compliance can be measured when building permits are requested and fees can be levied against projects that fail to meet the standards. The USGBC's LEED green building rating system established a voluntary standard that provides various options to encourage higher performance certification than code minimums. This is also the case for the latest ACI 323 Low Carbon Concrete Code, an industry standard where if adopted, will be the most ambitious in the nation for large commercial projects.

Cities and states themselves are also playing a leading role in setting enforceable limits on embodied carbon in concrete. Portland, Oregon limited embodied carbon of concrete to prescribed caps and are paired with a list of pre-approved concrete mix designs. Marin County, California looked to their local structural engineers to better understand the available low-carbon mixes to establish two pathways for compliance. Throughout Colorado and New York State, state-funded projects must comply with specific GWP thresholds set by the state. Also, federal General Services Administration established limits on multiple materials which apply to projects funded under the Inflation Reduction Act.

The resulting analysis proposes four (4) optional pathways to establish global warming potential limits for concrete and cement as directed by the Buy Clean Maryland Act.

- Option 1- Adopt local collected data with adjustment factor
- Option 2- Adopt the NRMCA Eastern Region Benchmark without adjustment factor
- Option 3- (PREFERRED) Adopt the NRMCA Eastern Region Benchmark with 15% adjustment factor
- Option 4- (PREFERRED) Cement GWP Limit

The Department of General Services can use these options to consider establishing Maryland GWP limits for the sector. These options will impact a diverse group of stakeholders, not just those who manufacture concrete. Manufacturers, architects and engineers must become aware of the limitations of the reporting tools to ensure the mandatory building requirements are still met. A clear understanding of how the policies are implemented offers insights to how the industry value chain can meet functional performance goals while maximizing the chances of successful carbon reduction of the built environment.

PURPOSE

To support enhanced climate actions in Maryland's manufacturing sector, this study assesses different programs with established emissions limits, quantifies the associated reductions, and discusses embodied carbon reduction options to help achieve Buy Clean Maryland's goals to the cement and concrete sector.

The intent of this document is to provide guidance on:

- Identifying and analyzing embodied carbon limits used in peer policies or standards;
- Creating a functionally acceptable global warming potential limit for cement and concrete;
- Submission requirements used for compliance.

SCOPE

The Buy Clean Maryland Act, requires the Department of General Services (DGS) conduct a study, submitted in a report to the of the legislature by December 1, 2025, that includes:

- a description of the method that the Department used to develop Maximum Global Warming Potential for each category of eligible material [cement and concrete].

In this study, the GreenPlum Street team assessed four codes and standards, five governmental agencies policies and Maryland's existing dataset in developing its acceptable global warming potential limits for cement and cast-in-place concrete. Other products such as precast, concrete masonry or shotcrete are not considered as they do not meet the legislative intent. We evaluate the scope and functionality of the programs so they may provide decision-useful guidance to meet Buy Clean Maryland embodied carbon reduction goals.

While there are other similar programs like ASHRAE Standard 189.1-2023, the New Jersey Low Embodied Carbon Concrete Leadership Act (2023) and the Embodied Carbon in Vancouver Building Bylaw 2025 that do address the embodied carbon of concrete, they were excluded from the Study as they did not establish global warming potential (GWP) limits but addressed CO_2 reductions in other ways. Likewise, the U.S. Federal Highway Administration (FHWA) established GWP limits of low carbon materials, but its intended applicability is for infrastructure instead of buildings.

METHODOLOGY

Sharing of knowledge and priorities unique to the region by a variety of forums:

- Stakeholder feedback was accepted through various outreach programs;
- Field visit to a key cement manufacturer in Maryland;
- Key actors in the concrete disclosure value chain were interviewed;

In this study, assessments were made of ten (10) programs including the Maryland dataset with varying GWP limits of concrete and/or cement. Each were compared to the North American or regional industry-wide benchmarks;

- An evaluation was made on their impacts to a variety of stakeholders, their limitations, uncertainty factors and structural functionality.
- Options for establishing Maryland GWP limits were derived.

ACKNOWLEDGEMENT

Interviews and/or peer reviews with Katie Poss, Building Transparency; Matthew Lemay, Lionel Lemay, Tiffany Reed-Villarreal, NRMCA; Kareem Hammoud, US Climate Alliance provided valuable insight and were welcomed inclusions.

Table of Contents

1. INTRODUCTION

Cement and concrete production have emerged as significant contributors to greenhouse gas emissions, necessitating decarbonization efforts. The environmental impact of these industries is driven by the carbon dioxide (CO_2) released during cement manufacturing, along with energy-intensive processes. Concrete, which heavily relies on cement, further amplifies these environmental challenges. Agencies around the United States are taking steps to incorporate enforceable global warming potential (GWP) limits for concrete mixes into building and infrastructure projects. Like several other states, Maryland has done this by making commitments in climate action plans and designing government procurement requirements and performance standards.

On April 4, 2023, Maryland Governor Wes Moore signed the Eligible Projects – Procurement of Construction Materials bill (Buy Clean Maryland Act) into law[i]. The Act instructs the Maryland Department of General Services (DGS) to assess the global warming potential (GWP) impact of each category of cement or concrete mixture used in the construction of a public project. Beginning July 1, 2026, state agencies would be required to specify in each solicitation for a government-funded construction project the cement or concrete mixture that would be used in the building materials and prioritize proposals with the lowest carbon (a.k.a. carbon dioxide) footprint. The Act is limited to buildings that have to comply with the High Performance Green Building Program (SF&P §3–602.1) and requires the DGS to establish a maximum acceptable global warming potential for certain categories of eligible materials by January 1, 2026.

To ensure success of this green procurement policy, this Study builds upon the *Literature Research and Analysis Implementation of Buy Clean Programs* (for DGS) and references precedents from other similar types of policies. Finally, this Study provides recommendations on establishing embodied carbon global potential limits for cement and concrete into Maryland DGS Procedure Manual as it relates to the Maryland Green Building Council's High Performance Green Building Program. The goal of the research is to provide insight that foster the decision-making process, helping identify opportunities and risks of establishing Maryland's own benchmarks.

1.1. Legislative requirements

This assessment will focus on established baselines from industry, building standards, public policies to address key implementation elements of the Buy Clean Maryland Act (Act) for a successful realization of the policy:

1. [SF&P §4-903 (B)] on or before January 1, 2026, the department shall, in consultation with the department of transportation, establish a maximum acceptable global warming potential for each category of eligible materials used in an eligible project in accordance with this section.
2. [SF&P §4-903 (C)(1)] base the maximum acceptable global warming potential on the industry average of global warming potential emissions for that material;
3. [SF&P §4-903 (C)(2)] determine the industry average of global warming potential emissions, which may include transportation–related emissions, by consulting nationally or internationally recognized databases of environmental product declarations; and
4. [SF&P §4-903 (C)(3)] express the maximum acceptable global warming potential as a number that states the maximum acceptable global warming potential for each category of eligible materials, consistent with criteria in an environmental product declaration.
5. [SF&P §4-903 (D)(1)] establish additional subcategories within each category of eligible material with distinct maximum acceptable global warming potential limits;
6. [SF&P §4-903 (D)(2)] establish a maximum acceptable global potential for each material category in the aggregate;
7. [SF&P §4-905 (B)] the report submitted on or before December 1, 2025, shall include a description of the method that the Department used to develop Maximum Global Warming Potential for each category of eligible material [cement and concrete].

1.2. Engaging stakeholders

To establish global warming potential (GWP) limits for cement and concrete as required by the Buy Clean Maryland Act, it is essential to adopt context-relevant methods that consider local mitigation potential and data availability. The first step was to engage stakeholders through forums to facilitate the sharing of knowledge and priorities unique to the region. The stakeholder engagement process for Buy Clean Maryland included:

- Green Plum Street LLC (GPS) contacted EPD program operators, the Maryland Ready Mix Concrete Association (MRMCA), data aggregator Building Transparency, and individual concrete producers.
- Green Plum Street LLC (GPS) participated in a panel discussion addressing Buy Clean Maryland issues at the 24th MRMCA Annual Conference 2024 where concrete producer members convened.
- The Maryland Green Building Council, DGS staff and GPS conducted a field visit to a cement plant manufacturing low-carbon cement that meets the proposed intent of the Act.
- Public comments from the initial *Literature Research and Analysis Implementation of Buy Clean Programs Study*.
- Two public workshops hosted in 2024 sought to educate stakeholders on the Act and encourage public participation in the development of the DGS process to implement the Buy Clean Maryland Act to achieve its climate goals. Sessions included the following participants: Maryland AIA Baltimore members, Maryland AGC members, ASCE Maryland members, AIA Chesapeake Bay members, MRMCA and NRMCA members, Maryland University, Towson University, Maryland Office of School Facilities and contractors.

Photo by Vinayak Sharma via Unsplash

2. IMPLEMENTATION

2.1. Structure of Buy Clean policies

Each Buy Clean policy has a different scope, regulatory framework, incentives, and mechanisms for implementation. Many policies require agencies to consider the embodied carbon emissions of industrial "eligible materials" – concrete, structural steel, carbon steel rebar, flat glass and/or mineral wool board insulation – when contracting for capital projects. Some solely focus on cement and concrete. Eligible projects may also have a commencing date or minimum project threshold (e.g. “eligible project”) to trigger the regulation such as a gross area square footage or contracts costs.

The Buy Clean policies emphasize reducing its global warming potential (GWP) measured in $kgCO_2e/m^3$, specifically the cradle-to-gate embodied carbon impact, by identifying emissions in construction products using reporting tools. The burden is placed on the bidding contractor to deliver environmental disclosure reports called ***environmental product declarations*** (EPD) and select material providers with lower GWP impacts. Further, many agencies developed "maximum acceptable" GWP limits of materials to which materials must comply to be considered for contract bidding. The type of limit to be set by the named agency may also vary depending on the policy design.

Two components that are key to understanding this the requirements:

- **Disclosure:** Requirement to disclose the carbon footprint of eligible material using facility-specific EPDs.
- **Limits**: Requirements that a product’s carbon footprint be below a maximum acceptable GWP limit established by a government agency or third party. These limits may decrease over time at intervals to reflect decreases in the industry average GWP due to reductions in industrial emissions.

2.2. Measurement and disclosure[ii]

2.2.1. Environmental Product Declarations (EPD) are independently verified and registered documents that communicates transparent information about the life-cycle environmental impact of products, including GWP among others. EPDs adhere to strict regulations and standards and are often valid for five years. EPDs are developed from an in-depth life cycle assessments (LCA) of a material or product in accordance with a consensus-established product category rules (PCR) document. That is, LCAs are comprehensive environmental evaluations. Whereas EPDs are shorter, simpler, and verified versions of the LCA to make them easier to understand and communicate to stakeholders.

2.2.2. Life Cycle Assessments (LCAs) that complies with standards in the ISO 14040 series and ISO 21930 are used to analyze and quantify the environmental impacts of a product, system, or process. This product LCA examines inputs of materials and energy and outputs of emissions, wastes, and products from raw material production to end-of-life. Environmental impact assessment tools use the total emissions and wastes to quantify the potential environmental impacts for a variety of characterization factors.

2.2.3. Product Category Rules (PCR) are developed for specific product categories and EPDs generated based on different PCRs should not be compared to assess environmental performance. PCRs offer calculation rules and guidelines to ensure comparability between EPDs within the same product category by following the same calculation methods and reporting guidelines.

2.3. Submittal process

The awarding agency will review the submittals for compliance before awarding a project and confirms before installation in the construction phase. Specifications for concrete in construction documents establish project requirements where the contractor and material suppliers must comply. Project specifications that adhere to industry standard specifications, such as ACI 301 Specification for Structural Concrete, generally applicable for buildings, are supportive of performance-based criteria and sustainable concrete construction and can be adopted by reference in a project specification.

1. A first step for the contractor is to establish a bill of materials. A bill of material is a list of materials and products (a.k.a. mixes) and their quantities that make up the physical building. Sources can be from:
    a. Building information model (BIM)
    b. A cost estimate
    c. Takeoffs from drawings

2. Specifications: The AIA MasterSpec format, Section 033000 for Cast-in-place concrete provides context to the typical sections seen in the project specifications. Bidding teams should include the following:
    a. Required Data:
        i. Product quantity in Declared Units;
        ii. Environmental Product Declaration (EPD) which is product- and facility-specific.
    b. Applicable project-specific sustainable materials goals for the work of this Section include Low Embodied Carbon Materials.
        i. Embodied carbon material baseline (a.k.a. limit);
        ii. Actual embodied carbon of the products listed;
        iii. Calculations per mix design or project weighted average. Submit these calculations at the time of the concrete mixture design submittal prior to installation.

2.4. Compliance per mix design or weighted average

Per the Buy Clean Maryland Act, the DGS shall

> "establish a maximum acceptable global potential for each material category in the aggregate;"[iii]

For most Buy Clean type policies, the GWP limits for the eligible concrete material is a performance metric in addition to other performance requirements on the project specific specifications. Typically, compliance can be achieved on a "per mix" basis or project "weighted average" basis (a.k.a. aggregated). The project team may also submit the required EPDs for concrete strengths between the stated values by using linear interpolation to determine concrete embodied carbon limits and/or weighted average calculations to demonstrate compliance per Equation (1).

Total embodied carbon (EC_{proj}) of all concrete mix designs within the same project shall not exceed the project limit ($EC_{allowed}$) determined using jurisdiction established GWP limits.

$$\mathbf{EC_{proj} < EC_{allowed}} \qquad (1)$$

where

$EC_{proj} = \Sigma EC_n \, v_n$ and $EC_{allowed} = \Sigma EC_{th} \, v_n$ (2), (3)

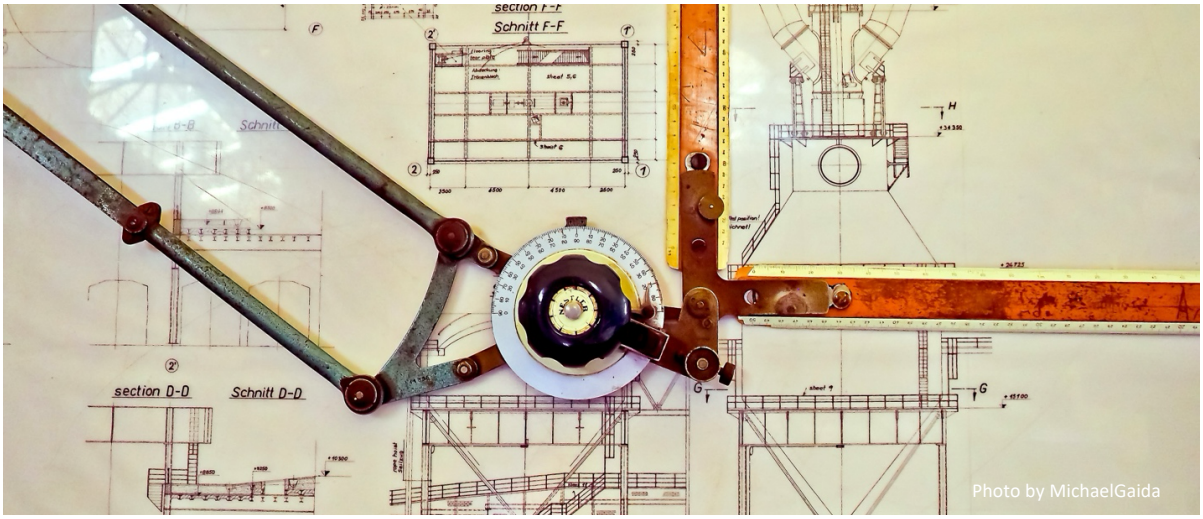
and

n = the total number of concrete mixtures for the project

EC_n = the embodied carbon for mixture n per approved EPD, GWP/m^3

EC_{th} = the embodied carbon threshold for mixture n per jurisdiction limit, GWP/m^3

v_n = the volume of mixture n concrete to be placed, m^3



3. BENCHMARKING

It is helpful to understand the industry benchmarks as the backdrop to the limits being established in Buy Clean policies. Benchmark values represent Product Stage (A1-A3) carbon impacts — that is, the *cradle-to-gate* impacts from raw material extraction to manufacturing. This cradle-to-gate scope comprises the majority of embodied carbon impacts for concrete and is consistent with the scope of concrete EPDs.

Industry-wide (IW) EPDs are developed by industry associations representing multiple manufacturers and locations and declare the environmental impacts associated with an "average product" in a clearly defined sector or geographic area. Products covered in an industry-wide EPD follow the same Product Category Rule (PCR) and have the same declared unit. All industry-wide EPDs are published, peer-reviewed documents based on rigorous LCA models.

Per the Buy Clean Maryland Act:

> "base the maximum acceptable global warming potential on the industry average of global warming potential emissions for that material;"

3.1. Cement Benchmark

For cement, the Portland Cement Association (PCA) published an industry-wide EPDs based on the survey of cement produced in the United States (US) by members posted at ASTM International, a program operator. Four main categories of cement have been covered; ASTM C150 portland cement, ASTM C595 portland-limestone cement, ASTM C595 blended cements, and ASTM C91 masonry cement produced in North America. Table 1 shows the Production Stage Cradle-to-gate EPD Results for Cements (2023).

Table 3.1. Production Stage Cradle-to-gate Global Warming Potential results from PCA industry-wide EPDs for Cements (2023)

Global Warming Potential, GWP 100, IPCC 2013	***Per 1 metric ton***	***Unit***
ASTM C-150 portland cement[iv]	919	$KgCO_2$ eq
ASTM C595 portland-limestone cement[v]	844	$KgCO_2$ eq
ASTM C595 blended cement[vi]	739	$KgCO_2$ eq
ASTM C91 masonry cement[vii]	587	$KgCO_2$ eq

3.2. Concrete Benchmark

As a concrete EPD program operator, the National Ready Mixed Concrete Association (NRMCA) used data collected in developing the LCA and Industry-Wide EPDs (IW-EPD) for concrete to develop a set of regional benchmarks for key environmental impacts. The NRMCA Member National and Regional LCA Benchmarks Report (Benchmark Report) represents the environmental impacts of products with varying strengths for different applications and exposure conditions at the national level and eight NRMCA regions. The methodology used statistical assessment of GWP developed based on primary data gathered as part of the NRMCA industry regional benchmark LCA for each life cycle modules. Table 1 is adopted from the NRMCA Benchmark Report - v3.2 (2022)[viii]. The Eastern Region values are **bolded** as a Maryland reference point for comparing the varying limits being established.

Table 3.2. Global Warming Potential results from NRMCA national and regional benchmarks for ready-mixed concrete (2022) in $kgCO_2e/m^3$

		Normal weight (2,000-2,600 kg/m^3)						Lightweight (<2,000 kg/m^3)		
Compressive Strength in PSI (MPa)		*2500 psi (17.2)*	*3000 psi (20.7)*	*4000 psi (27.6)*	*5000 psi (34.5)*	*6000 psi (41.2)*	*8000 psi (55.2)*	*3000 psi (20.7)*	*4000 psi (27.6)*	*5000 psi (34.5)*
REGION	Pacific Southwest	257	279	323	378	401	456	500	546	594
	Pacific Northwest	235	261	316	386	408	487	518	575	632
	Rocky Mountains	232	255	301	358	379	440	484	532	580
	South Central	226	245	286	336	356	409	468	510	555
	North Central	241	264	312	372	394	460	487	537	591
	Southeastern	247	268	309	360	382	435	478	521	562
	Great Lakes	232	255	303	363	383	452	499	551	603
	Eastern	**240**	**264**	**314**	**378**	**399**	**472**	**517**	**573**	**628**
	National	240	262	308	365	385	446	492	540	588

3.3. Aligning Decarbonization Goals

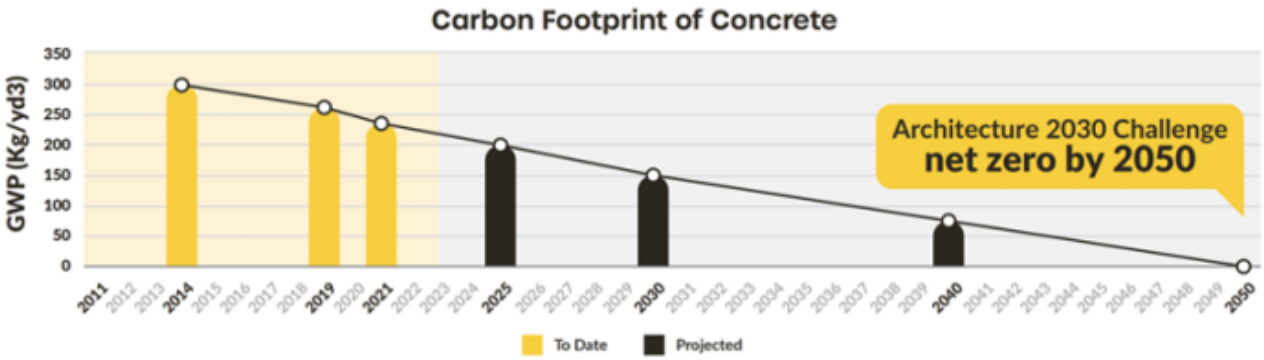
The Maryland's Climate Pollution Reduction Plan published 28 December 2023[ix] outlines opportunities to implement a sustainable path to meet the Climate Solutions Now Act of 2022 (CSNA)[x] GHG reduction goals. As listed in the Priority Climate Action Plan (PCAP) State of Maryland published in 2024 MEASURE 15:

> *Buy Clean - Requires producers of cement and concrete mixtures to submit environmental product declarations to the state and for the state to establish a maximum acceptable global warming potential values for each category of eligible materials.*

This requires Maryland to reduce state-wide greenhouse gas (GHG) emissions by 60% from a 2006 baseline by 2031. The CSNA estimate of the quantifiable GHG emissions reduction benefit from Buy Clean in 2031 to be 0.299 $MMTCO_2e$ and estimate reduction in 2045 to be 0.464 $MMTCO_2e$.

The cement and concrete industries have committed to meet the challenge of reducing its carbon footprint. The Global Cement and Concrete Association (GCCA) set out a net zero pathway to help limit global warming to $1.5^{O}C$ with its 2050 Cement and Concrete Industry Roadmap for Net Zero Concrete[xi]. Likewise, The US Portland Cement Association (PCA), the Cement Association of Canada, and the National Ready Mixed Concrete Association (NRMCA) have committed to the goal of reaching carbon neutrality throughout the cement-concrete-construction value chain by 2050[xii]. The Roadmap to Carbon Neutrality involves the entire value chain to carbon neutrality and leverages relationships at each step of the value chain which include the production of clinker, the manufacture and shipment of cement, the production of concrete, the construction of the built environment, and the capture of carbon dioxide using concrete as a carbon sink. The NRMCA National and Regional LCA Benchmarks Report updates every 3-4 years.

Figure 3.3.1. Carbon footprint of concrete per NRMCA net-zero workplan (Image courtesy of NRMCA).



4. CODES, STANDARDS AND GREEN RATING SYSTEMS CASE STUDIES

Building codes, standards and green rating systems serves different purposes in the construction and sustainability landscape. Building *codes* establishes minimum regulations for building systems using prescriptive- and performance-related provision pertaining to the design and construction of buildings. The primary purpose of building codes is to protect the health and safety of the general public as well as the building's occupants through proper design and construction methods. Similarly, a *standard* is a set of guidelines and criteria that overlay the minimum requirements of code by which a product or building can be judged.

On the other hand, green building *rating systems* are an aspirational evaluation tool that measures superior environmental performance of a building. Embodied carbon reduction in rating systems is not limited to setting limits on GWP. It can be achieved through multiple compliance pathways including awarding building reuse, recycled content, salvaged building materials, or building deconstruction techniques which may realize greater carbon savings.

The unique difference between codes verses green building rating systems is that codes are *mandatory* and enforced by local governments. Although there may be some overlap, the green rating systems are typically *voluntary* and certifications are awarded by a third-party. They are meant to encourage higher performance than code minimums. The distinction between base minimum and more ambitious levels of performance permits jurisdictions to award incentives such as tax credits, fee reductions, grants, expedited permitting processes and density bonuses. Moreover, building codes provisions are not intended to unnecessarily increase the construction costs, restrict the use of materials, restrict construction methods, nor give preferential treatment to particular materials. Green building systems may favor one product or method to meet their performance agenda and add costs – registration, certification, third-party consultants, testing, and new technologies.

The Maryland High-Performance Green Building Program (HPGBP) applies to state-funded projects. The HPGBP requires the use of one of the three approved green building rating programs or codes in the design, construction, and operation of facilities:

- Leadership in Energy and Environmental Design (LEED), a program of the U.S. Green Building Council;
- International Green Construction Code (IgCC), one of the codes of the International Code Council;
- The Green Globes protocol of the Green Building Initiative.

We can start our analysis to establishing an acceptable GWP limits for Buy Clean Maryland by evaluating the various GWP limits for concrete created by several codes, standards and rating systems.

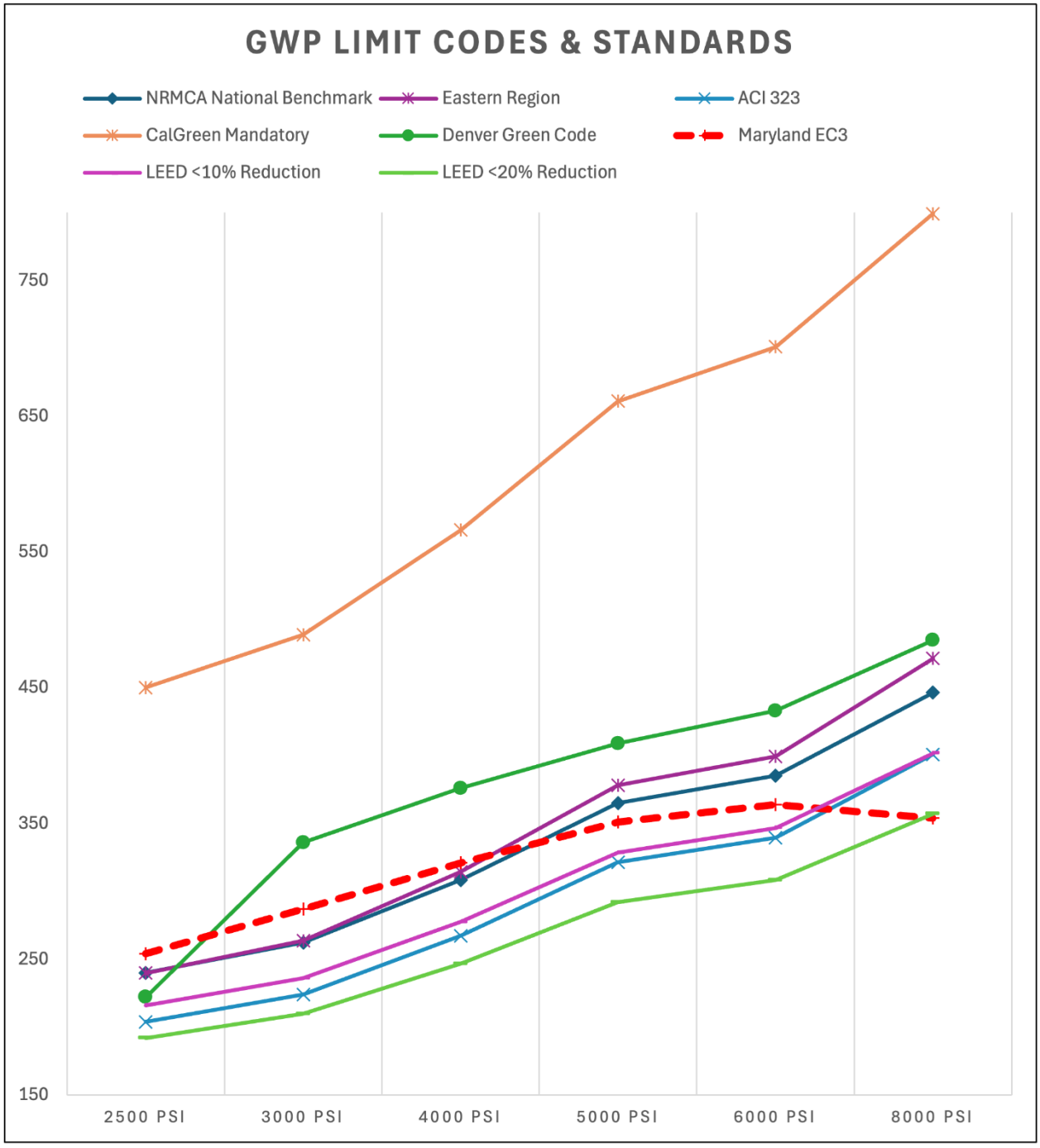


Figure 4.1. Maryland data compared to codes and standards with GWP limits

4.1. The California Green Building Standards Code (CalGreen)

On August 2, 2023, California became the first state in the country to make Embodied Carbon emission control a mandatory part of the building code. The measures were included in the 2022 Intervening Cycle updates to the California Green Building Standards Code (CALGreen) Part 11, Title 24, effective July 1, 2024 statewide. Nonresidential commercial building projects over 100,000 square feet and school building projects over 50,000 square feet will be required to comply with one of three pathways:

1. Building Reuse: Reuse at least 45% of an existing structure and exterior. When reuse is combined with new construction, the total addition area using this pathway is limited to double the area of the existing structure.
2. Performance: Complete a whole building lifecycle assessment (WBLCA) demonstrating 10% lower embodied carbon emission than a baseline project design.
3. Prescriptive: Document environmental product declarations (EPDs) for listed materials (steel, glass, mineral wool, concrete) that are on average lower than a specified threshold of global warming potential.

Table 4.1.1. Maximum allowable GWP Prescriptive Limits for CalGreen (2022) in $kgCO_2e/m^3$

	Normal weight						Lightweight		
*Compressive Strength in PSI (MPa)**	*2500 psi (17.2)*	*3000 psi (20.7)*	*4000 psi (27.6)*	*5000 psi (34.5)*	*6000 psi (41.2)*	*8000 psi (55.2)*	*3000 psi (20.7)*	*4000 psi (27.6)*	*5000 psi (34.5)*
CalGreen Mandatory (175%)	450	489	566	661	701	799	875	956	1039
% Compared to NRMCA Pacific SW Regional Benchmark	175%	175%	175%	175%	175%	175%	175%	175%	175%
CalGreen Tier 1 (150%)	386	419	485	567	601	685	750	819	891
% Compared to NRMCA Pacific SW Regional Benchmark	150%	150%	150%	150%	150%	150%	150%	150%	150%
CalGreen Tier 2 (130%)	334	363	421	491	521	593	650	710	772
% Compared to NRMCA Pacific SW Regional Benchmark	130%	130%	130%	130%	130%	130%	130%	130%	130%

*High Early Strength ready-mixed shall be calculated at 130% of the concrete GWP allowed values

While this Prescriptive path limits material choices to those that are less than 175% of industry average GWP, even those poor performing materials could be used in a project under the Performance compliance path as the analysis allows balancing poor GWP performing materials with high GWP performing materials. CALGreen includes Tier 1 and Tier 2 requirements that will be available for local jurisdictions to voluntarily adopt. The tiers serve to 'predict the future', i.e. where things are headed allowing stakeholders to plan accordingly. The use of Tier framework also support local reach codes increases consistency across the state, while also lowering costs and efforts required for adoption.

4.2. The Denver Green Code

The Denver Green Code is a *voluntary* set of guidelines aimed at promoting sustainable building practices in Denver, Colorado. In 2023 the Denver Green Code placed a strong emphasis on reducing embodied carbon emissions in building projects when it set specific greenhouse gas performance (GWP) limits for materials such as concrete and steel for commercial and multifamily developments. Commercial projects in Denver must choose about 10% of the green code with both required and elective provisions to follow to comply with local law. Along with provisions on water use and residential energy are the embodied carbon amendments on concrete and steel.

Table 4.2.1. Maximum allowable GWP Limits for Denver Green Code in $kgCO_2e/m^3$

	Normal weight						Lightweight		
Compressive Strength in PSI (MPa)	*2500 psi (17.2)*	*3000 psi (20.7)*	*4000 psi (27.6)*	*5000 psi (34.5)*	*6000 psi (41.2)*	*8000 psi (55.2)*	*3000 psi (20.7)*	*4000 psi (27.6)*	*5000 psi (34.5)*
Denver Green Code	222	336	376	409	433	485	578	626	675
High Early Strength (HES)	305	439	490	533	566	631			
% Compared to NRMCA Rocky Mountain Region Benchmark	96%	132%	125%	114%	114%	110%	120%	118%	116%
% Compared to NRMCA National Benchmark	93%	128%	122%	112%	112%	109%	117%	116%	115%

The Denver Green Code accounted for high early strength (HES) concrete with GWP values approximately 30% greater than the allowable values. High early strength concrete may require more cement because a higher cement content leads to a faster hydration reaction, resulting in rapid strength gain in the early stages of curing. HES concrete allows for faster floor construction cycles with post-tensioned slabs and earlier stripping of formwork after tendon stressing or opening up pavements to traffic.

To better understand the differences between the average (mean) values in the NRMCA benchmarks verses median values in the collected data: The values represented in the Denver Green Code GWP limits table are based on the 50th percentile of the local EPDs collected by Building Transparency's EC3 tool. The 50th percentile, also known as the median, can appear to be 10-32% more than the average as compared to the NRMCA Rocky Mountain Region data set because of a skewed distribution, where a small number of very high values significantly pull the average upwards, while the middle point (50th percentile) remains relatively unaffected by these outliers. Essentially, the majority of data points are clustered below the average, making the Denver EC3 collected median seem higher in comparison.

4.3. US Green Building Council's LEED v4.1

Only one of the three HPGBP approved green building rating programs have established GWP limits as a credit option. LEED is the most widely used green building rating system globally. It is designed for various types of buildings and assesses them based on a point system, awarding points for criteria such as energy efficiency, water usage, and sustainable site development.

The Materials and Resources category encourage the use of products and materials for which life-cycle information is available with EPDs and that have environmentally, economically, and socially preferable life-cycle impacts. To reward project teams for selecting products from manufacturers who have verified improved environmental life-cycle impacts. As typical with rating systems, the EPD credit is an option among other decarbonization pathways.

LEED v4.1 utilizes two Options for the EPD credit with one available point each.

- **Option 1-Disclosure**- Use at least 20 different permanently installed products sourced from at least five different manufacturers that meet one of the disclosure criteria. This credit awards Product-specific Type III EPD for Products with third-party certification (Type III), including external verification and external critical review are valued as 1.5 products for the purposes of credit achievement calculation.

- **Option 2-Optimization** - Use products that have a compliant embodied carbon optimization report or action plan separate from the LCA or EPD. Use at least 5 permanently installed products sourced from at least three different manufacturers. Valuation to achieve the one point are listed and include:

Table 4.3.1. Maximum allowable GWP limit LEED v4.1 Optimization Option 2.1 in $kgCO_2e/m^3$

	Normal weight						Lightweight		
Compressive Strength in PSI (MPa)	*2500 psi (17.2)*	*3000 psi (20.7)*	*4000 psi (27.6)*	*5000 psi (34.5)*	*6000 psi (41.2)*	*8000 psi (55.2)*	*3000 psi (20.7)*	*4000 psi (27.6)*	*5000 psi (34.5)*
<10% Reduction in Embodied Carbon	216	236	277	328	347	402	443	486	529
% Compared to NRMCA National Benchmark	90%	90%	90%	90%	90%	90%	90%	90%	90%

Table 4.3.2. Maximum allowable GWP limit LEED v4.1 Optimization Option 2.2 in $kgCO_2e/m^3$

	Normal weight						Lightweight		
Compressive Strength in PSI (MPa)	*2500 psi (17.2)*	*3000 psi (20.7)*	*4000 psi (27.6)*	*5000 psi (34.5)*	*6000 psi (41.2)*	*8000 psi (55.2)*	*3000 psi (20.7)*	*4000 psi (27.6)*	*5000 psi (34.5)*
<20% Reduction in Embodied Carbon	192	210	247	292	308	357	394	432	471
% Compared to NRMCA National Benchmark	80%	80%	80%	80%	80%	80%	80%	80%	80%

Table 4.3.3. Maximum allowable GWP limit LEED v4.1 Optimization Option 2.3 in $kgCO_2e/m^3$

	Normal weight						Lightweight		
Compressive Strength in PSI (MPa)	*2500 psi (17.2)*	*3000 psi (20.7)*	*4000 psi (27.6)*	*5000 psi (34.5)*	*6000 psi (41.2)*	*8000 psi (55.2)*	*3000 psi (20.7)*	*4000 psi (27.6)*	*5000 psi (34.5)*
20%+ Reduction in Embodied Carbon	≤191	≤209	≤246	≤291	≤307	≤356	≤393	≤431	≤470
% Compared to NRMCA National Benchmark	≤80%	≤80%	≤80%	≤80%	≤80%	≤80%	≤80%	≤80%	≤80%

4.4. ACI 323-24 Low-Carbon Concrete Code

The first edition of the American Concrete Institute's Low-Carbon Concrete Code[xiii] (ACI 323), published on November 2, 2024, has a narrow scope focused on up-front embodied carbon emissions for cast-in-place concrete systems. The Code is more of a Standard as it may be adopted as a stand-alone document or can be used in combination with a structural design code or low-carbon material code adopted by an authority having jurisdiction. ACI 323 is entirely technology agnostic, meaning that it does not require or limit the types of concrete technologies that can be used in concrete mixtures. It is the first industry publication to define what low-carbon concrete is and how to meet policy and code requirements is an important task for all members of the concrete industry.

In determining the ACI 323 requirements, projects less than 50,000 ft^2 have reporting requirements but no GWP limits to meet. This is a significantly greater threshold than the 7,500 ft^2 scope for the Maryland Green Building Council High Performance Green Building Program (HPGBP) provisions which would fall under Tier 2 (BL2) which requires only documentation of GWP of the project.

The Tier 1 (BL1) compliance path, currently reserved for large construction projects greater than or equal to 50,000 ft^2, will require jurisdictions to define a weighted GWP limit for the cast-in-place concrete used on their project by setting α where,

$$GWP_{project\ avg} \leq \alpha GWP_{benchmark\ avg} \quad (4)$$

Similar to the Section 2.4 Compliance method, the weighted GWP used in ACI 323 will be a reduction (α) from the local GWP benchmark, as defined by the adopting jurisdiction. In lieu of collecting local data, the local jurisdiction may choose to utilize the NRMCA Regional Benchmarks which the Code defines low-carbon as α= 85% of the NRMCA Regional benchmarks.

Table 4.4.1. Maximum allowable GWP limit ACI 323 Low-Carbon Concrete Code in $kgCO_2e/m^3$

	Normal weight						Lightweight		
Compressive Strength in PSI (MPa)	*2500 psi (17.2)*	*3000 psi (20.7)*	*4000 psi (27.6)*	*5000 psi (34.5)*	*6000 psi (41.2)*	*8000 psi (55.2)*	*3000 psi (20.7)*	*4000 psi (27.6)*	*5000 psi (34.5)*
ACI 323	204	224	267	321	339	401	440	487	534
% Compared to NRMCA Eastern Region Benchmark	85%	85%	85%	85%	85%	85%	85%	85%	85%

Photo by m880 on Freeimages

5. PEER POLICY CASE STUDIES

To further the analysis to establish acceptable GWP limits in line with the Maryland policy effort, we can consult the actions of other governmental agencies which have set limits on the embodied carbon of cement or concrete. Since Buy Clean California (which did not include cement nor concrete) passed in 2017, several states, local jurisdictions and the federal government have established low-carbon procurement programs with acceptable GWP limits.

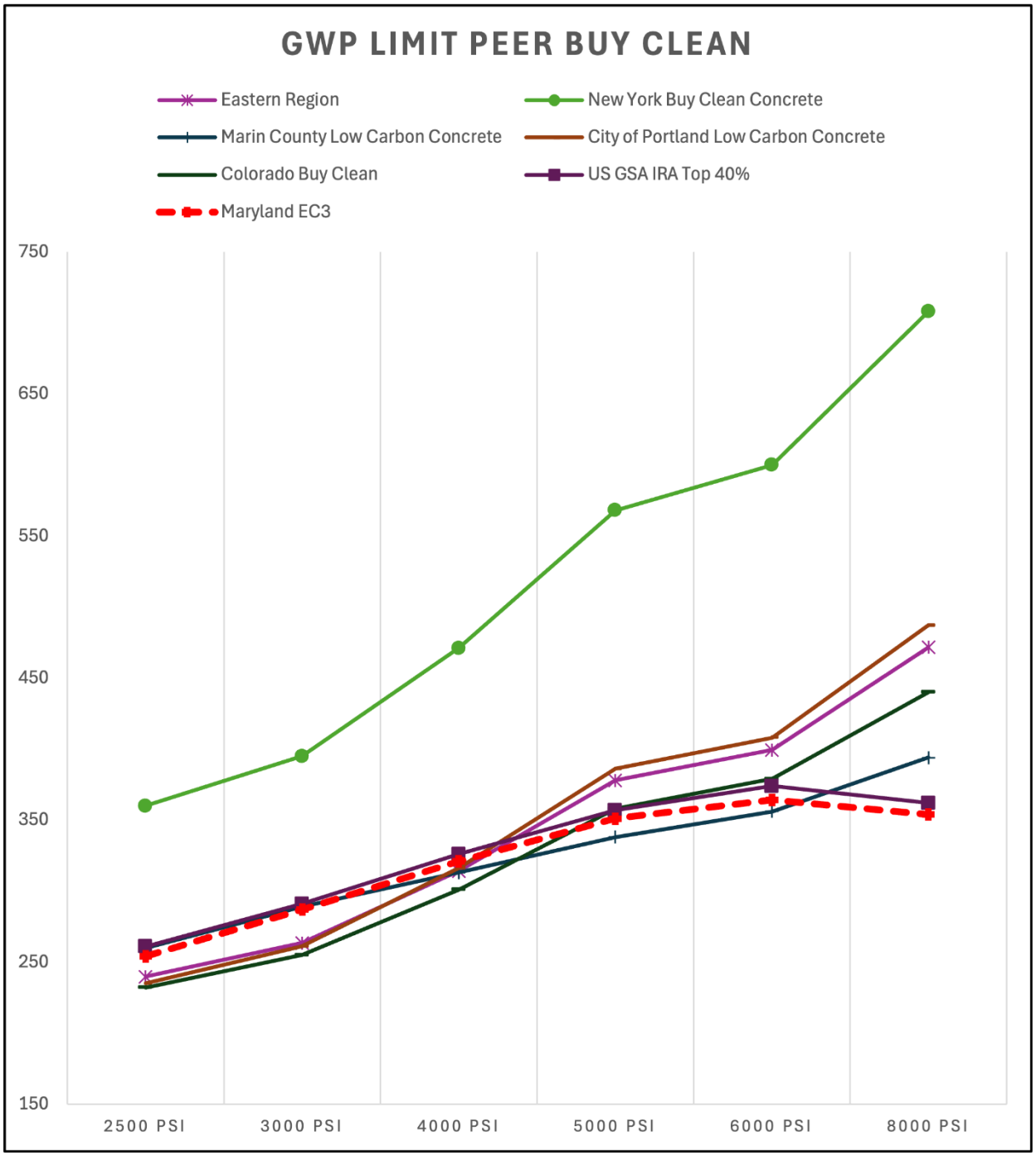


Figure 5.1. Maryland data compared to peer Buy Clean GWP limits programs

5.1. Marin County, California- Low Carbon Concrete Code

Marin County adopted the first-of-its-kind effort to address embodied emissions in local government. As of November 19, 2019, all projects placing concrete within unincorporated Marin County[xiv] must comply with concrete or cement composition standards that maintains adequate strength and durability while reducing embodied carbon emissions. The county partnered with engineers, and academia, and a robust stakeholder group to develop model code language for adoption and low embodied carbon concrete specifications for residential and nonresidential applications. Marin County proposed two pathways for compliance- a maximum cement content in lbs/yd^2 (limited to concrete with less than 5,000psi compressive strength) and an embodied carbon limit in Table 5.1.1.

Table 5.1.1. Maximum allowable GWP Limits for Marin County Low-carbon concrete code in kgCO2e/m^3

	Normal weight						Lightweight		
Compressive Strength in PSI (MPa)	*2500 psi (17.2)*	*3000 psi (20.7)*	*4000 psi (27.6)*	*5000 psi (34.5)*	*6000 psi (41.2)*	*8000 psi (55.2)*	*3000 psi (20.7)*	*4000 psi (27.6)*	*5000 psi (34.5)*
Marin County	260	289	313	338	356	394*	578	626	675
% Compared to NRMCA Pacific SW Regional Benchmark	101%	104%	97%	89%	89%	86%	116%	115%	114%
% Compared to NRMCA National Benchmark	108%	110%	101%	93%	93%	97%	118%	116%	115%

*Marin Co strength class set at ≥7001psi (48.3MPa)

The embodied carbon limits proposed above were developed based upon an iterative process with consultation from the stakeholders. A group of volunteer structural engineers evaluated the cement and embodied carbon impacts for different concrete mix designs in use in Northern California, a wide set of data was analyzed[xv]. Over 400 mix designs were collected, primarily for projects within San Francisco. The set included:

a. data from the NRMCA LCA report for the US and Pacific Southwest, which includes California;
b. data from ClimateEarth, a life cycle assessment / data aggregator; and
c. data collected by structural engineers in the Structural Engineer's Association of Northern California

The mixes collected fell below the 10% reduction to the NRMCA benchmark number. For higher strength mixes, the majority fall below the 30% reduction based on the NRMCA benchmark. The final agreed limits factored this into calculations. The rigorous process was well documented allowing other local jurisdictions to replicate. The City of Santa Monica adopted the same pathways – cement content and GWP limits as Marin County in 2024.

In the implementation process, the County utilizes a batch certificates approach where EPDs are reviewed for compliance by the building department prior to approving any inspections following placement of concrete. Similar to the Denver Green Code, concretes needing early strength – precast, prestressed, beams and slabs above grade, and retaining walls requiring immediate backfill – have been allowed a 30% increase in these limits.

5.2. City of Portland, Oregon- Low Carbon Concrete Purchasing Program

In 2016 the City of Portland published its Sustainable Supply Chain Analysis with the goal of establishing a variety of policies to guide it's work on sustainability. The analysis identified purchases from the construction sector as a top contributor of supply chain GHG. From 2019 the City establishing a product-specific EPD requirement for concrete mixes used on City projects, both public and private, and conducting pilot tests of lower-embodied carbon concrete mixes as compared to 100% cement mixes.

The City of Portland then established its Low-Carbon Concrete Initiative to reduce the overall carbon intensity of the concrete mixes used on City projects starting January 2020. The City used EPD data collected since 2020 [8][xvi], usage

data, stakeholder feedback, and the NRMCA Benchmark Report to decide the GWP threshold (aka limits) values. In 2022 the City established GWP limits and corresponding implementation strategies to reduce the carbon intensity of the concrete used on City projects. Compliance can be:

a. Concrete Embodied Carbon Thresholds (aka Limits)– Per Mix.
b. Concrete Embodied Carbon Thresholds – Project Weighted Average.

Table 5.2.1. Maximum allowable GWP Limit for City of Portland Low-Carbon Concrete Purchasing Program in $kgCO_2e/m^3$

	Normal weight						Lightweight		
Compressive Strength in PSI (MPa)	*2500 psi (17.2)*	*3000 psi (20.7)*	*4000 psi (27.6)*	*5000 psi (34.5)*	*6000 psi (41.2)*	*8000 psi (55.2)*	*3000 psi (20.7)*	*4000 psi (27.6)*	*5000 psi (34.5)*
City of Portland	235	261	316	386	408	487	518	575	632
% Compared to NRMCA Pacific Northwest Region Benchmark	100%	100%	100%	100%	100%	100%	100%	100%	100%
% Compared to NRMCA National Benchmark	98%	100%	103%	106%	106%	109%	105%	107%	108%

5.3. Buy Clean Colorado Act

With the passage of Buy Clean Colorado (BCCO) Act[xvii] in 2021, the state moves toward their climate goals, which plans to cut overall GHG emissions to half their 2005 levels by 2030 and eliminate GHG emissions by 2050. The Office of the State Architect (OSA) administered a program pertaining to all construction projects for state agencies and institutions of higher education whereas the Colorado Department of Transportation (CDOT) will administer a program relevant to horizontal construction projects only. Contractors must submit product-specific EPDs to the design team before the material will be approved for installation.

This law requires the OSA to establish a maximum acceptable GWP limit for each category of eligible materials. The BCCO Act applies to asphalt and asphalt mixtures, cement and concrete mixtures, glass, post-tension steel, reinforcing steel, structural steel, wood structural elements. These materials are the focus for Buy Clean Colorado due to their high carbon emissions impact and volume use in public projects. For concrete and cement below, the OSA determined the initial GWP limits based on the industry average of GWP emissions. The OSA is required to update the GWP limits at a minimum of every 4 years.

Table 5.3.1. Maximum allowable GWP Limit for Buy Clean Colorado Act in $kgCO_2e/m^3$

	Normal weight						Lightweight		
Compressive Strength in PSI (MPa)	*2500 psi (17.2)*	*3000 psi (20.7)*	*4000 psi (27.6)*	*5000 psi (34.5)*	*6000 psi (41.2)*	*8000 psi (55.2)*	*3000 psi (20.7)*	*4000 psi (27.6)*	*5000 psi (34.5)*
Colorado	232	255	301	358	379	440	484	532	580
% Compared to NRMCA Rocky Mountain Region Benchmark	100%	100%	100%	100%	100%	100%	100%	100%	100%
% Compared to NRMCA National Benchmark	97%	97%	98%	98%	98%	99%	98%	99%	99%

Cement	1,112 kgCO2e/t	Eq to 121% of PCA IW Benchmark

5.4. New York Buy Clean Concrete

The NYS Buy Clean Concrete[xviii], signed into law in December 2021, effective June 2022. The law calls for the NY Office of General Services (OGS) to establish guidelines requiring the procurement of low embodied carbon concrete on public projects. The law is intended to accelerate the use and innovation of low-carbon concrete in state projects. Starting January 1, 2025, EPDs must be submitted for all concrete mixes used in qualifying state construction projects and must demonstrate that they achieve an environmental impact below the limits set by NY OGS. This law is for New York State contracts, over $1 million, and for concrete mixes 50 cubic yards (38.2 m^3) or more as the disclosure limit.

New York State's initial mandatory emissions limits are based on the NRMCA regional benchmarks, equivalent to 150% of the average emissions for concrete mixes in the Eastern Region. They will be progressively lowered in 2027 and in subsequent years, representing a commitment to gradually reducing emissions from the concrete sector.

Table 5.4.1. Maximum allowable GWP Limits for NYS Buy Clean Concrete guidelines in $kgCO_2e/m^3$

	Normal weight						Lightweight		
Compressive Strength in PSI (MPa)	*2500 psi (17.2)*	*3000 psi (20.7)*	*4000 psi (27.6)*	*5000 psi (34.5)*	*6000 psi (41.2)*	*8000 psi (55.2)*	*3000 psi (20.7)*	*4000 psi (27.6)*	*5000 psi (34.5)*
New York	360	395	471	568	600	708	NA	NA	NA
% Compared to NRMCA Eastern Region Benchmark	150%	150%	150%	150%	150%	150%	-	-	-
% Compared to NRMCA National Benchmark	150%	151%	153%	157%	156%	159%	-	-	-

Like Buy Clean Maryland, the New York State Finance Law required the Office of General Services (OGS) to establish guidelines requiring the procurement of low embodied carbon concrete. The State convened a stakeholder advisory group consisting of professionals and representatives from several state agencies, industries, and academia. NYS uses several phases to allow for State agencies, contractors, and suppliers to become familiar with the new requirements, prior to them becoming mandatory. In 2024, contracts for relevant projects required contractors to only submit the EPDs of concrete mixes, where available. Starting in January 2025, the GWP limits above become mandatory. These limits reflect 150% of the Eastern Region average GWP figures from the NRMCA Benchmark – Version 3.2. Starting in 2027, pending availability of sufficient data for analysis, New York State will revise (lower) the mandatory concrete GWP limits in the table shown above.

5.5. US General Services Administration IRA Low Embodied Carbon Material

The Inflation Reduction Act (IRA) of 2022[xix] appropriated $2.15 billion for the procurement of low embodied carbon construction materials to help reduce carbon emissions and catalyze innovation for federal buildings. This implemented an EPD disclosure standard of four construction materials: concrete, asphalt, steel, and glass in construction and paving projects. The General Services Administration (GSA) developed the IRA Low Embodied Carbon Material requirements to specify material attributes when contracting for construction services that are funded in whole or in part by the GSA. Contractors will need to provide a product specific third-party verified EPD (from the supplier) the amount of embodied carbon involved in the product's extraction, transportation, and manufacture. Similar to Maryland's ambition, this law puts the United States on a pathway to achieving the Administration's climate goals, including a net zero operational emissions federal building portfolio by 2045, and net zero emissions procurement by 2050.

Table 5.5.1. GWP limits from US General Services Administration - IRA low embodied carbon cement

Facility-specific EPD Reported GWP in $kgCO_2e/t$		
Top 20% Limit	Top 40% Limit	Better than Average
751	819	858

Table 5.5.2. Maximum allowable GWP limits from US General Services Administration - IRA low embodied carbon concrete requirements in $kgCO_2e/m^3$

	Normal weight*						Lightweight		
Compressive Strength in PSI (MPa)	*2500 psi (17.2)*	*3000 psi (20.7)*	*4000 psi (27.6)*	*5000 psi (34.5)*	*6000 psi (41.2)*	*8000 psi (55.2)*	*3000 psi (20.7)*	*4000 psi (27.6)*	*5000 psi (34.5)*
GSA IRA Top 20%	228	257	284	305	319	321**	NA	NA	NA
% Compared to NRMCA National Benchmark	95%	98%	92%	84%	83%	72%	-	-	-
GSA IRA Top 40%	261	291	326	357	374	362**	NA	NA	NA
% Compared to NRMCA National Benchmark	109%	111%	106%	98%	97%	81%	-	-	-
GSA IRA Better Than Average	277	318	352	382	407	402**	NA	NA	NA
% Compared to NRMCA National Benchmark	115%	121%	114%	105%	106%	90%	-	-	-

*Add 30% to these numbers for GWP limits where high early strength concrete mixes are required for technical reasons

**GSA strength class set at ≥7,200 psi (49.6 MPa)

Materials qualify if their product-specific GWP is in the best performing 20 percent (Top 20 percent or lowest 20 percent in embodied GHG emissions), when compared to similar materials/products. If materials/products in the Top 20 percent are not available in a project's location, then a material/product qualifies per this determination if its GWP is in the Top 40 percent (lowest 40 percent in embodied GHG emissions). If materials/products in the Top 40 percent are not available in a project's location, then a material/product qualifies per this determination if its GWP is better than the estimated industry average. These requirements apply to all GSA projects that use at least ten (10) cubic yards of concrete.

Here, we see again that the top 20th percentile is only slightly lower than the industry average benchmark. The top 20th percentile indicates that a value is higher than 80% of scores in a dataset, which can still be lower than the average (mean) value. This occurs in datasets with a non-normal distribution (e.g., skewed distributions), where the majority of scores may cluster at a lower end while a few high scores pull up the

average. Thus, while 20% of the data lies above this percentile, the average can be influenced heavily by a few high values, making it possible for the top 20th percentile to be just below the average.

6. CONSIDERATIONS FOR MARYLAND GWP LIMITS

In order to establish GWP limits to cement and concrete, a the various established GWP limits were analyzed. This set included the codes and standards such as CalGreen and LEED along with the peer Buy Clean policies established by Marin County, City of Portland, Colorado, New York and the GSA. The existing EPDs within the state as collected by Building Transparency's EC3 tool was also evaluated in order to provide additional context.

6.1. Process of setting GWP limits

The following steps are considered to assign maximum acceptable GWP limit values:

1. Select the product category. Currently Maryland is considering cement and concrete.
2. Gather and assess the available LCA data.
3. Evaluate the representativeness of available data sources to select one of the following methods:
    a. Method A: Use the collection of product-specific EPDs (including facility-specific EPDs) to calculate an average.
    b. Method B: Use the industry-wide EPD value (e.g. from an industry association) to calculate an average.
    c. Method C: Use either the collection (Method A) or industry-wide EPD (Method B) and adjust the value to meet the goals of the policy (e.g. 85%, 100%, 150%, etc. of industry-wide EPD value).
4. Assign a "maximum acceptable" GWP limit value.

6.2. Local Maryland context

In Maryland, cement production is currently the largest contributor to emissions in the Maryland manufacturing sector, dominated by process emissions with limited mitigation options. The majority of emissions occur due to process emissions in clinker production - the active ingredient required to create cement. Process emissions are a chemical byproduct of the materials used in clinker production and cannot be avoided based on the established recipe for cement. A significant challenge in decarbonizing Maryland's cement sector is that the primary emissions blend into other major sectors, including transportation, energy, and buildings. These overlapping emissions materialize as the transportation of raw materials, electricity usage in facility buildings, and energy use required to power manufacturing processes.

The two cement plants in Maryland, Lehigh's Union Bridge and Holcim's Hagerstown, emit significantly more than non-cement facilities. Historical emissions from these plants have grown over time. Moreover, Union Bridge emitted 2,277,259 tCO_2in 2020, more than five times the 431,936 tCO emitted by the Hagerstown facility in the same year[xx]. The industry average emissions intensity for cement production in the U.S. is 776 kg CO_2/mt of cement. Union Bridge's emissions intensity is slightly more efficient than average at 720 kg CO_2 /mt of cement, while Hagerstown's emissions intensity is significantly less efficient than average at ~1000 kg CO_2/mt cement. These facilities have already taken actions or made plans to reduce emissions. Both plants switched the bulk of their production in 2023 to Portland Limestone Cement (PLC), which has a lower clinker factor and correspondingly lower emissions[xxi]. Both facilities also have plans to phase-down coal use.[xxii]

The existing available EPDs in Maryland are collected using the Building Transparency's Embodied Carbon in Construction Calculator (EC3) tool, which aims to collect all third party reviewed EPDs for published categories.

While the number of available EPDs has grown over the last few years, there is still a small number of Maryland manufacturers producing them in the state. At the time of access (January 28, 2025), there were six manufacturers listed in the EC3 tool with 1454 valid EPDs so the data may not necessarily statistically representative of the whole population of producers in the state. The values are listed in Table 6.2.1. Other values beyond 28-day strengths (3-day, 7-day, 56-day , etc) were not included.

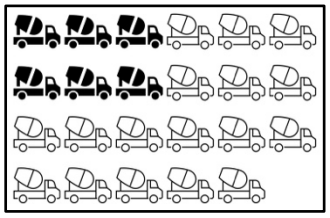


Figure 6.2.1. Maryland manufacturers represented in EC3

Table 6.2.1. Average GWP values (28 day) from EC3 tool - Maryland

	Normal weight						Lightweight		
Compressive Strength in PSI (MPa)	*2500 psi (17.2)*	*3000 psi (20.7)*	*4000 psi (27.6)*	*5000 psi (34.5)*	*6000 psi (41.2)*	*8000 psi (55.2)*	*3000 psi (20.7)*	*4000 psi (27.6)*	*5000 psi (34.5)*
Maryland EC3 Average ($kgCO_2e/m^3$)	254	287	321	351	364	354	393	450	452
Number of EPDs (28d)	55	265	386	371	64	26	3	6	2
% Compared to NRMCA Eastern Region Benchmark	106%	109%	102%	93%	91%	75%	76%	79%	72%

6.3. Limitations of EPDs

An EPD and its underlying LCA offers valuable data, but making effective use of it and avoiding the pitfalls of overconfidence in its precision requires an understanding of its limitations and inherent uncertainties. Researchers express concern when using it for comparison, "This is particularly dangerous in the case of comparative LCA where, for example, the intention can be to reduce carbon emissions by selecting a product or design alternative with a lower footprint."[xxiii]

6.3.1. Weighted Averages—An important limitation of the figures in Table 6.2.1 is to recognize that the EPD data currently does not have access to production or consumption quantities. That is, we do not know how many yards of 4000 psi concrete is being produced vs 5000 psi concrete. The fact that there are 369 EPDs for 5000 psi concrete does not mean there is an equal amount of concrete being placed as 4000 psi concrete. Thus, the values presented in the database are not weighted to production values.

6.3.2 Functional equivalence— Functional equivalence is heavily dependent on the application in which the product type is being used. Currently, EPDs do not provide information on application. Products that serve the same purpose and meet the same performance standards within the building or infrastructure design. Different product types within the same product category have varying performance characteristics that may or may not make them comparable[xxiv]. In LEED a "product" is defined by the distinct function it serves. For example, footings, foundations walls, shear walls, bearing walls, columns, beams, slabs, early-strength slab, sidewalks and parking areas, each with a unique mix design, would all be considered different products or functions. A 4000 psi mix cannot simply be compared to another 4000 psi mix without knowing the other performance requirements it is designed to meet including durability, finishability and strength gain, among others.

6.3.2. **Uncertainties**—There are many uncertainties inherent in the calculations and reporting of EPDs. LCA methodologies and assumptions (scope, boundaries, data) can vary widely enough to preclude meaningful comparison of products, even when their EPDs are based on the same PCR. Type of uncertainty[xxv]:

6.1.3.1. Product uncertainty arises when an EPD reports impacts for an entire product line (or set of products) and the impacts reported are an average of multiple products.
6.1.3.2. Plant uncertainty arises when an EPD reports impacts for a product as an average of multiple production facilities (typically as a weighted average).
6.1.3.4. Batch uncertainty arises from small batch-to-batch variations in environmental impacts.
6.1.3.3. Supply chain uncertainty arises from using average background life cycle inventory (LCI) data for impactful upstream inputs that are highly variable in terms of global warming potential. Data collected may be made up of either (a) primary data from the actual facilities and processes in the product supply chain (a.k.a. supply chain specific), or (b) from generic or representative data from a database or similar source (e.g. industry average)[xxvi]. LCAs sometimes rely on industry averages (also called secondary data) due to a lack of actual raw data (primary data). For instance, imported cement from Turkey or China. This may lead to results that are inaccurate or misleading.

These sources of uncertainty can be accounted for or removed when the EPDs are using the same LCA tool and background dataset. However, when the EPD values are taken out of the context of the proprietary LCA calculation tool and compared with EPDs from another LCA tool, the user will need to exercise caution as it may have unintentional consequences.

6.4. Proposed Options for GWP Limits

Despite the many problems with comparability as discussed above, the Buy Clean Maryland policy requires the use of EPDs for product-to-product comparisons for specification and procurement. DGS weighed different options.

6.4.1 Option 1. Adopt collected data with adjustment factor

Collection of local data most aligns with the process that the Marin County, City of Portland, and the ACI 323 Standard recommended. Unfortunately at the time of assessment, there are limited data points as the Act has not been in effect long enough to enact pilot projects. Therefore we can make adjustments that align with the inherent uncertainties of the values. This method serves the purpose of informing the user about the general data quality of an EPD using a numerical value (quantitative) simplifying the transmission of information to the user.

Table 6.4.1. Option 1. Maximum acceptable GWP limits Buy Clean Maryland

	Normal weight						Lightweight		
Compressive Strength in PSI (MPa)	*2500 psi (17.2)*	*3000 psi (20.7)*	*4000 psi (27.6)*	*5000 psi (34.5)*	*6000 psi (41.2)*	*8000 psi (55.2)*	*3000 psi (20.7)*	*4000 psi (27.6)*	*5000 psi (34.5)*
Maryland EC3 Average value ($kgCO_2e/m^3$)	254	287	321	351	364	354	393	450	452
Method A - Adjusted EC3 Value	**292**	**330**	**369**	**404**	**437**	**425**	**472**	**540**	**542**
% Compared to NRMCA Eastern Region Benchmark	122%	125%	117%	107%	109%	90%	91%	94%	86%

Building Transparency has selected the 80th percentile of the range of possible GWP impact as the uncertainty-adjusted GWP. This value was selected because the 80th percentile is a reasonable conservative estimate that incentivizes higher EPD data quality and specificity versus comparing the reported value in the EPD (i.e. an average value)[xxvii].

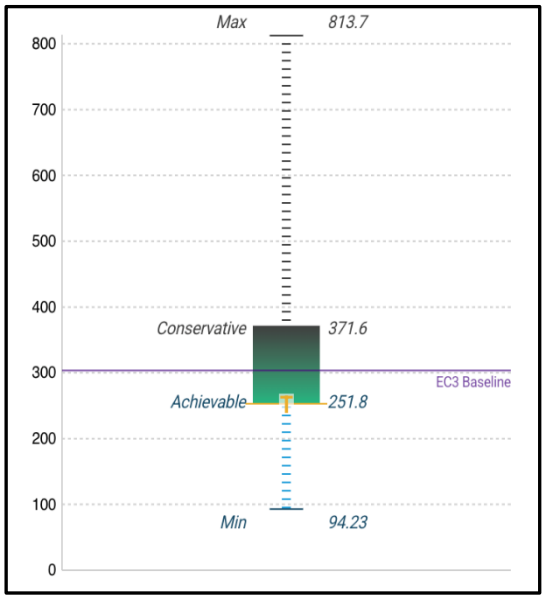


Figure 6.2.1 Maryland GWP Range from EC3

According to the EC3 database, the Maryland overall average and range in Figure 6.2.1 (per m^3):

- Conservative: 372 $kgCO_2e$
- Average: 315 $kgCO_2e$ ± 0.249%
- Achievable: 252 $kgCO_2e$

315 $kgCO_2e$ verses 372 $kgCO_2e$ ~ 15% difference
252 $kgCO_2e$ verses 315 $kgCO_2e$ ~ 20% difference

By adding a 15% adjustment factor based on the range of the achievable values in EC3, we can account for the uncertainty in the values from 2500 to 5000 psi. At the higher end of compressive strength and the lightweight values, where there is a lack of data points, we can add a factor of 20%:

- for f'c $\leq$ 5,000 psi, we use 115% of the EC3 values;
- for f'c > 5000 psi we use 120% of EC3 values, and;
- for LW concrete we use 120% of EC3 values.

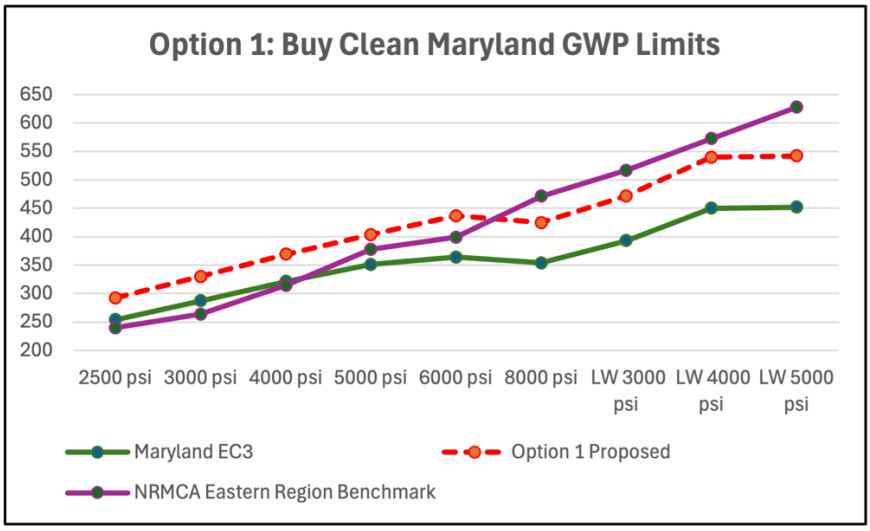


Figure 6.4.1. Option 1 maximum acceptable GWP limits compared

6.4.2. Option 2- Adopt the NRMCA Eastern Region Benchmark without adjustment factor

Maryland has set a 2045 goal for net-zero emissions. The industry is on track to meet its 2050 Cement and Concrete Industry Roadmap for Net Zero Concrete. NRMCA's five-year work plan established the industry carbon reduction ambition to achieve carbon neutrality by 2050. Therefore, with regular adjustments every three (3) years, the Maryland acceptable GWP limits can exceed the concrete industry benchmark as it aligns the embodied carbon net-zero targets for the material to 2045.

To understand the scale of the Eastern Region Benchmark: The Eastern Region includes all the states along the east coast from Maine to Virginia including West Virginia. The data points are dispersed throughout 22,58,942 m^3 of NRMCA surveyed production. Maryland's 3,404,563 m^3 total production (2023) is 9.1% of the 37,493,006 m^3 of total production of the Eastern Region[xxviii].

Table 6.4.2. Option 2 and 3. Maximum acceptable GWP limits Buy Clean Maryland in $kgCO_2e/m^3$

	Normal weight						Lightweight		
Compressive Strength in PSI (MPa)	*2500 psi (17.2)*	*3000 psi (20.7)*	*4000 psi (27.6)*	*5000 psi (34.5)*	*6000 psi (41.2)*	*8000 psi (55.2)*	*3000 psi (20.7)*	*4000 psi (27.6)*	*5000 psi (34.5)*
NRMCA Eastern Region Benchmark	240	264	314	378	399	472	517	573	628
Option 2 – No Adjustments	240	264	314	378	399	472	517	573	628
Option 3 – Adjusted 15%	**276**	**303**	**361**	**435**	**459**	**542**	**595**	**659**	**722**

Alignment with the NRMCA Eastern Region Benchmark eliminates about half of the existing EPDs in the at the lower compressive strengths (f'c =2,500 - 4,000psi) currently in the EC3 database from meeting the Buy Clean Maryland requirements for public bids. Though the dataset is small, the upper ranges with higher strengths and lightweight concrete will have more available EPDs to meet this GWP limit.

This may spur innovation among the AEC sector to take additional steps before the requirement is mandated in July 2026. With decarbonization efforts such as cement substitution (e.g. portland-limestone cement), waste fuels and efficiency in concrete production in place, the AEC community will need to seek optimization of design and novel solutions. However, this may also have a high risk of project bids requesting the waivers per the Act Section 4-904:

> "(E) The department may waive the requirements of this section if it determines that requiring the relevant eligible materials would:
>
> (1) be technically infeasible;
>
> (2) result in a significant increase in project cost;
>
> (3) result in a significant delay in project completion; or
>
> (4) result in only one source or manufacturer being able to provide the necessary materials."

6.4.3. Option 3 (PREFERRED)- Adopt the NRMCA Eastern Region Benchmark with 15% adjustment factor

This is similar to the process adopted by New York State, and CalGreen. While less targeted to the Maryland-specific supply chain, it has the benefit of offering a phasing in schedule allowing manufacturers to create EPDs and build capacity among the AEC community to meet policy requirements and government agencies to refine requirements and implement.

Like Option 2, this iterative method aligns the adoption process with the regular consensus updates to the concrete PCR and the NRMCA Benchmarks. As the industry benchmarks its reduction, the entities can regularly set targets relative to the benchmarks as necessary to achieve their goals as per 4-903 (E)(1) of the Act the DGS is obligated to,

> "subject to paragraph (2) of this subsection, by January 1,2029, and every 3 years thereafter, the department shall review the maximum acceptable global warming potential for each category of eligible materials and may adjust the potential for any category to reflect industry conditions."

Moreover, any agency can lower the GWP limit from this baseline per the Act:

> "(2) a unit of state government may include in a solicitation for an eligible project a global warming potential for any eligible material that is lower than the maximum acceptable global warming potential for that material as determined under § 4–903 of this subtitle."

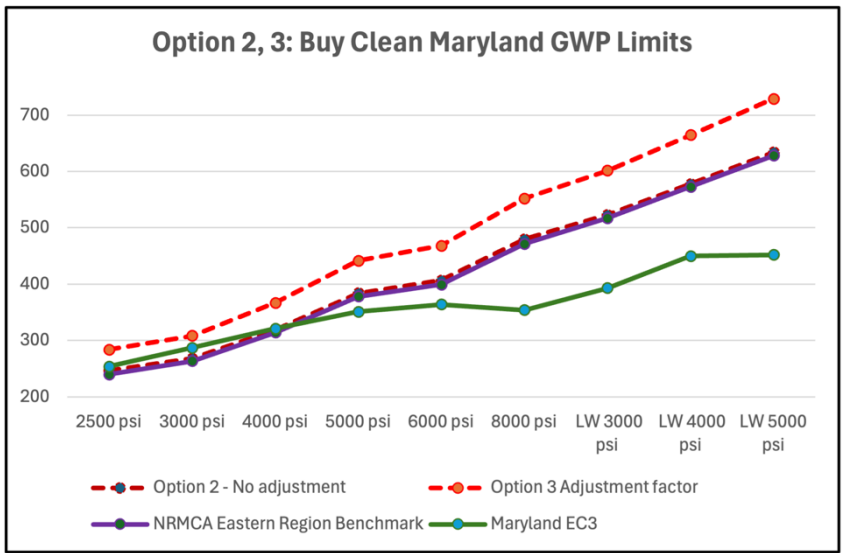


Figure 6.4.2. Option 2,3 maximum acceptable GWP limits compared

6.4.4. Option 4 (PREFERRED) - Cement GWP Limit

To ensure the methodology and calculations of the concrete uncertainty factors used in EC3 are transparent, Building Transparency documented the methodology for quantifying the uncertainty of a material or product category. The survey data from the Global Cement and Concrete Association (GCCA) was analyzed[xxix]. Without describing the details in this paper, the EC3 uncertainty factor for Industry-wide GWP impact from the median GWP value to the 80th percentile value (a.k.a. "top 20 percent") was set at 13.4%. Therefore it is appropriate that we consider setting a 13% adjustment (downward) factor for Maryland acceptable GWP limit for ASTM C-150 portland cement as the State has the benefit of two sizeable cement plants producing low-carbon cement solutions.

Similar to the cement options in Buy Clean Colorado and the US GSA IRA requirements, when the application of concrete GWP limit is impractical, the cement GWP limit based on the ASTM C-150 portland cement IW average may be applied. Project teams can employ strategies that include, but are not limited to, the use of alternative cements, supplementary cementitious materials, or alternative aggregates.

Table 6.4.3. Maximum allowable cement limit results for Buy Clean Maryland compared

Global Warming Potential, GWP 100, IPCC 2013	*Per 1 metric ton*	*Unit*
ASTM C-150 portland cement	919	$KgCO_2$ eq
Buy Clean Maryland cement limit	**800**	**$KgCO_2$ eq**

7. CONCLUSION

Green procurement program like Buy Clean are important to help entities reach their carbon targets, execute climate action plans, reduce embodied carbon, develop consistent regulations, and support economic competitiveness.

- Buy Clean actions in federal, state, county and city governments are addressing the embodied carbon of concrete in public projects, and, more specifically, its intention of leveraging the procurement in pursuit of its climate change policy objectives.
- Codes and standards provide diverse pathways to achieve decarbonization of concrete.

Implementation of Buy Clean policies is not easy. There is no consensus across jurisdictions on how best to implement the policies or establish GWP limits.

- Different jurisdictions have established a range of eligibility for projects from 10 yd^3 to $1 million minimum thresholds.
- The "maximum acceptable" GWP limits also vary widely from 72% of the NRMCA National Benchmark to 150% of the NRMCA Eastern Region Benchmark.

Buy Clean policies impact a diverse group of stakeholders, not just those who manufacture eligible concrete.

- Some programs phase in requirements over several years to mitigate many of the perceived costs and performance challenges.
- Designers need to be aware of the limitations in comparability of the disclosure reports to ensure adequate performance of the material. This can include equivariances, uncertainties in data and trade-offs.
- With the Buy Clean Maryland, the manufacturer, architects and structural engineers all have a unique opportunity to become key players in global carbon dioxide removal efforts using current and developing carbon-efficient materials.

The resulting Options to set GWP limits has the potential to allow Maryland to reach its legislatively mandated emissions reductions while spurring innovation and reducing future exposure to climate-related impacts.

- Option 1- Adopt local collected data with adjustment factor
- Option 2- Adopt the NRMCA Eastern Region Benchmark without adjustment factor
- Option 3- (Preferred) Adopt the NRMCA Eastern Region Benchmark with 15% adjustment factor
- Option 4- (Preferred) Cement GWP Limit

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