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RECOMMENDATIONS FOR SETTING EMBODIED CARBON TARGETS FOR CONCRETE PRODUCED IN NEW ENGLAND

Concrete industry stakeholders, including specifiers, policymakers, owners, and suppliers, point to the need for more uniformity around specifying concrete for building and other projects. The following guidelines are a step in that direction. Policymakers, owners, and specifiers can decide how aggressively they wish to reduce the embodied carbon of the concrete used for their projects. Policymakers may choose to be less aggressive, say by filtering out the most carbon-intensive 10, 20 or 25% of the available mixes, while owners with strong sustainability objectives may wish to specify concrete that is better-than-average. These guidelines offer the means to implement any of these options.

Selecting the threshold for a project or policy requires some knowledge of the availability and cost of low-carbon concrete. These factors are in constant flux, making it more difficult to set the threshold. Regulatory requirements should be less demanding to account for this uncertainty, whereas project-specific thresholds can be more aggressive, particularly if the specifiers have access to contractors and suppliers who can provide guidance based on current market conditions. We recommend that specifiers check with local producers that might be supplying mixes when specifying low-carbon concrete to confirm availability and pricing.

When EPDs are available, we recommend specifying low-carbon concrete using GWP as the performance metric. Using this metric will provide a more accurate measure of climate performance compared to setting cement limits. For example, the carbon emissions of cement itself varies with source. This variation will likely be accounted for in mix-specific EPDs. The number of EPDs available in Massachusetts is increasing. The MassCEC has initiated a program offering financial incentives for ready-mix companies wishing to produce EPDs for their mixes, which should accelerate this trend.

We recommend setting targets for low-carbon concrete using a Percentile-Based approach. The Percentile-Based approach allows the specifier to exclude the use of a selected percentage of available mixes, with the 50th percentile representing typical practice.

The following tables provide the recommended GWP and cement limits for Massachusetts (and the northeastern United States) using the Percentile-Based approach. The figures are rounded to the nearest multiple of 5 so as not to imply an unwarranted level of precision. GWP limits are given per cubic meter, corresponding to the units reported in most EPDs. Cement limits are per cubic yard, the units ready-mix producers normally use. The derivation of these tables is described in detail below.

	Concrete 28-Day Strength (psi)								
Percentile	**2500**	**3000**	**4000**	**5000**	**6000**	**8000**	**3000 LW**	**4000 LW**	**5000 LW**
90%	400	355	420	495	530	605			
80%	345	325	385	455	485	560			
75%	325	310	370	440	470	540			
50%	240	265	315	380	400	470			
25%	155	215	260	315	330	400			
20%	135	205	245	300	315	385			

Table 1: Recommended GWP Limits for Reduced-Carbon Concrete Using Percentile-Based Approach (kg CO2e/m3)

	Concrete 28-Day Strength (psi)								
Percentile	**2500**	**3000**	**4000**	**5000**	**6000**	**8000**	**3000 LW**	**4000 LW**	**5000 LW**
90%	575	520	635	770	820	955			
80%	495	475	580	705	750	880			
75%	465	460	560	680	725	855			
50%	345	385	475	585	620	745			
25%	225	315	390	490	515	635			
20%	195	300	370	465	490	610			

Table 2: Recommended Portland Cement Limits for Reduced-Carbon Concrete Using Percentile-Based Approach (lb/cy)

BACKGROUND OF RECOMMENDATIONS

Benchmarks

The Athena Sustainable Materials Institute published benchmark concrete mixes for U.S. regions based on data provided by National Ready Mixed Concrete Association (NRMCA) members for the ready-mixed concrete industry-average EPD[1]. For each region, Athena started

[1] Athena Sustainable Materials Institute, *Appendix C: NRMCA Member National and Regional LCA Benchmark (Industry Average) Report–V 3.2*, December 2021.

with a typical regional mix based on total concrete materials reported by the ready-mix producers. These benchmark mixes are assumed to represent typical or average mixes in each region. Athena then adjusted the mix design using American Concrete Institute (ACI) mix design guidelines for each reported concrete strength.

Massachusetts is part of the NRMCA Eastern Region, which runs from Virginia to Maine, and includes Pennsylvania and New York. 65 plants within this region provided data, accounting for about 3.9 million cubic yards of concrete production.

The intended purpose of the Athena report is to provide benchmarks against which mixes can be compared to assess their embodied carbon relative to the regional norms. The Eastern Region benchmark mixes are summarized in Table 5.

Compressive Strength	psi	**2500**	**3000**	**4000**	**5000**	**6000**	**8000**	**3000 LW**	**4000 LW**	**5000 LW**
Cement	lb/cy	345	387	475	585	620	746	393	481	572
Total Cementitious	lb/cy	440	493	604	745	789	950	494	605	719
w/cm		0.66	0.59	0.48	0.40	0.41	0.34	0.59	0.48	0.41
Cement replacement		22%	22%	21%	21%	21%	21%	20%	20%	20%
GWP	kg CO2e /cy	183	201	240	289	305	361	395	438	480

Table 3: NRMCA Eastern Region Concrete Mix Benchmarks

We compared these benchmark values to a sampling of 368 concrete mix designs provided by Boston-area concrete producers. The Boston-area mix designs we reviewed are not out of line with respect to the Athena benchmark values. While for some strengths the cement and total cementitious quantities are 10 to 12 percent higher than the benchmark, for others they are within 2% of the benchmark. We attribute the variation to the relatively small sample size for each strength class. We therefore recommend using the Athena/NRMCA benchmarks as the basis for benchmarking concrete in the Boston area until more definitive data is collected and analyzed for our area.

The Percentile-Based Approach

Once benchmarks are established, policy-makers, designers, and others can use the benchmarks to set the embodied carbon performance criteria for concrete used on projects. With the benchmarks alone, one can define the 50th percentile of performance. Mixes in a strength category with less cement and lower GWP than the benchmark exceed average performance, while mixes with more cement and higher GWP are worse than average. Thus specifiers could eliminate the worst 50% of mixes simply by specifying concrete meeting the benchmarks.

But let's say one wished to establish a different performance metric.

If EPDs are available, performance can be readily verified by referencing the EPDs for the mixes. If EPDs are not available, specifiers will need to use cement content as a proxy for GWP.

Fortunately there is a close correlation between cement content and GWP. Figure 1 shows this relationship for the benchmark mixes. The ratio of GWP to cement content varies from 0.53 for 2500 psi concrete to 0.48 for 8000 psi concrete.

Now that we have defined the relationship between GWP and cement content, we can generate two useful tables for specifying low-embodied-carbon concrete.

Using these tables, specifiers, policy makers, and others can establish GWP or cement caps that correspond to desired reduction in GWP relative to the Athena regional benchmark.

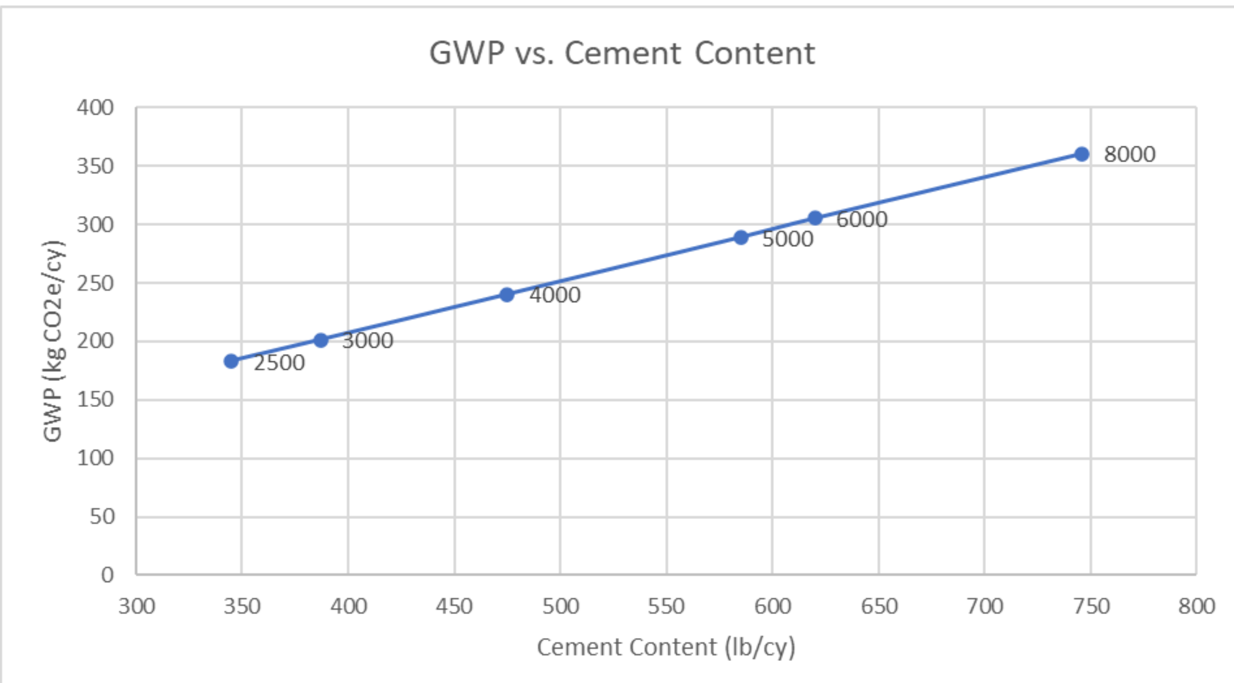

Figure 1: GWP vs. Cement Content for Athena Benchmark Mixes

What's missing from this discussion is application of the concrete. For example, the "typical" concrete used for footings may have a different GWP than the "typical" concrete used for post-tensioned slabs, even if these concretes have the same specified strengths. Post-tensioned slabs require rapid strength gain to meet typical project schedules, and therefore may on the average have lower SCM replacement rates, because high replacement rates can slow strength gain. Some specifiers and policymakers are now recommending setting limits on three types of concrete: typical mixes, high-early strength mixes, and lightweight mixes. We support this approach, and discuss it further below.

The New Buildings Institute (NBI) conducted a study of concrete GWP values using EPDs from the EC3 database.[2] NBI GWP values for high-early strength mixes are 30% higher than typical mixes, an increase arising from extensive stakeholder talks leading to the Marin Code thresholds. The NBI report proposes the GWP limits shown in Table 4 which represent the 75th percentile of GWP values in each strength class. The 75th percentile means that 75% of the reviewed mixes meet the criteria. Note that the following NBI figures are converted from m3 to yd3 for comparison with the NRMCA GWP values presented in Table 3. As expected, the NBI 75th percentile values are higher (more lenient) than the benchmark values, which represent the 50th percentile.

Compressive Strength	psi	**2500**	**3000**	**4000**	**5000**	**6000**	**8000**	**3000 LW**	**4000 LW**	**5000 LW**
NRMCA Eastern Benchmark GWP	kg CO2e /cy	183	201	240	289	305	361	395	438	480
NBI 75th Percentile GWP	kg CO2e /cy	231	292	330	368	386	396	442	479	516

Table 4: Comparison of NRMCA Eastern Benchmark GWP values to NBI national 75th percentile GWP values

We contacted NBI and they provided us with additional percentile information as shown in Table 5. Unfortunately, NBI does not have percentile data for the lightweight concrete mixes.

We used this data to create the same percentiles for Northeast region concrete as follows:

- We set the 50% percentile to the Northeast region benchmark value.
- Assuming the GWP distribution for each strength is a normal distribution, we estimated the standard deviation of each strength concrete from the national NBI data.
- We applied the same standard deviation to the Northeast region 50% values to estimate the remaining percentiles for each strength mix.

[2] New Buildings Institute, *Lifecycle GHG Impacts in Building Codes,* January 2022.

Compressive Strength	psi	2500	3000	4000	5000	6000	8000	3000 LW	4000 LW	5000 LW
90%		274	336	370	404	434	429			
80%		248	304	343	378	400	399			
75%		231	292	330	368	386	385	442	479	516
50%		170	257	287	313	331	326			
25%		97	222	246	271	284	280			
20%		78	213	238	260	270	269			

Table 5: NBI National GWP Percentiles (kg CO2e/cy)

The results are shown in Table 6. For comparison, the last row are the GSA requirements for concrete which are taken as 80% of the NBI national 75th percentile figures.

Compressive Strength	psi	2500	3000	4000	5000	6000	8000	3000 LW	4000 LW	5000 LW
90%		400	355	420	495	530	605			
80%		345	325	385	455	485	560			
75%		325	310	370	440	470	540			
50%		240	265	315	380	400	470			
25%		155	215	260	315	330	400			
20%		135	205	245	300	315	385			
GSA		242	306	346	385	404	414			

Table 6: Proposed GWP Percentiles for Northeast Region (kg CO2e/m3)

Table 7 includes the same categories in terms of cement content for each concrete strength.

Compressive Strength	psi	**2500**	**3000**	**4000**	**5000**	**6000**	**8000**	**3000 LW**	**4000 LW**	**5000 LW**
90%		577	521	634	769	821	953			
80%		497	475	580	706	752	882			
75%		467	458	559	682	726	855			
50%		345	387	475	585	620	746			
25%		223	316	391	488	514	637			
20%		193	299	370	464	488	610			

Table 7: Proposed Portland Cement Content Percentiles for Northeast Region (lb/cy)

Adjustments

Adjustments may be made for special conditions.

High-Early-Strength Concrete: Concrete that requires high early strength may require more portland cement and therefore have higher carbon emissions. If aggressive carbon reduction thresholds are specified for a project, these thresholds may need to be relaxed if high early strength is required. We do not expect high-early strength allowances will be required for concrete in the 90th percentile. As noted above, NBI proposed a 30% high-early-strength allowance for concrete in the 75th percentile.

Cold Weather: The lower heat of hydration associated with low-carbon concrete can make it challenging to keep the concrete warm enough during curing in cold weather conditions (typically below freezing) to avoid damage. Specifiers may wish to offer an allowance such as that for high-early-strength concrete for cold weather conditions.

Flatwork: Finishing slabs with high cement replacement can be challenging, especially for installers who are not familiar with working with these mixes. Longer drying times may affect installation of finishes. Some designers choose to be more cautious about specifying embodied carbon reductions for slabs. Experienced finishers report that they can finish slabs with 30% slag replacement without difficulty.

Durability: For concrete exposed to certain corrosive environments, the code caps the quantity of SCMs in the mix. Designers need to be aware of these provisions when specifying cement and GWP limits on their mixes.