White Paper

On the Development of CDOT Embodied Carbon Benchmark Limit Values for the Buy Clean Colorado Act

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Benchmarking

HB 21-1303, the Buy Clean Colorado (BCCO) Act, was passed into law in July 2021 by the Colorado state legislature. The BCCO Act required CDOT to begin collecting Environmental Product Declarations on eligible materials, including asphalt, concrete, and steel, starting on July 1, 2022. CDOT must establish a policy with maximum Global Warming Potential (GWP) limits for eligible materials by January 1, 2025. CDOT's GWP limits will apply to projects advertised on or after July 1, 2025. This white paper aims to explain the procedure developed by CDOT to calculate and verify GWP benchmarks and to establish limits for asphalt, concrete, and steel materials.

The BCCO Act provided limited guidance to CDOT for the development of benchmark GWP limits. CDOT is required to track and report the greenhouse gas emissions from the eligible material categories used on CDOT projects and to report methodology, findings, and obstacles to legislature annually. The BCCO Act states that tracking and reporting processes should be consistent with criteria in an EPD. CDOT may establish subcategories within each eligible material with distinct GWP limits. For the BCCO Act, an EPD shall consist of a Type III Environmental Product Declaration (EPD), which is an environmental declaration providing quantified environmental data using predetermined parameters and is third-party verified in accordance with the International Organization for Standardization (ISO) Standard 14025:2006.

ISO Standard 21678:2020 identifies three types of benchmarks: limit value (maximum acceptable value), reference value (state of the current practice), and target value (ideal practice value). The CDOT benchmarks will be a limit value, where an eligible material will not be allowed if its GWP exceeds the published GWP limit. A limit value (versus a reference value or target value) makes the most sense from a contractual enforcement perspective and best meets the intent of the BCCO Act. ISO standards state that the data used to establish benchmarks should be representative of the industry including geography, time-period coverage, and technology.

CDOT has decided to use the A1-A3 GWP data within published EPDs for materials used on CDOT projects as the basis for the limit value calculation for asphalt, concrete, and steel. The published EPDs for the limit value calculation consist of those that were submitted to CDOT projects and those that were publicly available from national databases. The A1-A3 modules represent the production stage of a product's life cycle, including material extraction (A1), transportation to the plant (A2), and plant energy use (A3).

The asphalt EPDs were created by the National Asphalt Pavement Association (NAPA) Emerald Eco-Label tool and were retrieved from the Emerald Eco-Label website. The concrete EPDs were obtained from the EC3 database maintained by Building Transparency and from the National Ready Mix Concrete Association EPD website. The steel EPDs were obtained from the American Institute of Steel Construction (AISC) website and from the EC3 database.

Initially, CDOT decided to set the limit value thresholds at the 90^{th} percentile of A1-A3 GWP data from collected asphalt, concrete, and steel EPDs. For the limit value calculation, CDOT utilized EPD data for CDOT materials published between October 2, 2021, and November 18, 2024. The 90^{th} percentile limit means that 90% of the collected EPDs for material subcategories will fall below the threshold and 10% will be above the threshold. Prior to setting the 90^{th} percentile from asphalt and concrete EPDs, CDOT self-performed GWP calculations from collected mixture data using "GWP intensity factors" and quantities of the individual components of asphalt and concrete mixtures. A GWP intensity factor is the intensity of GWP causing emissions per unit of production (e.g., kg CO_2-eq / metric ton, kg CO_2-eq / m^3, or kg CO_2-eq / yd^3) for a particular constituent of an asphalt or concrete mixture. An example of a material intensity factor is one metric ton of crushed aggregate causing 1.94 kg of GWP causing emissions. An example of a transportation intensity factor is one metric ton-km of truck transportation causing 0.09 kg of GWP causing emissions. GWP intensity factors were provided by the eligible material's Program Operator. Self-performed GWP calculations were consumption weighted reflecting the amount (mass or volume) of material procured by CDOT. The self-performed, weighted GWP calculations were used to help establish subcategories of the eligible materials and to serve as a quality check for the collected EPD data.

The BCCO Act required CDOT to "strive to achieve a continuous reduction of greenhouse gas emissions over time." It was deemed reasonable by CDOT that eliminating the worst performing 10% of products, through the 90^{th} percentile limit, would be an appropriate initial baseline for GHG reductions. Preliminary testing of the 90^{th} percentile limit revealed asphalt and concrete mixtures with uncharacteristically high GWP values. In general, the worst performing asphalt mixes (in A1 and A2 GWP) contained low or no RAP content, and high binder content. In general, the worst performing concrete mixtures contained disproportionately high cement contents. Another justification for setting the limit at the 90^{th} percentile was the stipulation in the BCCO Act that states CDOT shall not adjust the policy for any eligible material to be less stringent. The 90^{th} percentile was deemed to be a practical starting point for BCCO Act compliance by CDOT. As suppliers become more familiar with EPD requirements and carbon reduction opportunities, it is expected that the 90th percentile threshold will decrease to provide greater incentive to reduce greenhouse gas emissions to meet the intent of BCCO Act.

The benchmarking process outlined below summarizes general steps to calculate limit value benchmarks for asphalt and concrete. The outline is followed by specific examples for asphalt and concrete to demonstrate the calculations and procedures. The process began with a self-performed GWP calculation from mixture data with GWP intensity factors. The GWP calculations were consumption weighted to mass or volume placed on CDOT projects, and then subcategories were established. Next, EPDs were collected and analyzed, and the EPD data was compared to the GWP calculation data. Finally, limit values for the asphalt and concrete subcategories were calculated for asphalt and concrete at a percentile level. The process was similar for steel, except that no self-performed GWP calculations or consumption weighting were performed.

Limit Value Benchmarking Steps for Asphalt and Concrete

Step 1. Obtain mix design data from CDOT approved mixtures. Asphalt mixture data was obtained from approved Form 43s in CDOT's Laboratory Information Management System (LIMS), and concrete mix design data was obtained from the internal CDOT concrete mix design database. Perform GWP calculations from mixture data for all mixtures submitted to CDOT projects using GWP intensity factors.

Step 2. Consumption weight GWP calculations from mixture data based on estimated quantities on CDOT projects from a three-year period (2021-2024). Estimated bid item quantities of asphalt and concrete were obtained from the CDOT Engineering Estimates and Market Analysis (EEMA) cost data book.

Step 3. Evaluate potential subcategories of consumption weighted GWP calculations based on functional classifications and CDOT regions. Subcategories are functional categories of materials and should be established for similar material types with performance criteria defined by agency specifications for different applications.

Step 4. Collect EPDs from national databases for materials used on CDOT projects.

Step 5. Compare EPD data to calculated GWP data (consumption weighted) from Steps 1-2 and perform a quality check on the EPD data. Identify outliers and exclude any anomalous data.

Step 6. Bin the EPD data into percentiles, analyze data, and set a percentile threshold for the limit value for each subcategory.

Limit Value Calculation for Asphalt Mixtures

Step 1. Using mix design data from approved mixtures, estimate GWP from all mixtures submitted to CDOT projects using GWP intensity factors.

For each asphalt job mix formula (JMF), perform a mass balance of asphalt mixture ingredients to ensure the sum of all ingredients totals 1 metric ton of mix. This can be accomplished by balancing the percent of total mix by mass of each ingredient to sum to 100% as shown in Table 1.

Table 1: An example of mass balancing of asphalt mix ingredients

Example mix ingredients	JMF percentages	Mass balanced percentages
Adjusted Binder Content	N/A	4.50%
Aggregate 1	36.5%	34.95%
Aggregate 2	23.2%	22.15%
Aggregate 3	19.3%	18.34%
RAP	20.0%	19.11%
Hydrated Lime	1.0%	0.95%
Total	100.00%	100.00%

Following the A1 portion of Equation 1, multiply the mass of the asphalt mix ingredient x_i by the GWP intensity factor y_i for the A1 calculation. The x_i value should be a percentage of 1 metric ton of total mix. For example, the quantities of Table 1 would be 0.0450 metric tons of asphalt binder, 0.7544 metric tons of aggregate, 0.1911 metric tons of RAP, and 0.0095 metric tons of hydrated lime. The GWP intensity factor y_i for asphalt mixture ingredients can be found in the NAPA EPD Benchmark report, which is based on the background LCI specified in the PCR for each constituent material.

$$GWP_{A1+A2} = A1 + A2 = (x_1y_1 + \cdots + x_ny_n) + [x_1(a_1t + b_1r) + \cdots + x_n(a_nt + b_nr)] \qquad (1)$$

Following the A2 portion of Equation 1, take the product of the truck transport distance a_i for ingredient i and GWP intensity of truck transportation t. This product would be added to the products of other transportation modes and GWP intensities (such as the rail transport distance b_i and the GWP intensity of rail r), then multiply the summed products by the mass of the asphalt mix ingredient x_i. Based on discussions with the Colorado asphalt industry, the truck/rail transportation distribution for major ingredients was 95% truck/5% rail for aggregates, 100% truck/0% rail for asphalt binder, 100% truck/0% rail for RAP, and 50% truck/50% rail for hydrated lime. The GWP intensities for truck and rail are shown in Table 2. In Table 2, the truck and rail transportation factors have been multiplied by 1.35 to account for empty return hauls per the asphalt mixture PCR. An example calculation for steps 3 and 4 is shown in Table 3.

Table 2: GWP transportation intensity factors for asphalt mixture ingredients

Transportation mode	**GWP Intensity (kg CO_2eq/metric ton-km**
Freight truck	0.1271
Rail	0.0302

Table 3: A1 and A2 calculations of an example asphalt mixture

Example mix	**Ingredient mass**	**GWP Intensity**	**A1**	**Truck Transport Distance**	**Rail Transport Distance**	**A2**
Ingredients	Metric tons per metric ton of asphalt	kg CO_2eq/metric ton ingredient	kg CO_2eq/metric ton	km	km	kg CO_2eq/metric ton
Adj. Binder	0.0450	631.51	28.42	80.5	0.0	0.46
Aggregate 1	0.3495	1.94	0.68	29.8	1.6	1.34
Aggregate 2	0.2215	1.94	0.43	34.0	1.8	0.97
Aggregate 3	0.1834	1.94	0.36	57.0	3.0	1.35
RAP	0.1911	0.781	0.15	50.0	0.0	1.21
Lime	0.0095	1389	13.20	97.5	97.5	0.15
Total	**1.0000**		**43.23**			**5.33**

Step 2. Consumption weight mixture data based on estimated quantities on CDOT projects for the past 3 years.

Step 2a. Collect agency procurement quantities over an adequate period of time to obtain a sufficiently large set of representative data. Estimated quantities of asphalt for specific projects were obtained from CDOT's bid item cost data book. Link the estimated total mass of asphalt placed to each job mix and to the GWP of each job mix. In many cases, there were multiple asphalt mixtures approved for a specific asphalt pavement bid item. When multiple mix designs were approved for a single bid item, consumption amounts were evenly allocated to all the listed mix designs. An example of quantities linked to job mixtures and GWP is shown in Table 4.

Step 2b. Sort the GWP values in ascending order. Calculate the normalized consumption of asphalt per mixture by dividing the mixture mass quantity m_i by the total quantity as in Equation 2.

$$normalized\ consumption = \frac{m_i}{\sum_{k=1}^{N} m_k} \qquad (2)$$

Table 4 displays the weighting calculations and cumulative distribution performed on 28 mixes of Gradation ST (3/8" NMAS and neat binder). Table 4 calculates a cumulative sum of the consumption values for the mixes where the first value at the top of the GWP data column has been added to the second value in the column, and so forth. As a check on the calculation, the last value of the cumulative distribution column is equal to one. Calculate the weighted GWP of a mixture by multiplying the "A1+A2 GWP" by the "normalized consumption" for that mixture

Table 4 Cumulative distribution of 28 Grade ST (Neat binder) asphalt mixtures

A1+A2 GWP	**Asphalt placed**	**Normalized consumption**	**Cumulative distribution**	**Weighted GWP**
kg CO_2eq/metric ton	metric ton	%	%	kg CO_2eq/metric ton
50.02	7214	=7214/380,885 = 0.02	0.02	=0.02x50.02=0.95
50.56	12002	0.03	=0.02+0.03=0.05	=0.03x50.56=1.59
52.27	9008	0.02	=0.05+0.02=0.07	1.24
52.55	11201	0.03	0.10	1.55
53.04	7214	0.02	0.12	1.00
53.04	26481	0.07	0.19	3.69
54.20	25499	0.07	0.26	3.63
54.78	9008	0.02	0.28	1.30
58.17	13591	0.04	0.32	2.08
58.77	9322	0.02	0.34	1.44
59.28	13709	0.04	0.38	2.13
60.23	2459	0.01	0.39	0.39
60.23	2459	0.01	0.39	0.39
60.24	13709	0.04	0.43	2.17
60.89	31273	0.08	0.51	5.00
62.31	27636	0.07	0.58	4.52
62.86	16121	0.04	0.62	2.66
63.13	9392	0.02	0.65	1.56
63.92	28322	0.07	0.72	4.75
64.30	18110	0.05	0.77	3.06
65.36	16121	0.04	0.81	2.77
65.55	10666	0.03	0.84	1.84
65.55	10666	0.03	0.87	1.84
65.55	10666	0.03	0.90	1.84
65.61	9311	0.02	0.92	1.60
68.77	10279	0.03	0.95	1.86
71.23	9311	0.02	0.97	1.74
74.99	10139	0.03	1.00	2.00
	380,885			Total = average = 60.55

Step 2c. With the cumulative distribution in Table 4, use the INDEX function in Excel to calculate the desired percentiles. Sum the weighted GWP values in Table 4 to calculate the average, i.e., weighted average, of the data set. A graphical depiction of the 20th, 40th, 60th, 80th, and 90th percentiles on a cumulative distribution function plot of the A1-A2 values of the 28 Neat ST mixes is shown in Figure 1.

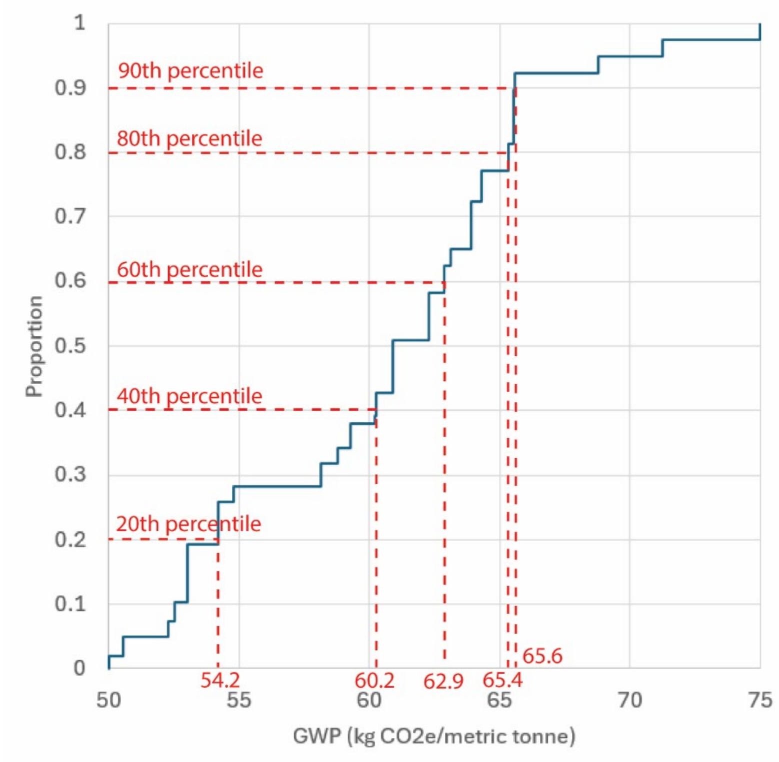

Figure 1: Cumulative distribution function plot of weighted GWP calculation for Neat ST asphalt mixtures

Step 2d. Add the unweighted average A3 value computed from all CDOT asphalt EPDs to the weighted A1 and A2 percentile data. The current CDOT unweighted average A3 value is 24.40 kg CO_2eq/metric ton for all mixture types in Colorado. Table 5 shows the weighted A1 and A2 data for Neat ST added the average A3 value added with the summation being the total weighted A1-A3 GWP. The A3 value does not get weighted and is not part of the percentile calculation since it is simply an average of the EPDs from multiple mixture gradations. Per the asphalt PCR, energy use for asphalt mixture production is not recorded separately for each mixture produced at a plant in an EPD; therefore, it would not make sense to calculate and incorporate A3 percentiles or to consumption weight the A3 value.

Table 5 Weighted GWP calculation results for subcategory Neat ST (3/8” NMAS)

Quintile	**Weighted A1-A2 GWP**	**Average A3**	**Total Weighted A1-A3 GWP**
	kg CO_2eq/metric ton	kg CO_2eq/metric ton	kg CO_2eq/metric ton
20th	54.2	24.4	78.6
40th	60.3	24.4	84.7
60th	62.9	24.4	87.3
80th	65.4	24.4	89.8
90th	65.6	24.4	90.0
Average	60.6	24.4	85.0

Step 3. Evaluate potential subcategories of consumption weighted GWP calculations based on functional classifications and CDOT regions.

Variations within CDOT-specific specifications were evaluated for asphalt subcategories including nominal maximum aggregate size (NMAS), polymer modification, high-traffic pavements versus low-traffic pavements, surface versus non-surface layers, and CDOT geographic regions. Based on the analysis and considering the current representativeness and sample quantity of available data, CDOT established four distinct subcategories based on CDOT asphalt mixture gradations, namely Neat ST (3/8" NMAS), Neat SX (1/2" NMAS), Modified SX (1/2" NMAS), and Neat S (3/4" NMAS). There are additional CDOT asphalt mix classifications that did not have adequate data to establish limit values They Include, but are not limited to, portable plant mixtures, SG graded mixes, S/ST/SMA modified binder mixes. As more data becomes available for other asphalt classifications, CDOT will establish limit values for additional subcategories.

Step 4. Collect EPDs from national databases for materials used on CDOT projects.

CDOT collected 118 total EPDs in the four asphalt subcategories from the Emerald Eco-label database for the benchmark limit value calculation. The number of EPDs by subcategory and the number of self-performed GWP calculation samples are shown in Table 6.

Table 6: Number of samples for asphalt mixture subcategories

Asphalt mix subcategory	Nominal maximum aggregate size (NMAS)	Average optimum asphalt content (AC)	Typical PG grades	No. of samples in EPD analysis	No. of samples in self-performed GWP calculation	Quantity placed over 3 yr period [metric ton]
Neat ST	3/8-in (9.5mm)	7.00%	PG 58-28, PG 64-22	7	28	0.381M
Neat SX	1/2-in (12.5mm)	5.60%	PG 58-28, PG 64-22	52	182	1.306M
Modified SX	1/2-in (12.5mm)	5.54%	PG 58-34, PG 64-28, PG 70-28, PG 76-28	33	191	1.795M
Neat S	3/4-in (19.0mm)	5.14%	PG 58-28, PG 64-22	26	37	0.536M
Totals				118	438	4.018M

Step 5. Compare EPD data to calculated GWP data from Steps 1-2 and perform a quality check on the EPD data.

The 20th, 40th, 60th, 80th, and 90th percentiles of the asphalt EPD data were compared to those of the calculated, weighted asphalt GWP data from Steps 1-2 for the Neat ST, Neat SX, Modified SX, and Neat S subcategories. As shown in Table 7, the percentiles and the averages compared favorably, in that all of them were within +/- 6.5% of each other besides the Neat S 80th percentile difference, which was a positive 9.0% difference. Further investigation of the 9.0% difference revealed that there were relatively high GWP Neat S mixes on a few projects with large placement quantities, which likely skewed the higher percentiles to larger percent differences. Given that most of the mixtures were within the 6.5% difference, the EPD data was deemed to be sufficient and representative of CDOT mixtures.

Table 7 Weighted GWP calculation and EPD data percentiles for 4 asphalt mixture subcategories

Quintile	**Asphalt mix subcategory**	**Weighted GWP calculation**	**EPD data**	**Percent difference**
		LCA modules	**LCA Modules**	
		Total A1-A3	**Total A1-A3**	
20th percentile	Neat ST	78.6	79.8	-1.5%
	Neat SX	71.0	71.3	-0.4%
	Modified SX	76.4	72.1	6.0%
	Neat S	71.7	67.3	6.5%
40th percentile	Neat ST	84.7	82.4	2.8%
	Neat SX	74.7	72.6	2.9%
	Modified SX	79.4	76.0	4.5%
	Neat S	71.7	69.9	2.6%
60th percentile	Neat ST	87.3	83.3	4.8%
	Neat SX	78.0	76.5	2.0%
	Modified SX	83.1	79.0	5.2%
	Neat S	74.2	70.6	5.1%
80th percentile	Neat ST	89.8	85.2	5.4%
	Neat SX	80.8	80.5	0.4%
	Modified SX	85.5	85.2	0.4%
	Neat S	79.9	73.3	9.0%
90th percentile	Neat ST	90.0	90.4	-0.5%
	Neat SX	83.5	83.4	0.2%
	Modified SX	87.5	89.0	-1.7%
	Neat S	81.0	77.0	5.2%
Average	Neat ST	85.0	83.7	1.4%
	Neat SX	77.2	75.3	2.5%
	Modified SX	81.6	78.9	3.4%
	Neat S	74.4	70.7	5.2%

A quality check on the EPD data revealed some anomalous asphalt mixture data that was excluded. There were two Modified SX mixture EPDs that incorporated a polyphosphoric acid (PPA) polymer modifier instead of a styrene-butadiene-styrene (SBS) modifier. CDOT specifications do not allow PPA, so these EPDs were excluded. Some EPDs did not include hydrated lime, which is required by CDOT specifications at a minimum of 1%. The EPDs without hydrated lime were also excluded.

Step 6. Bin the EPD data into percentiles, analyze data, and set percentile threshold for the limit value for each subcategory.

CDOT established a limit value at the 90th percentile of the A1-A3 GWP values from the EPD data. The 2025 CDOT limit values for asphalt are shown in Table 8 below.

Table 8: 2025 CDOT benchmark limit values for asphalt

	Neat ST (3/8" NMAS)	**Neat SX (1/2" NMAS)**	**Modified SX (1/2" NMAS)**	**Neat S (3/4" NMAS)**
2025 CDOT limit value at 90th percentile (**kg CO_2eq/metric ton**)	90.4	83.4	89.0	77.0

Limit Value Calculation for Concrete Mixtures

Step 1. Using mix design data from approved mixtures, estimate GWP from all mixtures submitted to CDOT projects using GWP intensity factors.

Calculate the A1 impacts by multiplying the metric tons or pounds of the concrete ingredient per unit of concrete production by the GWP intensity factor for the A1 calculation. An example calculation is shown in Table 10. This process is similar to the asphalt example, except the ingredient variable is now the mass of each ingredient per volume of concrete (metric tons per m^3 of concrete). For asphalt, the ingredient amount variable was mass of each ingredient per mass of asphalt (metric tons of ingredient per metric ton of asphalt).

Determine whether any EPDs are available for any of the constituents of the concrete mixture. If so, input the embodied carbon emission values in those constituent EPDs into the GWP Intensity column in Table 10. Including the GWP intensity from a product-specific or facility-specific EPD for cement production will significantly increase the precision of the total GWP calculation.

The GWP transportation intensity factors for the A2 calculation of concrete materials are different than asphalt, and these intensity factors are shown in Table 9. Per the concrete PCR, the truck transportation intensity factor in Table 9 has been multiplied by 2/1.35 to reflect two-way transport and to eliminate the 35% additional distance included in the US LCI. Also, per the concrete PCR, the train transportation intensity factor in Table 9 is not multiplied by 2/1.35.

A Google Maps Application Programming Interface (API) was used to determine distances from the mix design material source information in the self-performed A2 calculation. Transportation distances from the cement manufacturing facility to the rail terminal (by train) and then from the rail terminal to the concrete plant (by truck) were determined by evaluating all feasible sourcing scenarios. The scenario with the shortest transportation distance was selected to represent the GWP impact. Similarly, CDOT selected the truck and train transportation scenario with the lowest GWP impact as the default scenario, which most often resulted in the shortest trucking distance. This scenario selection approach does not provide the most conservative GWP impact calculation, but it does represent the most likely process used by concrete suppliers since truck transport would be relatively more expensive than rail transport. In some scenarios, cement would be transported by truck directly from the cement manufacturing facility to the concrete plant depending on the lowest GWP impact, and in other scenarios cement would be transported by train to a rail terminal and then by truck to the concrete plant. Fly ash followed the same procedure as cement. Assumptions for aggregate transportation were informed by industry input, establishing a standardized distribution of 95% truck and 5% rail, which was uniformly applied to all aggregate transport distances in the self-performed GWP calculation. Admixtures were assumed to be transported entirely by truck (100% truck).

Table 9: GWP transportation intensity factors for concrete mixture ingredients

Transportation mode	GWP Intensity (kg CO_2eq/metric ton-km
Freight truck	0.1634
Rail	0.0221

Table 10: A1 and A2 calculations for an example concrete mixture

	Ingredient volume	GWP Intensity	A1	Truck Transport Distance	Rail Transport Distance	A2
Mixture ingredient	metric ton per m^3 of concrete	kg CO_2eq/ metric ton ingredient	kg CO_2eq/ m^3	km	km	kg CO_2eq/ m^3
Cement (Type I/II)	0.2610	919	239.86	50.5	40.5	2.39
SCM (fly ash)	0.0653	0	0.00	50.5	95.3	0.68
Water	0.1341	0.22	0.03	-	-	-
Fine aggregate	0.5316	7.87	4.18	34.0	1.8	2.97
Coarse aggregate	1.3017	7.87	10.24	38.8	2.0	8.31
Air-entraining admixture	0.0004	439	0.18	110.0	-	0.01
Total	**2.2941**		**254.49**			**14.36**

Step 2. Consumption weight mixture data based on estimated quantities on CDOT projects.

Follow the same process explained in Step 2 of the asphalt example for the concrete production weighting. Concrete GWP data is production weighted the same way as asphalt, except the mixture quantity will be in units of volume (m^3) as opposed to units of weight/mass. Concrete volumes for consumption weighting are based on the values reported in two CDOT bid items: Item 412 for portland cement concrete pavement and Item 601 structural concrete (all classes). These two bid items represent the largest volume of concrete placement in the CDOT inventory. The volume of Item 412 material is calculated by multiplying the design thickness by the estimated area. There are other CDOT concrete bid items (e.g., Item 609 curb and gutter, Item 610 median cover material, etc.) that are not included in the concrete quantity calculation since it is challenging to match specific mixes and volumes to these bid items. Bid Item 601 is directly reported in units of volume.

Add the unweighted average A3 value computed from all CDOT EPDs to the weighted A1 and A2 percentile data. The unweighted average A3 value for concrete was 12.2 kg CO_2eq/m^3 for all CDOT mixture classes in Colorado.

Step 3. Evaluate potential subcategories of consumption weighted GWP calculations based on functional classifications and CDOT regions.

Various concrete properties from CDOT-specific specifications were evaluated for concrete subcategories including compressive strength, fly ash content, and CDOT geographic regions. Based on the analysis and considering the current representativeness and sample quantity of available data, CDOT established three distinct subcategories for concrete GWP limits, namely Class B, Class D, and Class P. There are additional CDOT concrete mix classifications that did not have adequate data to establish limit values including, but are not limited to, portable plant mixtures, Class DF, Class PS, and Class BZ.

Step 4. Collect EPDs from national databases for materials used on CDOT projects.

CDOT collected 278 total Colorado EPDs in the three concrete CDOT subcategories from the EC3 database for use in the benchmark limit value calculation. The number of EPDs by subcategory and the number of self-performed GWP calculation samples are shown below in Table 11.

Table 11: Number of samples for concrete mixture subcategories

Concrete mix subcategory	Compressive strength (psi)	Typical applications	Fly ash requirement	No. of samples in EPD analysis	No. of samples in GWP calculation[1]
Class B	4500	Curb & gutter, medians, sidewalks	No requirement	107	481
Class D	4500	Bridge decks	No requirement	114	491
Class P	4500	Pavement	Minimum 20% by weight	57	418

[1]The number of samples for the subcategory in the self-performed GWP calculation includes mixes that are dual classified (e.g., Class B/D/P, Class B/D, etc.) into multiple subcategories, meaning mixes are counted more than once in different subcategories.

Step 5. Compare EPD data to calculated GWP data from Steps 1-2 and perform a quality check on the EPD data.

The 20th, 40th, 60th, 80th, and 90th percentiles of the concrete EPD data were compared to those of the weighted GWP calculation from Steps 1-2 for each subcategory. As shown in Table 12, the percentiles and the averages compared favorably, in that most of them were within +/- 6.0% of each other. The weighted GWP calculation data at the 20th percentile and 90th percentile exhibited a relatively larger differences than the other percentiles since the sample size of the weighted GWP calculation was significantly larger than the EPD data set. Given that most of the mixtures were less than a 6% difference, the EPD data was deemed to be sufficient and representative of CDOT mixtures. For both EPD data and weighted GWP calculation, the Class P mixtures consistently demonstrated a lower GWP than Class B or Class D at almost every percentile, which is attributed to the minimum 20% by weight requirement for fly ash in Class P mixes that is not required for Class B and Class D mixes.

Table 12 Weighted GWP calculation and EPD data percentiles for 3 concrete mixture subcategories

Quintile	Concrete mix subcategory	Weighted GWP calculation	EPD data	Percent difference
		kg CO_2eq/m^3	kg CO_2eq/m^3	
		Total A1-A3	Total A1-A3	
20th percentile	Class B	301.1	308.0	-2.2%
	Class D	301.1	305.8	-1.5%
	Class P	286.4	308.6	-7.2%
40th percentile	Class B	316.8	320.8	-1.2%
	Class D	316.0	320.7	-1.5%
	Class P	302.3	319.0	-5.2%
60th percentile	Class B	337.0	334.0	0.9%
	Class D	328.3	333.8	-1.6%
	Class P	309.3	328.8	-5.9%
80th percentile	Class B	348.2	344.8	1.0%
	Class D	345.6	349.2	-1.0%
	Class P	329.6	339.4	-2.9%
90th percentile	Class B	389.9	360.0	8.3%
	Class D	370.0	365.1	1.3%
	Class P	390.6	346.2	12.8%
Average	Class B	331.3	329.5	0.5%
	Class D	329.1	330.8	-0.5%
	Class P	319.8	325.3	-1.7%

Anomalous concrete EPDs were excluded from the EPD data set. There were at least 9 concrete EPDs with high early strength mixes that were removed. Some of these high early strength mixtures had up to 600 lb of cement per cubic yard and therefore, inflated A1 GWP values. The high early strength mixtures were identified and excluded by manually searching for the term “high early” in the description field of the EPD.

Step 6. Bin the EPD data into percentiles, analyze data, and set percentile threshold for the limit value for each subcategory.

CDOT established a limit value at the 90th percentile of the A1-A3 GWP values from the concrete EPD data. The 2025 CDOT limit values for concrete are shown in Table 13 below.

Table 13: 2025 CDOT benchmark limit values for concrete

Concrete mixtures	**Class B**	**Class D**	**Class P**
2025 CDOT limit value at 90th percentile (**kg CO_2eq/m^3**)	360.0	365.1	346.2

Limit Value Calculation for Steel Products

Unlike asphalt and concrete, mixture ingredient data is not relevant for steel products to self-perform GWP calculations. Consumption data for steel products is also not readily available; therefore, no consumption weighting of steel products was performed.

CDOT reviewed the available published EPDs for steel products used on CDOT projects and determined there was sufficient data available to establish a GWP limit for steel reinforcing bars. CDOT established a limit value at the 90th percentile of the A1-A3 GWP values from the steel reinforcing bar EPD data. The 2025 CDOT limit values for reinforcing bars are shown in Table 14 below. The limit is based on all reinforcing steel EPDs available for mills listed on CDOT’s Qualified Manufacturers List (QML). The 90th percentile limit calculation is based on 25 EPDs, with the majority of those being EPDs for reinforcing bars including fabrication and a few being EPDs for rebar without fabrication. None of the 25 EPDs for reinforcing bars included epoxy coating in their GWP calculations.

Table 14: 2025 CDOT benchmark limit values for steel reinforcing bars

	Steel reinforcing bars
2025 CDOT limit value at 90th percentile (**kg CO_2eq/metric ton**)	915.9

Conclusions and Future Intentions

This white paper presented the process used by CDOT to calculate and verify GWP benchmarks and to establish GWP limits for asphalt, concrete, and steel materials. In the future, CDOT intends to establish additional material subcategories with distinct GWP limits. The additional subcategories could include SMA asphalt mixtures, precast products, and additional steel products. The limits presented in this white paper will be reviewed on an annual basis and are subject to change based on new information. Any new CDOT processes to calculate limit values will be communicated in a timely manner.