Low Carbon Concrete Codes Using the NRMCA Carbon Calculator

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Sustainability Requirements

- ACI 318, Appendix N
- ACI 323 – Low-Carbon Concrete – Code Requirements
- ACI 301 – Specifications for Concrete Construction

- EPA Interim Guidelines

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ACI 318 Appendix N

- For Sustainability - Comply with Appendix N
  - N.1 Notation and Terminology
  - N.2 Scope
  - N.3 Concrete mixtures
    1. Max GWP limit for each concrete mixture based on f'_c (or other basis)
       - Limits based on benchmark
       - Allows project GWP budget – limits for individual mix classes can be exceeded
       - Documented by – independent LCA, independent EPD, independent LCA tool
    2. Reduced GWP of mixture relative to mixtures of same class (producer specific) (EPD not available in region)
    3. Other sustainability limitation – designer's choice
    - Benchmark – industry, regional, or local average

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ACI 318 Appendix N

- N.4 Sustainability of Structural Concrete System
  - Compare systems - Whole building LCA - ASTM E2921
  - Impact categories - GWP, acidification, eutrophication, ozone depletion, smog potential
  - LCI categories – water consumption, solid waste, total energy demand, total nonrenewable energy demand
  - Permitted to include operational energy in WBLCA (thermal mass benefits of concrete)
  - Proposed Structural System - improvement over a reference building
- N.5 Resilience
  - Consider reliance for hazards and time to recover
  - Intended use, risk based on geography, consequences of damage, time to recover from damage state
  - Owner states required levels of performance for resilience (for hazards)

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ACI 323

- Low-Carbon Concrete – Code Requirements & Commentary
  - Cast in place concrete
    - Buildings
    - Pavements
    - Bridges
    - Other structures

    Does not apply to
    - precast concrete,
    - auger cast concrete,
    - shotcrete, or
    - concrete strength < 2500 psi or > 8000 psi
  - Purpose: Limit max GWP of concrete on a project
  - No compromise to strength, stability, serviceability, durability, or integrity of the concrete structure.

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ACI 323

- Upfront embodied GWP of Concrete Mixtures
  - GWP Documentation
    - Independent 3rd party LCA
    - Independent 3rd party product-specific EPD
    - Independent 3rd party LCA tool
  - EPD or LCA in accordance with ISO 21930
  - Current PCR – NSF International, 2021

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ACI 323

- Weighted average project benchmark GWP

$$GWP_{benchmark\ avg} = \frac{\sum_{i=1}^{n} GWP_{benchmark\ i} \times Vol_i}{\sum_{i=1}^{n} Vol_i}$$

- Weighted average project GWP

$$GWP_{project\ avg} = \frac{\sum_{i=1}^{n} GWP_{project\ i} \times Vol_i}{\sum_{i=1}^{n} Vol_i}$$

- $GWP_{project\ avg} \leq \alpha\ GWP_{benchmark\ avg}$
- $\alpha = 0.85$ for large projects with Appendix A

Appendix A in 323:
Appendix C: NRMCA Member National and Regional LCA Benchmark (Industry Average) Report – V 3.2 (Athena Sustainable Materials Institute 2022).

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ACI 323

- "Large projects"
  - Buildings floor area ≥ 50,000 sq ft
  - Pavements ≥ 7,500 yd^3
  - Bridges deck area ≥ 25,000 sq ft
  - Other structures ≥ 7,500 yd^3
- Smaller projects
  - Report GWP
  - Strategies to reduce GWP

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ACI 323 - Example

Table B.3 Weighted average benchmark GWP calculations

Column: Application	A Concrete Class	B f'_c (psi)	C Vol_i (yd^3)	D $GWP_{benchmark\ i}$ ($kgCO_{2e}/yd^3$)	E Total $GWP_{benchrmark}$ for class ($kgCO_{2e}$) (Column C x D)
Topping slabs, curbs, footings, SOMD	1	4000	1299	242	263,177
Below grade walls, SOG	2	5000	469	296	116,171
Elevator pit walls	3	5000	23	296	6472
Columns, shear walls, vehicle barrier walls	4	6000	1366	312	338,358
Elevated decks	5	6000	3867	312	1,037,902
			Σ = 7024		**Σ = 2,092,686**

$$GWP_{benchmark\ avg} = \frac{\sum_{i=1}^{n} GWP_{benchmark\ i} \times Vol_i}{\sum_{i=1}^{n} Vol_i} = \frac{2{,}092{,}686}{7024} = 297.9\ kgCO_{2e}/yd^3$$

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ACI 323 - Example

Table B.2 Weighted average project GWP calculations

Column: Application	A Concrete Class	B f'_c (psi)	C Vol_i (yd^3)	D $GWP_{project\ i}$ ($kgCO_{2e}/yd^3$)	E Total $GWP_{project}$ for class ($kgCO_{2e}$) (Column C x D)
Topping slabs, curbs, footings, SOMD	1	4000	1299	202.6	263,177
Below grade walls, SOG	2	5000	469	247.7	116,171
Elevator pit walls	3	5000	23	281.4	6472
Columns, shear walls, vehicle barrier walls	4	6000	1366	247.7	338,358
Elevated decks	5	6000	3867	268.4	1,037,902
			Σ = 7024		**Σ = 1,762,082**

$$GWP_{project\ avg} = \frac{\sum_{i=1}^{n} GWP_{project\ i} \times Vol_i}{\sum_{i=1}^{n} Vol_i} = \frac{1{,}762{,}082}{7024} = 250.8\ kgCO_{2e}/yd^3$$

$$\frac{GWP_{project\ avg}}{GWP_{benchmark\ avg}} = \frac{250.8}{297.9} = 0.84$$

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EPA Label Program

- Label Program - Low Embodied Carbon Const. Matls (EPA)
- Data Quality Improvement
  - US EPA Criteria for Product Category Rules (PCRs)
- Setting Thresholds for "Substantially Lower GWP"
  - Industry averages
  - Based on collected EPDs

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EPA Label Program

- GWP from product-specific Type III EPDs
- Concrete EPDs rely on upstream facility specific cement EPDs
- Targets based verified source of same product category
- EPA Interim Guidelines to GSA and FHWA
  - Lowest 20th percentile
  - Lowest 40th percentile
  - Less than Industry average

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FHWA GWP Benchmarks (from NRMCA)

- 6 Conventional Concrete Mixtures &
- 3 Lightweight Concrete Mixtures
- Developed 20th and 40th percentiles

Table 6: Benchmark for 3,000 psi mixture in Pennsylvania

[all values in kg CO2e / m3]	A1 (Eastern)	A2 (Eastern)	A3 (Eastern)	A1-A3 Total (Proposed Method)	Current A1-A3 GSA Thresholds
20%	207	12	7	**226**	257
40%	226	17	9	**252**	291
50%	229	20	10	**259**	x
Average	230	22	11	**263**	318

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NRMCA Concrete Carbon Calculator:

How to Reduce, Quantify, and Specify Carbon

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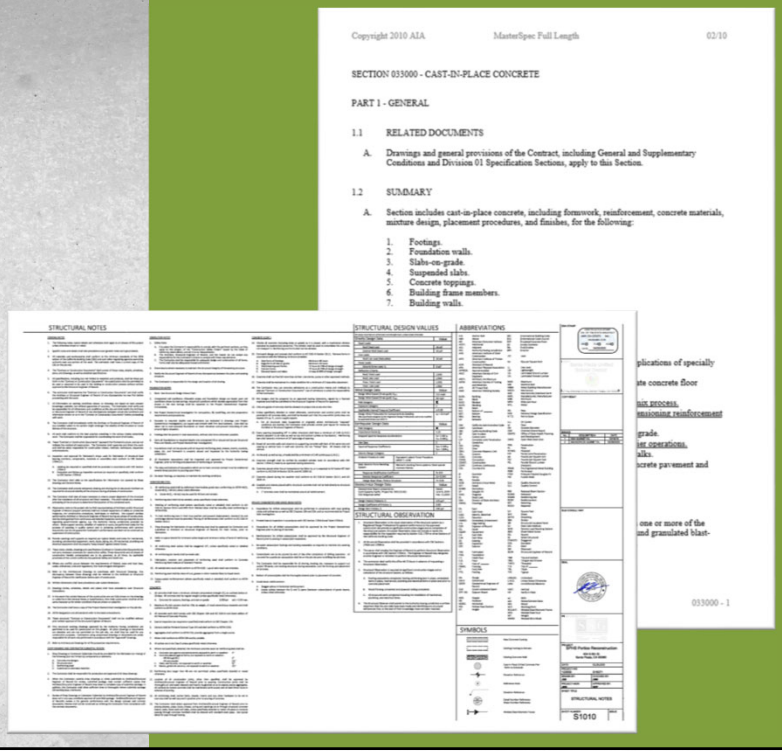
Division 03 Section 033000 Cast-In-Place Concrete

Step #1:

Performance-Based Improvements

Step #2:

Carbon Accounting and Targets



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Step #1 – Performance Based Improvements

Goal:

Prescription → Performance

Methods:

- Emphasize ACI 318 Exposure Classes
- Alt testing for durability/design
  - Shrinkage, MOE, RCP, ASR
- Expand acceptable materials
- Extended strength development

Results:

Efficient and Optimized Mix Designs

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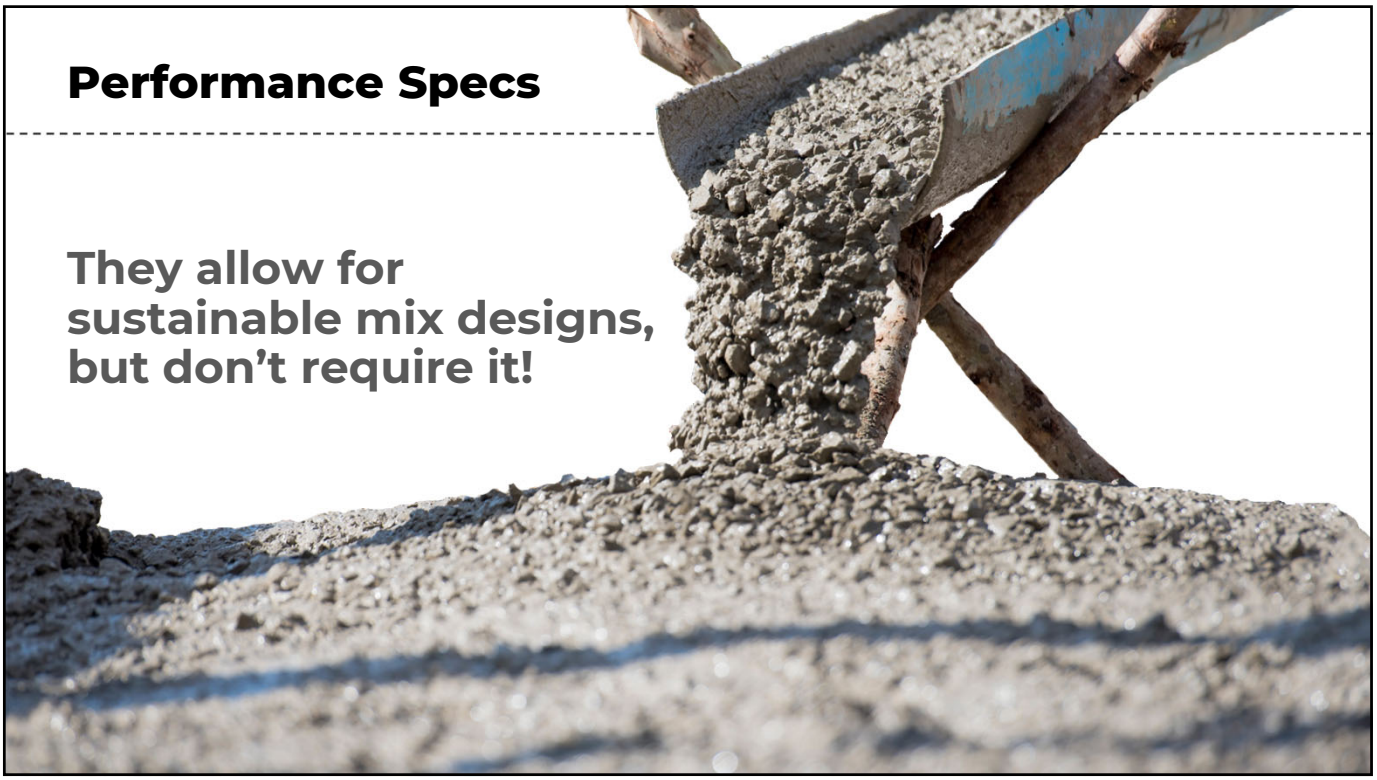
Performance Specs



They allow for sustainable mix designs, but don't require it!

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Step #2 – Carbon Accounting and Targets

Goal:

Trigger the use of low carbon materials

Methods:

- Collect EPDs
- Establish a Carbon Budget

Results:

- Procurement of low carbon concrete
- Flexibility for the contractor and producer
- Buffer for as-built conditions

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Specifications for Sustainability

Member	Mix ID	Durability Exposure F	S	W	C	Specified Strength, f'c, psi	Max w/cm or Performance Alternative	Nom. max Aggregate, in.	Air Content	Slump/ Slump Flow	Chloride Limit	Temp. Limits	Max. GWP (kg/yd3 CO_2e)
Footings													250
Foundation Walls													250
Slabs-on-grade													250
Exterior slabs													
Suspended slabs (interior)													3 0
Suspended slabs (exterior)													
Frame members													300
Columns (interior)													300
Columns (exterior)													300
Walls (interior)													250
Concrete toppings													250

Collaborative carbon budget **vs.** GWP limit per mix class

Preferred

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Specifications for Sustainability

Project Budget

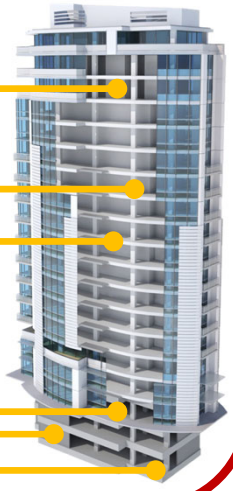
TOTAL GWP: 4.30 x 10^6

VS

Individual Mix Limits

TOTAL GWP: 4.30 x 10^6

- **Shear Walls:** 180 kg CO_2 eq/m^3
- **Columns:** 190 kg CO_2 eq/m^3
- **Floors 2-18:** 240 kg CO_2 eq/m^3
- **Floors B2-1:** 225 kg CO_2 eq/m^3
- **Basement Walls:** 190 kg CO_2 eq/m^3
- **Foundation:** 175 kg CO_2 eq/m^3



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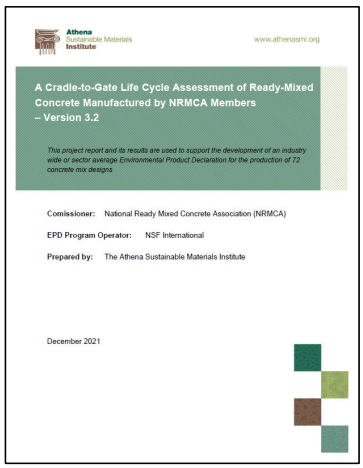
Establishing a Carbon Budget

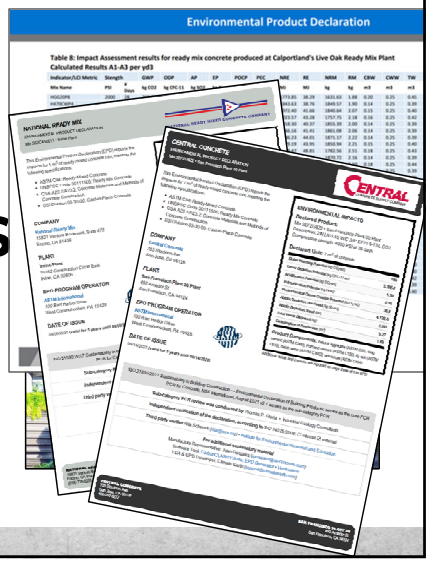
Structural Takeoff

Benchmark Project



VS

Proposed Project



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Example Project

Structure:
18-Story
Residential Tower

Location:
Boston, MA

Concrete:
6 Primary Classes

Material:
Fly Ash and Slag
Available

Shear Walls: (yd^3) x (GWP) = Impact

Columns: (yd^3) x (GWP) = Impact

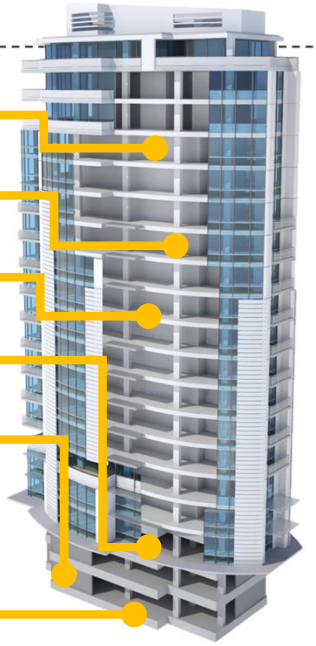
Floors 2-18: (yd^3) x (GWP) = Impact

Floors B2-1: (yd^3) x (GWP) = Impact

Basement Walls: (yd^3) x (GWP) = Impact

Mat Foundation: (yd^3) x (GWP) = Impact

TOTAL: Project Impact



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Estimating Quantities and Properties

Concrete Element	Concrete Volume (yd^3)	Benchmark Mixes (benchmark)*	Proposed Mixes (IW-EPD)*
Shear Walls	7,630	6,000 psi	**6,000 psi** 30% slag, 20% fly ash
Columns	366	8,000 psi	**8,000 psi** 40% fly ash
Floors 2-18	4,533	5,000 psi	**5,000 psi** 30% slag
Floors B2-1	1,067	5,000 psi	**5,000 psi** 40% fly ash
Basement Walls	444	5,000 psi	**5,000 psi** 30% slag, 20% fly ash
Foundation	3,844	6,000 psi	**6,000 psi** 40% slag, 30% fly ash

*Should be augmented with local data, knowledge, capabilities

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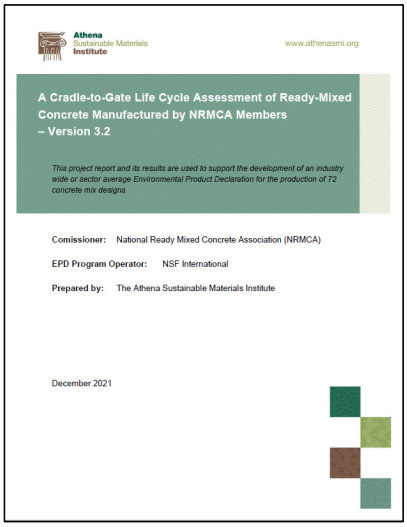
NRMCA Benchmark Mixes


Athena Sustainable Materials Institute www.athenasmi.org

A Cradle-to-Gate Life Cycle Assessment of Ready-Mixed Concrete Manufactured by NRMCA Members – Version 3.2

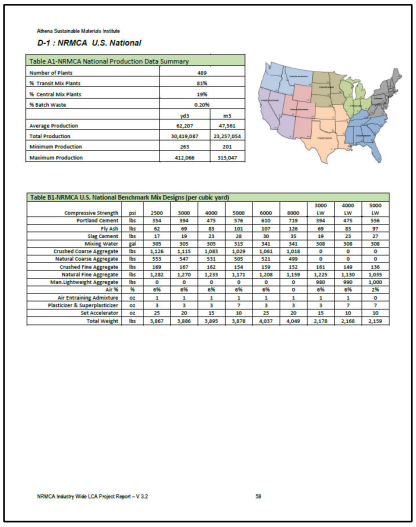
This project report and its results are used to support the development of an industry wide or sector average Environmental Product Declaration for the production of 72 concrete mix designs

Comissioner: National Ready Mixed Concrete Association (NRMCA)

EPD Program Operator: NSF International

Prepared by: The Athena Sustainable Materials Institute

December 2021


Athena Sustainable Materials Institute

D-1 : NRMCA U.S. National

Table A1-NRMCA National Production Data Summary

Number of Plants	469
% Transit Mix Plants	81%
% Central Mix Plants	19%
% Batch Waste	0.20%
	m3 / m3
Average Production	42,207 / 47,581
Total Production	30,419,087 / 23,257,654
Minimum Production	265 / 201
Maximum Production	432,066 / 315,047

Table B1-NRMCA U.S. National Benchmark Mix Designs (per cubic yard)

Compressive Strength	psi	2500	3000	4000	5000	6000	8000	3000 LW	4000 LW	5000 LW
Portland Cement	lbs	354	394	475	576	650	719	394	475	556
Fly Ash	lbs	62	69	83	101	107	126	69	83	97
Slag Cement	lbs	17	19	23	28	30	35	19	23	27
Mixing Water	gal	305	305	305	315	341	341	308	308	308
Crushed Coarse Aggregate	lbs	1,126	1,115	1,083	1,039	1,061	1,018	0	0	0
Natural Coarse Aggregate	lbs	553	547	531	505	521	499	0	0	0
Crushed Fine Aggregate	lbs	169	167	162	154	159	152	161	149	136
Natural Fine Aggregate	lbs	1,282	1,270	1,233	1,171	1,208	1,159	1,225	1,130	1,035
Man.Lightweight Aggregate	lbs	0	0	0	0	0	0	990	990	1,000
Air %	%	6%	6%	6%	6%	6%	0	6%	6%	2%
Air Entraining Admixture	oz	1	1	1	1	1	1	1	1	0
Plasticizer & Superplasticizer	oz	3	3	3	7	3	3	3	7	7
Set Accelerator	oz	25	20	15	10	25	20	15	10	10
Total Weight	lbs	3,867	3,898	3,895	3,873	4,037	4,040	2,178	2,160	2,159

NRMCA Industry Wide LCA Project Report – V 3.2 58

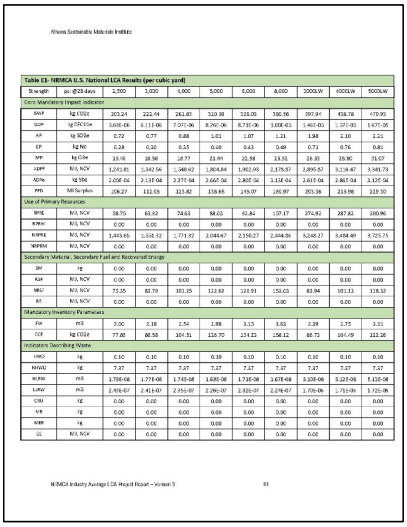

Athena Sustainable Materials Institute

Table E3- NRMCA U.S. National LCA Results (per cubic yard)

Strength	psi @28 days	2,500	3,000	4,000	5,000	6,000	8,000	3000LW	4000LW	5000LW
Core Mandatory Impact Indicators										
GWP	kg CO2e	203.24	222.44	262.85	310.39	328.05	386.96	397.94	458.78	479.99
ODP	kg CFC-11e	5.03E-06	6.11E-06	7.07E-06	8.29E-06	8.73E-06	1.00E-05	1.46E-05	1.87E-05	1.97E-05
AP	kg SO2e	0.72	0.77	0.88	1.01	1.07	1.21	1.98	2.10	2.21
EP	kg N2	0.28	0.30	0.35	0.40	0.43	0.49	0.71	0.76	0.81
SFP	kg O3e	15.41	18.56	18.77	21.44	22.58	23.31	28.33	30.90	31.67
ADPF	MJ, NCV	1,241.81	1,342.56	1,548.62	1,804.84	1,902.06	2,175.57	2,899.67	3,124.47	3,341.73
ADPe	kg Sbe	2.05E-04	2.13E-04	2.37E-04	2.66E-04	2.80E-04	3.15E-04	3.61E-04	3.86E-04	3.92E-04
PED	MJ Surplus	106.27	111.65	123.82	138.65	145.07	160.97	203.38	219.98	229.30
Use of Primary Resources										
RPRE	MJ, NCV	58.75	61.82	74.63	88.03	92.84	107.17	374.82	387.81	389.96
RPRM	MJ, NCV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NRPRE	MJ, NCV	1,449.65	1,558.92	1,771.92	2,044.67	2,156.27	2,464.36	3,248.27	3,484.49	3,725.75
NRPRM	MJ, NCV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Secondary Material, Secondary Fuel and Recovered Energy										
SM	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RSF	MJ, NCV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NRSF	MJ, NCV	75.35	82.79	101.35	122.82	131.01	150.03	83.94	101.13	118.32
RE	MJ, NCV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mandatory Inventory Parameters										
FW	m3	2.00	2.18	2.54	2.98	3.15	3.63	2.39	2.75	3.11
GHF	kg CO2e	77.88	86.58	104.51	126.70	134.23	158.12	86.73	104.09	122.26
Indicators Describing Waste										
HWD	kg	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
NHWD	kg	7.27	7.27	7.27	7.27	7.27	7.27	7.27	7.27	7.27
HLRW	m3	1.78E-08	1.77E-08	1.74E-08	1.68E-08	1.73E-08	1.67E-08	3.20E-08	3.12E-08	3.11E-08
ILRW	m3	2.40E-07	2.41E-07	2.45E-07	2.29E-07	2.32E-07	2.27E-07	1.70E-06	1.71E-06	1.72E-06
CRU	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MR	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MER	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EE	MJ, NCV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

NRMCA Industry Average LCA Project Report – Version 3 61

Download at **https://www.nrmca.org/sustainability**

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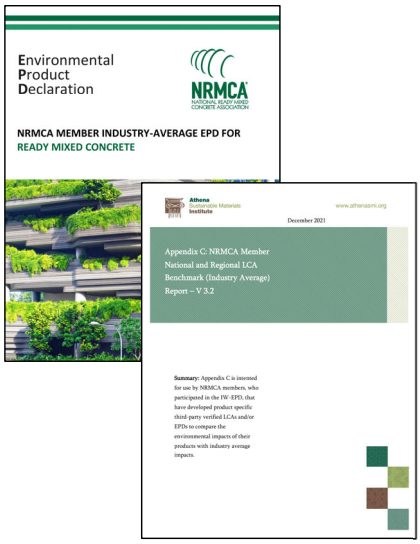
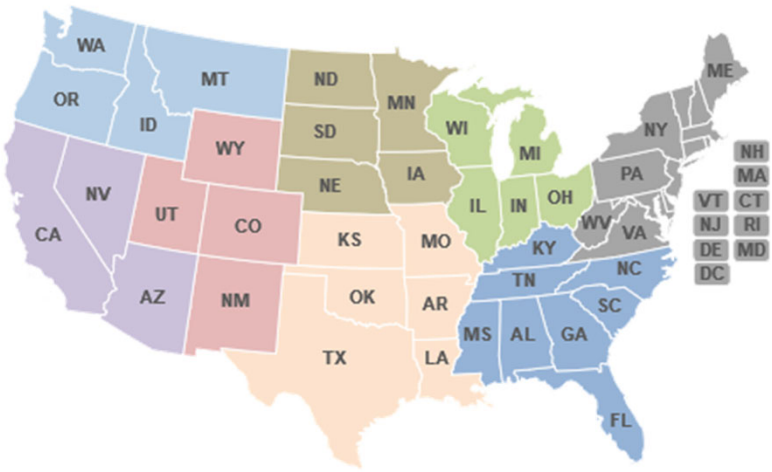
NRMCA Benchmarks - Regions



2021 Version 3



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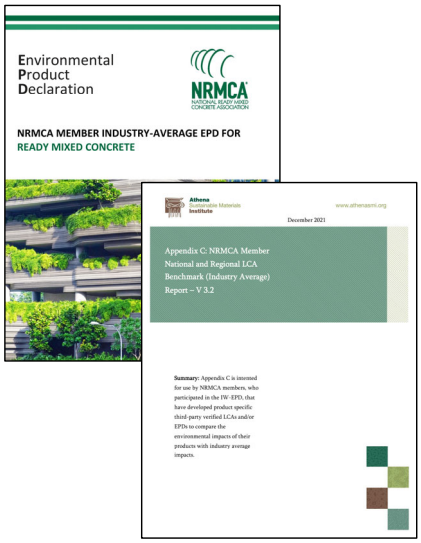
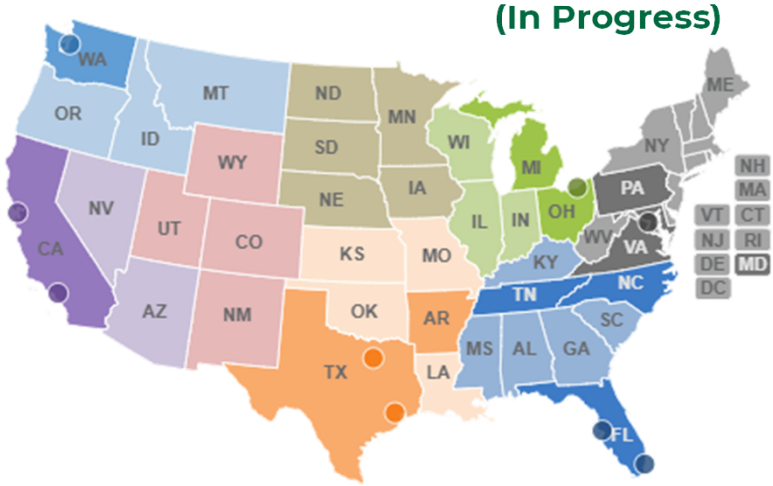
NRMCA Benchmarks - Regions



2021 Version 3 → **2024 Version 4 (In Progress)**



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NRMCA Benchmark Mixes

Shear Walls	7,630	6,000 psi	6,000 psi 30% slag, 20% fly ash

Results Table E2-Eastern LCA Results (per cubic yard)										
Strength	psi @28 days	2,500	3,000	4,000	5,000	6,000	8,000	3000LW	4000LW	5000LW
Core Mandatory Impact Indicator										
GWP	kg CO2e	183.29	201.48	240.22	289.03	305.26	360.51	395.35	437.90	480.10
ODP	kg CFC11e	5.91E-06	6.36E-06	7.32E-06	8.52E-06	8.96E-06	1.03E-05	1.47E-05	1.58E-05	1.69E-05
AP	kg SO2e	0.67	0.71	0.81	0.93	0.98	1.12	2.10	2.22	2.33
EP	kg Ne	0.24	0.26	0.30	0.36	0.37	0.44	0.69	0.74	0.79
SFP	kg O3e	14.31	15.21	17.18	19.61	20.57	23.34	29.65	31.81	33.89
ADPf	MJ, NCV	400.61	412.16	442.07	482.50	503.70	548.75	2,225.23	2,290.96	2,344.41
ADPe	kg Sbe	1.28E-04	1.30E-04	1.36E-04	1.42E-04	1.48E-04	1.55E-04	1.71E-04	1.79E-04	1.87E-04

Download at https://www.nrmca.org/sustainability

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Identifying Global Warming Potential

Concrete Element	Concrete Volume (yd^3)	Benchmark Mixes GWP (Eastern Region)*	Proposed Mixes GWP (IW-EPD)
Shear Walls	**7,630**	6,000 psi **305**	
Columns	**366**	8,000 psi **361**	
Floors 2-18	**4,533**	5,000 psi **289**	
Floors B2-1	**1,067**	5,000 psi **289**	
Basement Walls	**444**	5,000 psi **289**	
Foundation	**3,844**	6,000 psi **305**	

* Note: Pay attention to units as the report has GWP listed per yd^3 and per m^3

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Environmental Product Declaration (EPD)

3rd party verified & registered documents that communicate transparency

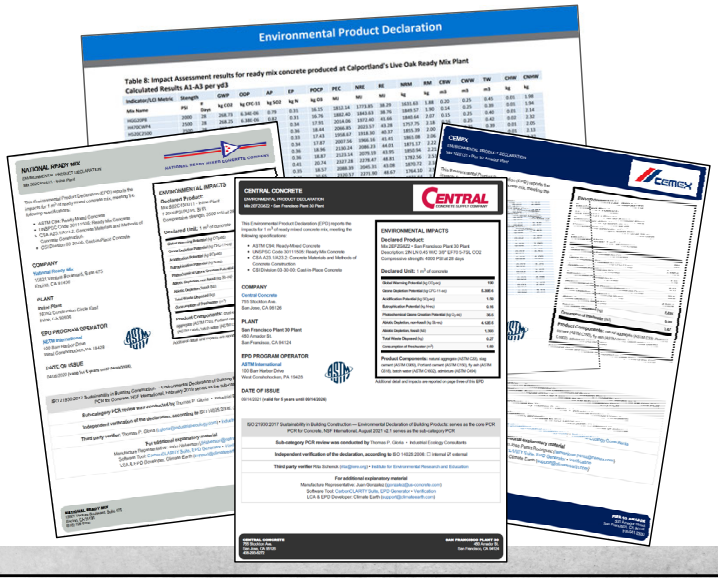
ENVIRONMENTAL IMPACTS

Declared Product:
Mix 2EFZG8Z2 • San Francisco Plant 30 Plant
Description: 2IN LN 0.45 W/C 3/8" EF70 5-7SL CO2
Compressive strength: 4000 PSI at 28 days

Declared Unit: 1 m^3 of concrete

Global Warming Potential (kg CO_2-eq)	190
Acidification Potential (kg SO_2-eq)	1.59
Eutrophication Potential (kg N-eq)	0.16
Photochemical Ozone Creation Potential (kg O_3-eq)	36.6
Abiotic Depletion, non-fossil (kg Sb-eq)	4.12E-5
Abiotic Depletion, fossil (MJ)	1,393
Total Waste Disposed (kg)	0.27
Consumption of Freshwater (m^3)	1.69

Product Components: natural aggregate (ASTM C33), slag cement (ASTM C989), Portland cement (ASTM C150), fly ash (ASTM C618), batch water (ASTM C1602), admixture (ASTM C494)



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NRMCA Proposed Industry Wide EPD Mixes

Shear Walls	7,630	6,000 psi	6,000 psi 30% slag, 20% fly ash

Table 10b. Summary Results (A1-A3): 5001-6000 psi (34.5-41.4 MPa) RMC product mix design, per cubic yard

		Minimum	Maximum	5001-6000-00-FA/SL	5001-6000-20-FA	5001-6000-30-FA	5001-6000-40-FA	5001-6000-30-SL	5001-6000-40-SL	5001-6000-50-SL	5001-6000-50-FA/SL
Core Mandatory Impact Indicator											
GWP	kg CO2e	231.47	377.44	377.44	322.63	293.01	261.73	290.83	261.97	233.1	231.47
ODP	kg CFC11e	6.50E-06	9.71E-06	9.16E-06	7.90E-06	7.22E-06	6.50E-06	9.49E-06	9.60E-06	9.71E-06	6.24E-06
AP	kg SO2e	0.81	1.10	1.07	0.95	0.88	0.81	1.08	1.09	1.10	0.97
EP	kg Ne	0.30	0.45	0.45	0.39	0.35	0.32	0.37	0.34	0.32	0.30
SFP	kg O3e	17.76	23.30	22.81	20.42	19.13	17.76	23.10	23.20	23.30	20.73
ADPf	MJ, NCV	503.28	575.31	575.31	541.31	522.84	503.28	550.69	542.48	534.27	515.21
ADPe	kg Sbe	1.21E-04	1.50E-04	1.50E-04	1.36E-04	1.29E-04	1.21E-04	1.36E-04	1.31E-04	1.27E-04	1.22E-04

Download at https://www.nrmca.org/sustainability

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Identifying Global Warming Potential

Concrete Element	Concrete Volume (yd^3)	Benchmark Mixes GWP (Eastern Region)	Proposed Mixes GWP (IW-EPD)*
Shear Walls	**7,630**	6,000 psi **305**	30% slag, 20% fly ash **232**
Columns	**366**	8,000 psi **361**	40% fly ash **303**
Floors 2-18	**4,533**	5,000 psi **289**	30% slag **277**
Floors B2-1	**1,067**	5,000 psi **289**	40% fly ash **249**
Basement Walls	**444**	5,000 psi **289**	30% slag, 20% fly ash **220**
Foundation	**3,844**	6,000 psi **305**	40% slag, 30% fly ash **166****

* Should be augmented with local data, knowledge, capabilities

** Use NRMCA Tool to input mix proportions which uses Life Cycle Inventory (LCI) data to estimate impact

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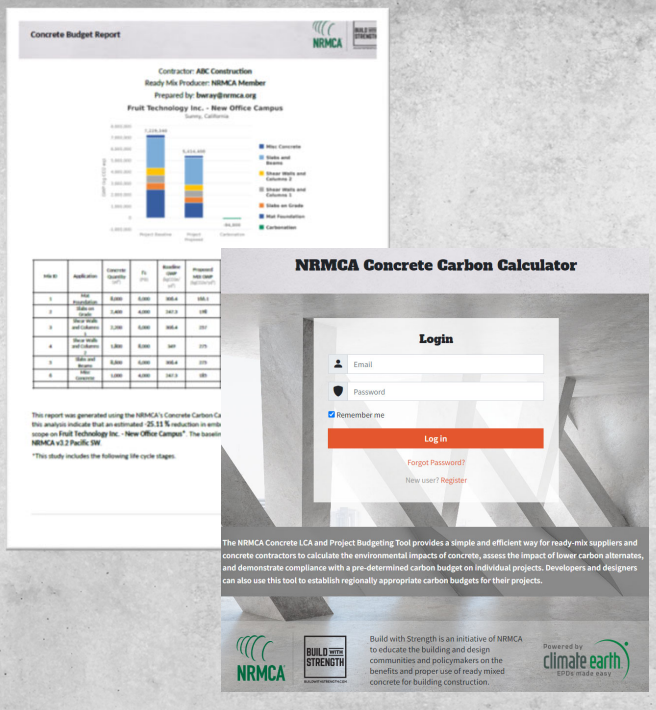
NRMCA Concrete Carbon Calculator

Producer

NRMCA Designer

Access at **https://nrmca.climateearth.com/**



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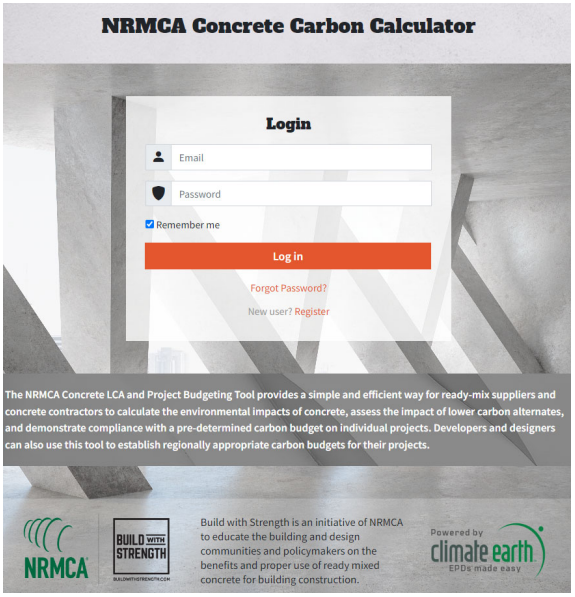
NRMCA Concrete Carbon Calculator

NRMCA's Carbon Tool can Simplify the Process

1. Automatically populates benchmark impacts
2. Calculates estimated carbon sequestration of the concrete through the life cycle of the structure
3. Generates a report documenting the anticipated reduction a low carbon concrete project can expect compared to the benchmark

Access at **https://nrmca.climateearth.com/**



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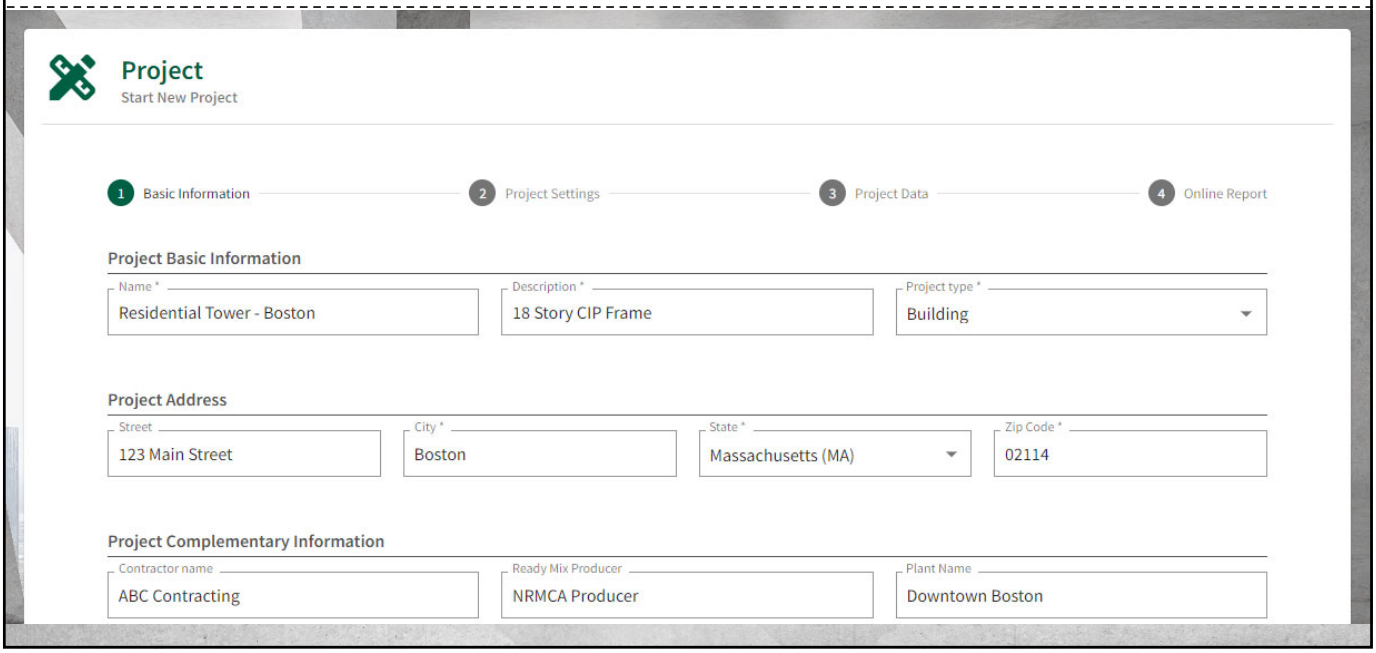
NRMCA Carbon Tool



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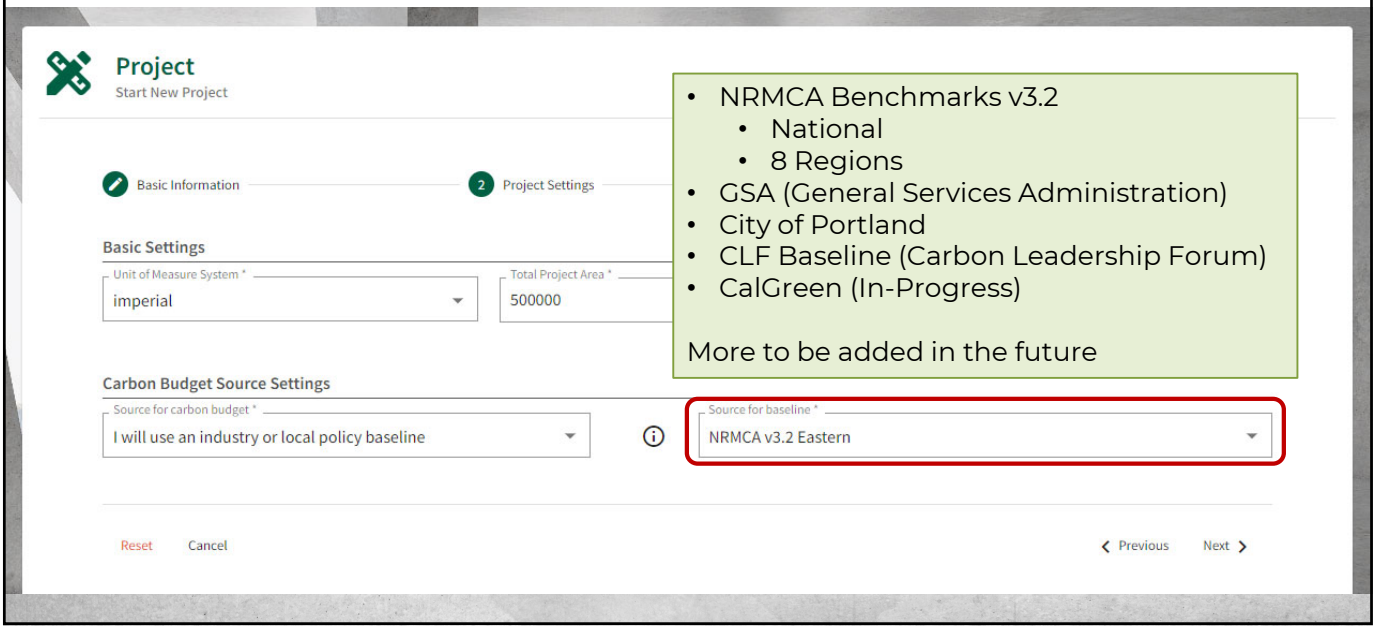
NRMCA Carbon Tool



- NRMCA Benchmarks v3.2
  - National
  - 8 Regions
- GSA (General Services Administration)
- City of Portland
- CLF Baseline (Carbon Leadership Forum)
- CalGreen (In-Progress)

More to be added in the future

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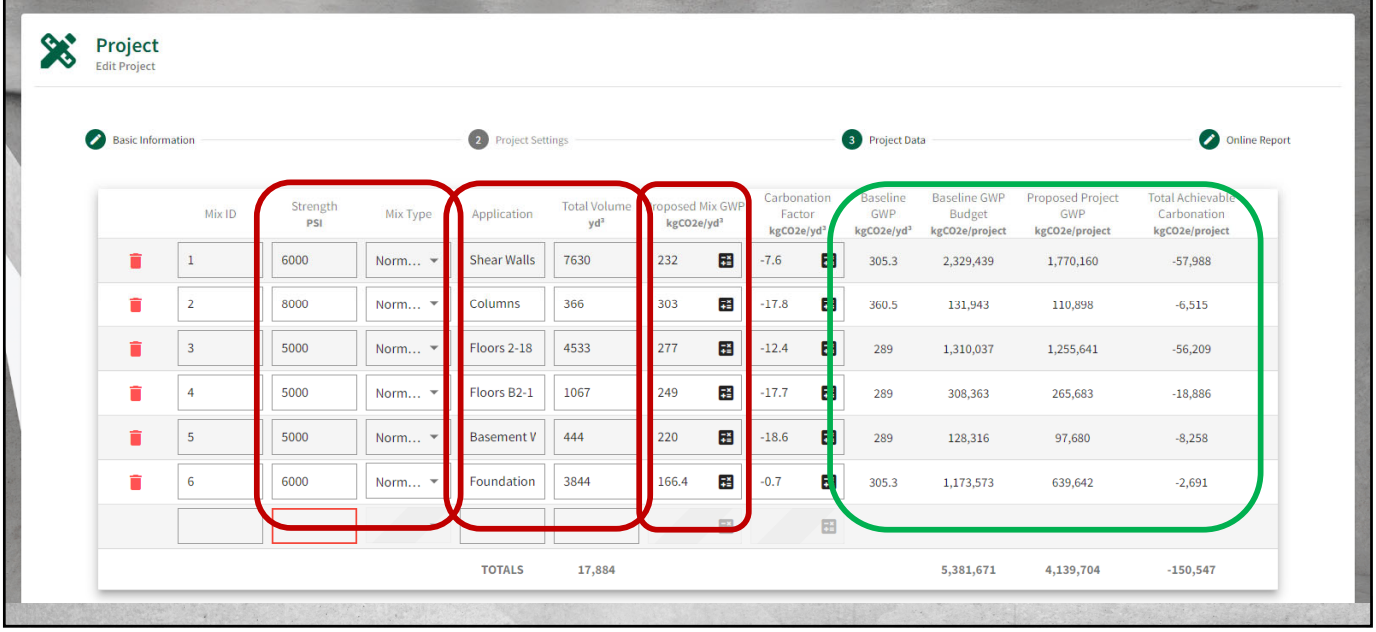
NRMCA Carbon Tool



	Mix ID	Strength PSI	Mix Type	Application	Total Volume yd³	Proposed Mix GWP kgCO2e/yd³	Carbonation Factor kgCO2e/yd³	Baseline GWP kgCO2e/yd³	Baseline GWP Budget kgCO2e/project	Proposed Project GWP kgCO2e/project	Total Achievable Carbonation kgCO2e/project
	1	6000	Norm…	Shear Walls	7630	232	-7.6	305.3	2,329,439	1,770,160	-57,988
	2	8000	Norm…	Columns	366	303	-17.8	360.5	131,943	110,898	-6,515
	3	5000	Norm…	Floors 2-18	4533	277	-12.4	289	1,310,037	1,255,641	-56,209
	4	5000	Norm…	Floors B2-1	1067	249	-17.7	289	308,363	265,683	-18,886
	5	5000	Norm…	Basement V	444	220	-18.6	289	128,316	97,680	-8,258
	6	6000	Norm…	Foundation	3844	166.4	-0.7	305.3	1,173,573	639,642	-2,691
				TOTALS	17,884				5,381,671	4,139,704	-150,547

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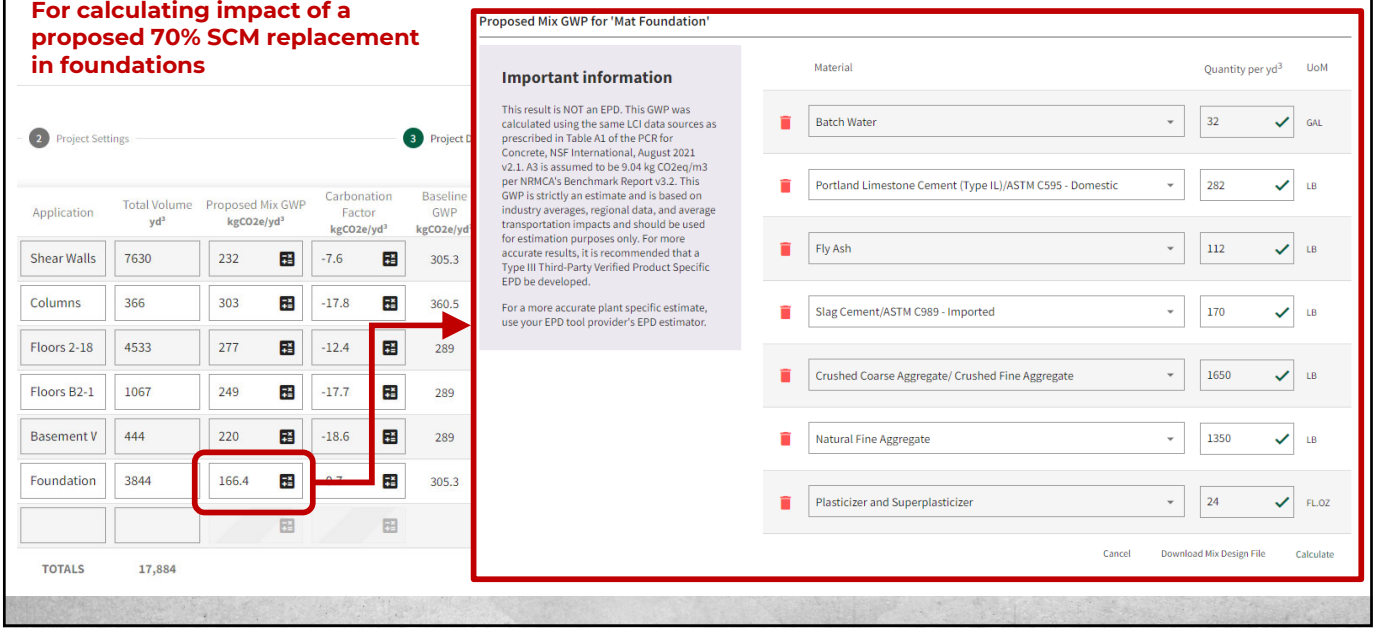
NRMCA Carbon Tool

For calculating impact of a proposed 70% SCM replacement in foundations



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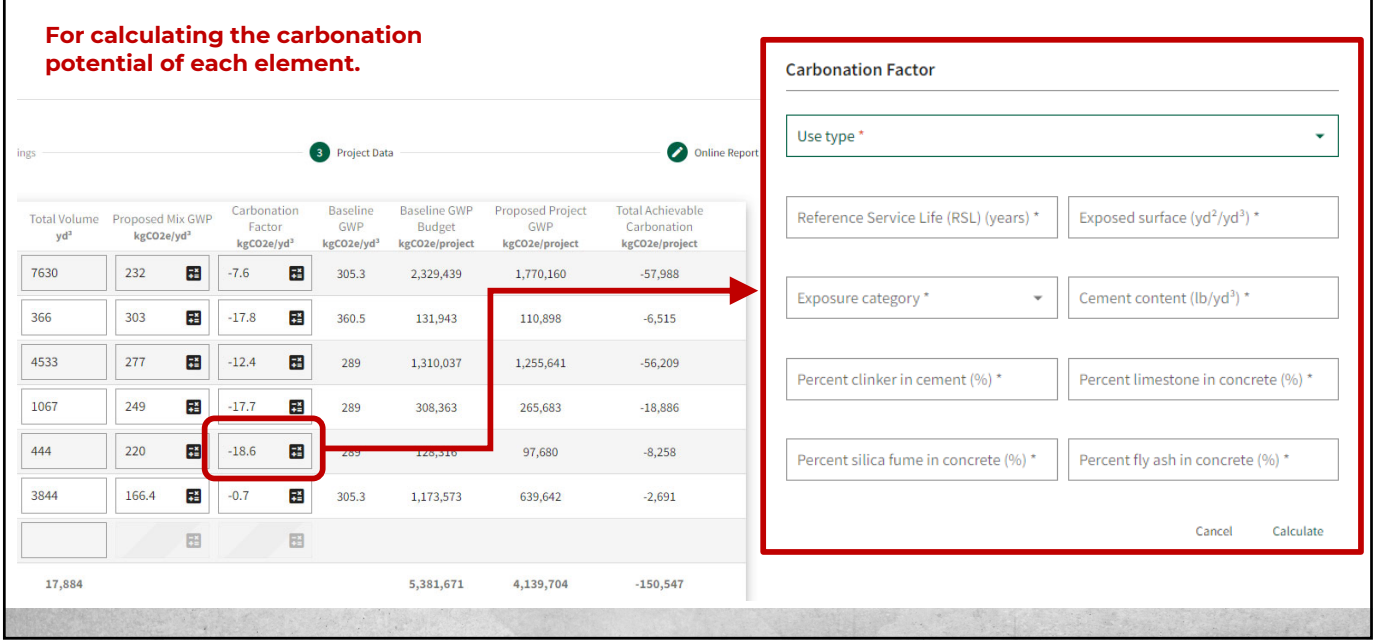
NRMCA Carbon Tool

For calculating the carbonation potential of each element.



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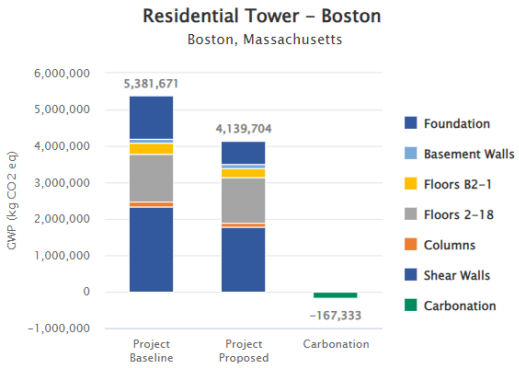
NRMCA Carbon Tool



Mix ID	Application	Concrete Quantity (yd³)	f'c (PSI)	Baseline GWP (kgCO2e/yd³)	Proposed Mix GWP (kgCO2e/yd³)	Total Project Baseline GWP (kgCO2e/yd³)	Total Project Proposed GWP (kgCO2e/project)	Difference from Baseline	Carbonation (kgCO2e/project)
1	Shear Walls	7,630	6,000	305.3	232	2,329,439	1,770,160	-24 %	-74,774
2	Columns	366	8,000	360.5	303	131,943	110,898	-16 %	-6,515
3	Floors 2-18	4,533	5,000	289	277	1,310,037	1,255,641	-4.2 %	-56,209
4	Floors B2-1	1,067	5,000	289	249	308,363	265,683	-13.8 %	-18,886
5	Basement Walls	444	5,000	289	220	128,316	97,680	-23.9 %	-8,258
6	Foundation	3,844	6,000	305.3	166.4	1,173,573	639,642	-45.5 %	-2,691
						5,381,671	**4,139,704**	**-23.1%**	**-167,333**

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Final Results

Project	Project GWP (kg)	Weighted GWP (kg/yd³)	GWP Reduction
Benchmark Mixes	**5,382,000**	**301**	**0**
Proposed with Fly Ash and Slag Mixes	**4,140,000**	**232**	**- 23%**
Establish Carbon Budget	**4,300,000**	**240**	**- 20%***

* Consider added buffer/tolerance

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Example – Specification Language

Recommended Specification Additions:

Section 033000 - CAST-IN-PLACE CONCRETE

Part 1 - GENERAL

1.1 - Related Documents

A. The basis for designing concrete mixtures and demonstrating compliance with carbon budget targets shall be in accordance with:

1. National Ready Mixed Concrete Association (NRMCA) Cradle-to-Gate Life Cycle Assessment of Ready-Mixed Concrete Manufactured by NRMCA Members – Version 3 (or later).
2. National Ready Mixed Concrete Association, NRMCA Member Industry Average EPD for Ready Mixed Concrete – Version 3 (or later).

1.2 - Summary

A. Embodied Carbon Footprint Goals

1. This project has a goal of reducing the embodied carbon footprint relative to a benchmark or typical project by **XX %.** To accomplish this goal, the **target carbon footprint reduction for concrete is 20% below the benchmark** established in the NRMCA Cradle-to-Gate Life Cycle Assessment of Ready-Mixed Concrete Version 3 (or later). Specific targets for Global Warming Potential (GWP) are provided in Section 2, CONCRETE MIXTURES. It shall be permitted to propose innovative products and manufacturing processes for approval by the Engineer of Record. Proposed alternatives shall meet all performance criteria for strength, durability, and constructability, and achieve the required reduction in carbon footprint.

1.5 - Action Submittals

A. Embodied Carbon Footprint Submittals

1. Plant specific Environmental Product Declaration (EPD) for each concrete mixture proposed for the project accompanying each concrete mixture submittal
   a. It shall be permitted to substitute plant-specific EPDs with those listed in NRMCA Member Industry Average EPD for Ready Mixed Concrete if the proposed mixtures are similar to those listed and the concrete producer participated in providing data for the NRMCA Cradle-to-Gate Life Cycle Assessment of Ready-Mixed Concrete.
2. A calculation showing that the Global Warming Potential (GWP) of all the concrete supplied for the project shall be lower than the GWP target set in Section 2.

Recommended Specification Additions (continued):

1.7 - Quality Assurance

A. Ready Mixed Concrete Manufacturer Qualifications: A company manufacturing ready mixed concrete who complies with ASTM C94/C94M requirements for production facilities and equipment

1. Concrete shall be supplied from concrete plants with current certification under the NRMCA Certification of Ready Mixed Concrete Production Facilities, certification or approval by a state or highway agency or equivalent. Criteria of equivalent certification shall be included in the submittal.
2. Quality Control personnel with responsibility for concrete mixtures shall document qualifications demonstrating knowledge and experience with concrete technology and development of performance-based concrete mixtures. certified as an NRMCA Concrete Technologist Level 2, or equivalent. Details covered in equivalent certification program shall be documented in the submittal.
3. When requested, the manufacturer shall furnish a Quality Plan
4. Documentation that the concrete supplier participated in supplying data to the NRMCA Cradle-to-Gate Life Cycle Assessment of Ready-Mixed Concrete.

Part 2 - PRODUCTS

2.2 - Concrete Materials

A. Cementitious Materials: Materials conforming to the following are permitted:

1. Portland Cement (ASTM C150), Blended Hydraulic Cement (ASTM C595), Hydraulic Cement (ASTM C1157), Fly Ash or Natural Pozzolan (ASTM C618), Slag Cement (ASTM C989)

2.11 - Concrete Mixtures

A. Embodied Carbon Compliance

1. Provide documentation that the total GWP of all proposed concrete on the project is less than or equal to **5,785,000 kg of CO2 equivalents or a weighted average of 241 kgCO2e/yd3**.

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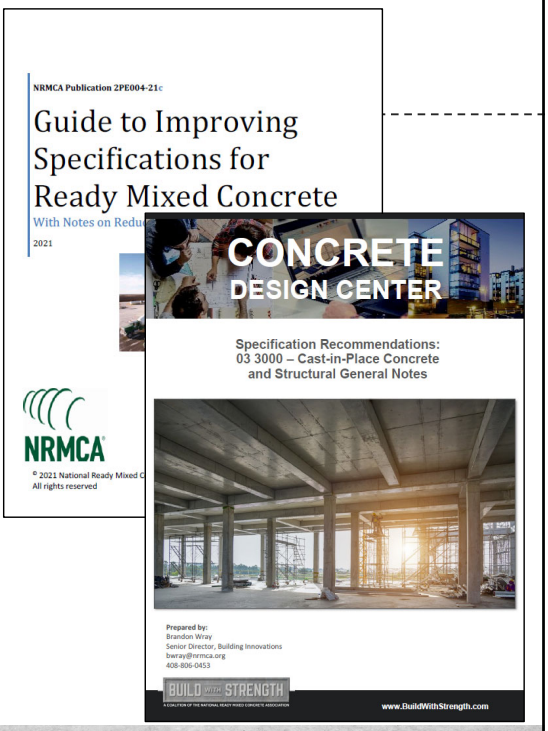
Example – Mix Table

Application	Strength (psi)	Exposure Classes	Maximum w/cm	Max. Aggregate Size (in)	Suggested GWP Target (kg/CO²e/yd)	Notes
Footings, Grade Beams	4000 @ 56 days	S2	0.45	1-1/2		1
Foundation Walls	5000 @ 56 days	S2	0.45	1		1
Retaining Walls	5000 @ 56 days	C2	0.40	1		2
Shear Walls, Columns	6000 @ 56 days			1		
Slabs-on-grade	4000 @ 28 days			1-1/2		3
Elevated Post-Tensioned Slabs	3000 @ 4 days 5000 @ 28 days			1		3
All other uses	4000			3/4		
	REQUIRED Weighted Average GWP (kg/CO²e/yd)				XXX	4

A. Notes:
1. S2 exposure classification requires the use of sulfate resistant cement, C150 Type II/V or C595/C1157 with HS designation.
2. C2 exposure classification requirement of 0.40 w/cm can be overridden with rapid chloride permeability values less than 1000 coulombs as tested per ASTM C1202.
3. ASTM C157 shrinkage requirement of 0.050% after 7 days of moist curing followed by 21 days of air drying.
4. Required weighted average GWP is taken across all concrete mix classes and their individual volumes, allowing suggested GWP to be exceeded for certain applications as long as overall GWP is achieved.



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Example – Tech Campus

Performance Improvements:

- BWS makes optimization recommendations

Carbon Bidding:

- BWS connects with member producers in region to identify locally applicable carbon targets

NRMCA Build With Strength: Low Carbon Concrete Project Analysis

Project:	Confidential (2024)	Location:		Producer:	

Designed

Application	Strength (psi)	Day	w/cm	Max Agg. Size	Air	Shrinkage	Exposure Class	Volume (yds)
Footings	4000	28	0.45	1"	4.5% ± 1.5%	0.050%	F2, S0, W1, C1	4,200
Walls (interior)	5000	28	0.45	3/4"		0.050%	F0, S0, W0, C1	3,500
Walls (exterior)	5000	28	0.45	3/4"	4.5% ± 1.5%	0.050%	F2, S0, W1, C1	2,600
Columns (interior)	5000	28	0.45	3/4"		0.050%	F0, S0, W0, C1	1,800
Suspended Slabs/Beams	5000	28	0.40	3/4"		0.045%	F0, S0, W0, C1	5,400
Slab on Grade (interior)	4000	28	0.45	1"		0.045%	F0, S0, W0, C1	4,300
Slab on Grade (exterior)	4500	28	0.40	1"	4.5% ± 1.5%	0.045%	F2, S0, W1, C2	2,500
Exterior Concrete (other)	4500	28	0.45	3/4"	4.5% ± 1.5%	0.050%	F2, S0, W1, C1	9,000
Topping Slab (interior)	4500	28	0.40	3/8"		0.040%	F0, S0, W0, C1	6,300
							TOTAL:	39,600

Optimized

Application	Strength (psi)	Day	w/cm	Max Agg. Size	Air	Shrinkage	Exposure Class	Volume (yds)
Footings	4000	56		1"			F0, S0, W1, C1	4,200
Walls (interior)	5000	56		3/4"			F0, S0, W0, C1	3,500
Walls (exterior)	5000	56	0.45	3/4"	4.5% ± 1.5%		F2, S0, W1, C1	2,600
Columns (interior)	5000	56		3/4"			F0, S0, W0, C1	1,800
Suspended Slabs/Beams	5000	28		3/4"		0.045%	F0, S0, W0, C1	5,400
Slab on Grade (interior)	4000	28		1"		0.045%	F0, S0, W0, C1	4,300
Slab on Grade (exterior)	4500	28	0.40	1"	4.5% ± 1.5%		F2, S0, W1, C2	2,500
Exterior Concrete (other)	4500	56	0.45	3/4"	4.5% ± 1.5%		F2, S0, W1, C1	9,000
Topping Slab (interior)	4500	28		3/8"		0.040%	F0, S0, W0, C1	6,300
							TOTAL:	39,600

*Changes highlighted

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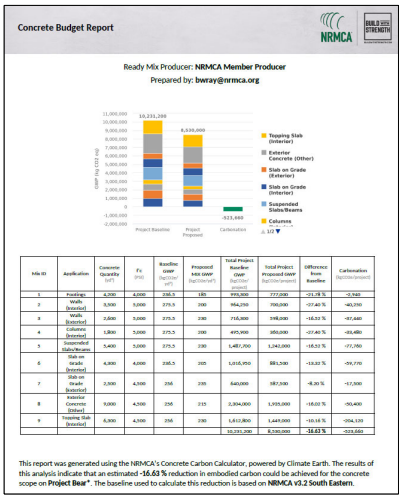
Example – Tech Campus

D. Embodied Carbon Compliance

1. Provide documentation that the total GWP of all proposed concrete on the project is less than or equal to a weighted average of **220 kgCO2e/yd3**.

2. Input values used to calculate the carbon targets are listed below. Adherence to prescribed class GWP values will achieve the project's weighted average goal

Mix ID	Application	Concrete Quantity (yd³)	f'c (PSI)	Baseline GWP (kgCO2e/ yd³)	Proposed MIX GWP (kgCO2e/yd³)	Total Project Baseline GWP (kgCO2e/ project)	Total Project Proposed GWP (kgCO2e/project)	Difference from Baseline
1	Footings	4,200	4,000	236.5	190	993,300	798,000	20 %
2	Walls (Interior)	3,500	5,000	275.5	210	964,250	735,000	24 %
3	Walls (Exterior)	2,600	5,000	275.5	240	716,300	624,000	13 %
4	Columns (Interior)	1,800	5,000	275.5	205	495,900	369,000	26 %
5	Suspended Slabs/Beams	5,400	5,000	275.5	230	1,487,700	1,242,000	17 %
6	Slab on Grade (Interior)	4,300	4,000	236.5	210	1,016,950	903,000	11 %
7	Slab on Grade (Exterior)	2,500	4,500	256	240	640,000	600,000	6 %
8	Exterior Concrete (Other)	9,000	4,500	256	220	2,304,000	1,980,000	14 %
9	Topping Slab (Interior)	6,300	4,500	256	230	1,612,800	1,449,000	10 %
		39,600			**220**	**10,231,200**	**8,700,000**	**15 %**


Concrete Budget Report

NRMCA

Ready Mix Producer: NRMCA Member Producer

Prepared by: bwray@nrmca.org

This report was generated using the NRMCA's Concrete Carbon Calculator, powered by Climate Earth. The results of this analysis indicate that an estimated **-16.63 %** reduction in embodied carbon could be achieved for the concrete scope on **Project Bear™**. The baseline used to calculate this reduction is based on **NRMCA v3.2 South Eastern**.

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Example – High Rise

SOM

400 North Lake Shore Drive
Chicago, IL

7/02/2024
Issued for Construction

B. Project Requirements: Sustainable Design Requirements:

1. The GWP of the concrete supplied for this project shall be in conformance with one of the two Contractor selected compliance methods described below:

a. Compliance Method A – Total Carbon Budget:

1) The total concrete supplied on the project (excluding waste) shall have a weighted average GWP less than or equal to 275 kg CO_2e/cu.yd. This limit may be exceeded by up to 5%.

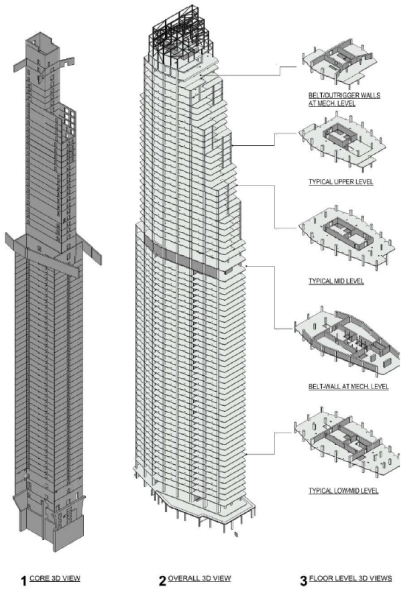
2) The table in Compliance Method B includes recommended GWP limits to achieve conformance, but are not required for Compliance Method A.

b. Compliance Method B – Individual Mix Carbon Limits:

1) Individual concrete classes/mixes shall have a GWP less than or equal to that shown in the table below.

2) Applications with an age for cylinder testing of 56 days may be extended to 90 days with approval from the Architect.

STRENGTH (PSI)	*AGE FOR CYLINDER TESTING (DAYS)*	*MAXIMUM GWP PER EPD (KGCO2E/CU.YD.)*
4,000	28	160
5,000	28	185
6,000	28	195
8,000	28	230
8,600	28	245
10,000	56	270
14,000	56	355



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Contractor – Carbon Accounting

	EMBODIED CARBON FOOTPRINT			CONCRETE MIX REQUIREMENTS PER SPECS									
MIX TYPES	EPD Available Y/N	Global Warming Potential (GWP)	Total GWP	TOTAL CY	Cost ($/CY)	STRENGTH (PSI)	SPECIFIED STRENGTH (DAYS)	EARLY STRENGTH (IF PT)	SLUMP (IN)	MAX (W/CM)	AGG SIZE (IN)	MAX OPC (LB/CY)	SCM (%)
Rat Slab	Y	160 kgCO2e/yd3	49,600 kgCO2e	310 CY		3,000	56 days		4"	0.45	1/2"	200	50-70
Tower Crane Foundation	Y	192 kgCO2e/yd3	28,800 kgCO2e	150 CY		6,000	56 days	4500 5-days	5"	0.45	1"	200	50-70
Mat Slab & Footings & Grade Beams	Y	175 kgCO2e/yd3	703,500 kgCO2e	4,020 CY		6,000	56 days		5"	0.45	1"	200	50-70
Slab on Grade & Curbs & B.U.S.	Y	175 kgCO2e/yd3	35,000 kgCO2e	200 CY		6,000	56 days		6"	0.45	3/4"	200	50-70
Mild Steel Decks/Beams - L2	Y	192 kgCO2e/yd3	48,000 kgCO2e	250 CY		8,000	56 days		6"	0.45	3/4"	300	30-60
PT Decks/Beams	Y	260 kgCO2e/yd3	1,076,400 kgCO2e	4,140 CY		6,000	56 days	4500 4-days	6"	0.45	3/4"	300	30-60
Ltwt. Metal Deck Fill	Y	442 kgCO2e/yd3	44,200 kgCO2e	100 CY		3,000	56 days		6"	0.45	1/2"	200	50-70
Columns	Y	190 kgCO2e/yd3	95,000 kgCO2e	500 CY		6,000	56 days		8"-10"	0.45	3/4"	250	50-70
Shear Walls, Strength 1 - L1	Y	236 kgCO2e/yd3	82,600 kgCO2e	350 CY		10,000	56 days		8"-10"	0.45	3/4"	250	50-70
Shear Walls, Strength 2 - L2-Roof	Y	188 kgCO2e/yd3	188,000 kgCO2e	1,000 CY		8,000	56 days		8"-10"	0.45	3/4"	200	50-70
Pump Primer	N		kgCO2e	50 CY									
PROJECT TOTAL		212 kgCO2e/yd3	2,351,100 kgCO2e	11,070 CY									
MAX PER CARBON BUDGET (25% BELOW NRMCA BENCHMARK)		283 kgCO2e/yd3	3,133,050 kgCO2e										
DELTA		-71 kgCO2e/yd3	-781,950 kgCO2e										

** Contractor recommended slumps. Check w/ specs, jobsite requirements and with producer

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CALGreen – Embodied Carbon

Effective Date:

July 1, 2024

Buildings Impacted:

Nonresidental: >100,000 ft^2

Schools: >50,000 ft^2

Compliance Paths:

1. Building Reuse:
   45%+ reuse of existing structure and enclosure
2. Life Cycle Analysis:
   10% reduction from baseline in a 60-year cradle-to-grave analysis
3. Prescriptive GWP:
   175% maximum GWP from NRMCA benchmark values

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CALGreen – Low Carbon Concrete

Prescriptive GWP Compliance Path:

- 175% maximum GWP from NRMCA benchmark values
- Additional 130% for high early concrete applications (227.5% of benchmark)
- Concrete can be treated as one collective product (weighted average)

Verification of Compliance:

Prescriptive Path #1:

- Type III product-specific EPDs for each mix
- Comparison to mix GWP limits

OR

Prescriptive Path #2 (Exception):

- Type III product-specific EPDs **or** NRMCA industry-wide EPDs
- Calculation of GWP totals where:
  Total $GWP_{Supplied}$ is less than **Total $GWP_{Allowed}$**

5.409.3 Product GWP compliance—prescriptive path. Each product that is permanently installed and listed in Table 5.409.3 shall have a Type III environmental product declaration (EPD), either product-specific or factory-specific.

5.409.3.1 Products shall not exceed the maximum GWP value specified in Table 5.409.3.

Exception: Concrete may be considered one product category to meet compliance with this section. A weighted average of the maximum GWP for all concrete mixes installed in the project shall be less than the weighted average maximum GWP allowed per Table 5.409.3 using Exception Equation 5.409.3.1. Calculations shall be performed with consistent units of measurement for the material quantity and the GWP value. For the purposes of this exception, industry-wide EPDs are acceptable.

Concrete, Ready-Mixed[2, 3]		
CONCRETE PRODUCT CATEGORY	MAXIMUM GWP ALLOWED VALUE ($GWP_{allowed}$)	UNIT OF MEASUREMENT
up to 2499 psi	450	kg CO_2e/m^3
2500–3499 psi	489	kg CO_2e/m^3
3500–4499 psi	566	kg CO_2e/m^3
4500–5499 psi	661	kg CO_2e/m^3
5500–6499 psi	701	kg CO_2e/m^3
6500 psi and greater	799	kg CO_2e/m^3
Concrete, Lightweight Ready-Mixed[2]		
CONCRETE PRODUCT CATEGORY	MAXIMUM GWP ALLOWED VALUE ($GWP_{allowed}$)	UNIT OF MEASUREMENT
up to 2499 psi	875	kg CO_2e/m^3
2500–3499 psi	956	kg CO_2e/m^3
3500–4499 psi	1039	kg CO_2e/m^3

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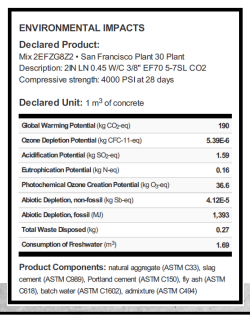
CALGreen – Prescriptive Path #1

Examples:

Prescriptive Path #1:

Mix	Class	Application	Max $GWP_{Allowed}$	*$GWP_{Supplied\ Mix}$	$GWP_A > GWP_S$
1	4000 psi	Foundations	566	225	Yes ✓
2	6000 psi	Columns/Walls	701	375	Yes ✓
3	5000 psi	Slabs	661	350	Yes ✓

* Requires Type III Product-Specific EPDs


ENVIRONMENTAL IMPACTS

Declared Product:
Mix 2EFZG8Z2 • San Francisco Plant 30 Plant
Description: 2IN LN 0.45 W/C 3/8" EF70 5-7SL CO2
Compressive strength: 4000 PSI at 28 days

Declared Unit: 1 m^3 of concrete

Global Warming Potential (kg CO_2-eq)	190
Ozone Depletion Potential (kg CFC-11-eq)	5.39E-6
Acidification Potential (kg SO_2-eq)	1.59
Eutrophication Potential (kg N-eq)	0.16
Photochemical Ozone Creation Potential (kg O_3-eq)	36.6
Abiotic Depletion, non-fossil (kg Sb-eq)	4.12E-5
Abiotic Depletion, fossil (MJ)	1,393
Total Waste Disposed (kg)	0.27
Consumption of Freshwater (m^3)	1.69

Product Components: natural aggregate (ASTM C33), slag cement (ASTM C989), Portland cement (ASTM C150), fly ash (ASTM C618), batch water (ASTM C1602), admixture (ASTM C494)

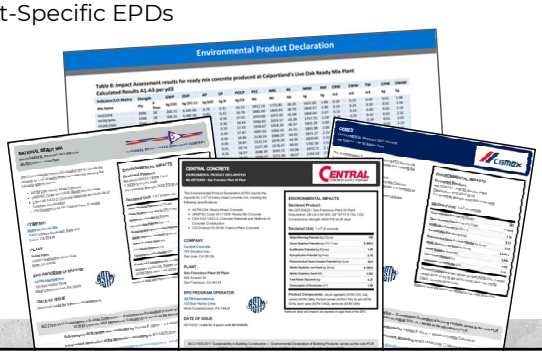


TABLE 5.409.3 PRODUCT GWP LIMITS		
Concrete, Ready-Mixed[2, 3]		
CONCRETE PRODUCT CATEGORY	MAXIMUM GWP ALLOWED VALUE ($GWP_{allowed}$)	UNIT OF MEASUREMENT
up to 2499 psi	450	kg CO_2e/m^3
2500–3499 psi	489	kg CO_2e/m^3
3500–4499 psi	566	kg CO_2e/m^3
4500–5499 psi	661	kg CO_2e/m^3
5500–6499 psi	701	kg CO_2e/m^3
6500 psi and greater	799	kg CO_2e/m^3
Concrete, Lightweight Ready-Mixed[2]		
CONCRETE PRODUCT CATEGORY	MAXIMUM GWP ALLOWED VALUE ($GWP_{allowed}$)	UNIT OF MEASUREMENT
up to 2499 psi	875	kg CO_2e/m^3
2500–3499 psi	956	kg CO_2e/m^3
3500–4499 psi	1039	kg CO_2e/m^3

1. The GWP values of the products listed in Table 5.409.3 are based on 175 percent of Buy Clean California Act (BCCA) GWP values, except for concrete products which are not included in the BCCA.
2. For concrete, 175 percent of the National Ready Mixed Concrete Association (NRMCA) 2022 version 3 Pacific Southwest regional benchmark values are used for the GWP allowed, except for High Early Strength.
3. Concrete High Early Strength ready-mixed shall be calculated at 130 percent of the ready-mixed concrete GWP allowed values for each product category.

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CALGreen – Prescriptive Path #2

Examples:
Prescriptive Path #2 (Exception):

Mix	Class	Application	Volume (cu. yd)	Max $GWP_{Allowed}$	Total $GWP_{Allowed}$	*$GWP_{Supplied\ Mix}$	Total $GWP_{Supplied}$
1	4000 psi	Foundations	2000	566	1,132,000	225	450,000
2	6000 psi	Columns/Walls	750	701	525,750	375	281,250
3	5000 psi	Slabs	1500	661	991,500	350	525,000
4	6000 psi	Shotcrete	500	701	350,500	725**	362,500**
		TOTAL	4750	632	2,999,750	341	1,618,750

* Can be Industry-Wide EPDs if producer is participant

** Note: Allows for individual mixes to be above individual GWP limits

$Total\ GWP_{Allowed} > Total\ GWP_{Supplied}$

Exception EQUATION 5.409.3.1

$GWP_n < GWP_{allowed}$

where

$GWP_n = \Sigma\ (GWP_n)(V_n)$

and

$GWP_{allowed} = \Sigma\ (GWP_{allowed})(V_n)$

n = each concrete mix installed in the project

GWP_n = the GWP for concrete mix n per concrete mix EPD, in kg CO_2e/m^3

$GWP_{allowed}$ = the GWP potential allowed for concrete mix n per Table 5.409.3

V_n = the volume of concrete mix n installed in the project, in m^3

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Low Carbon Concrete Codes

NRMCA's Concrete Carbon Calculator

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Senior Director, Building Innovations

NRMCA

BUILD WITH STRENGTH

PAVE AHEAD DURABLE. SUSTAINABLE. CONCRETE.

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