2024 REBUILD CONFERENCE

THURSDAY, OCTOBER 3, 2024 | TQL STADIUM

IMEG

emersion DESIGN

Leveraging the Properties of Concrete in Net-Zero Buildings

Frank Mruk, FAIA

NRMCA

NRMCA NATIONAL READY MIXED CONCRETE ASSOCIATION

BUILD WITH STRENGTH

Concrete LC2, designed by Stefan Zwicky in 1980

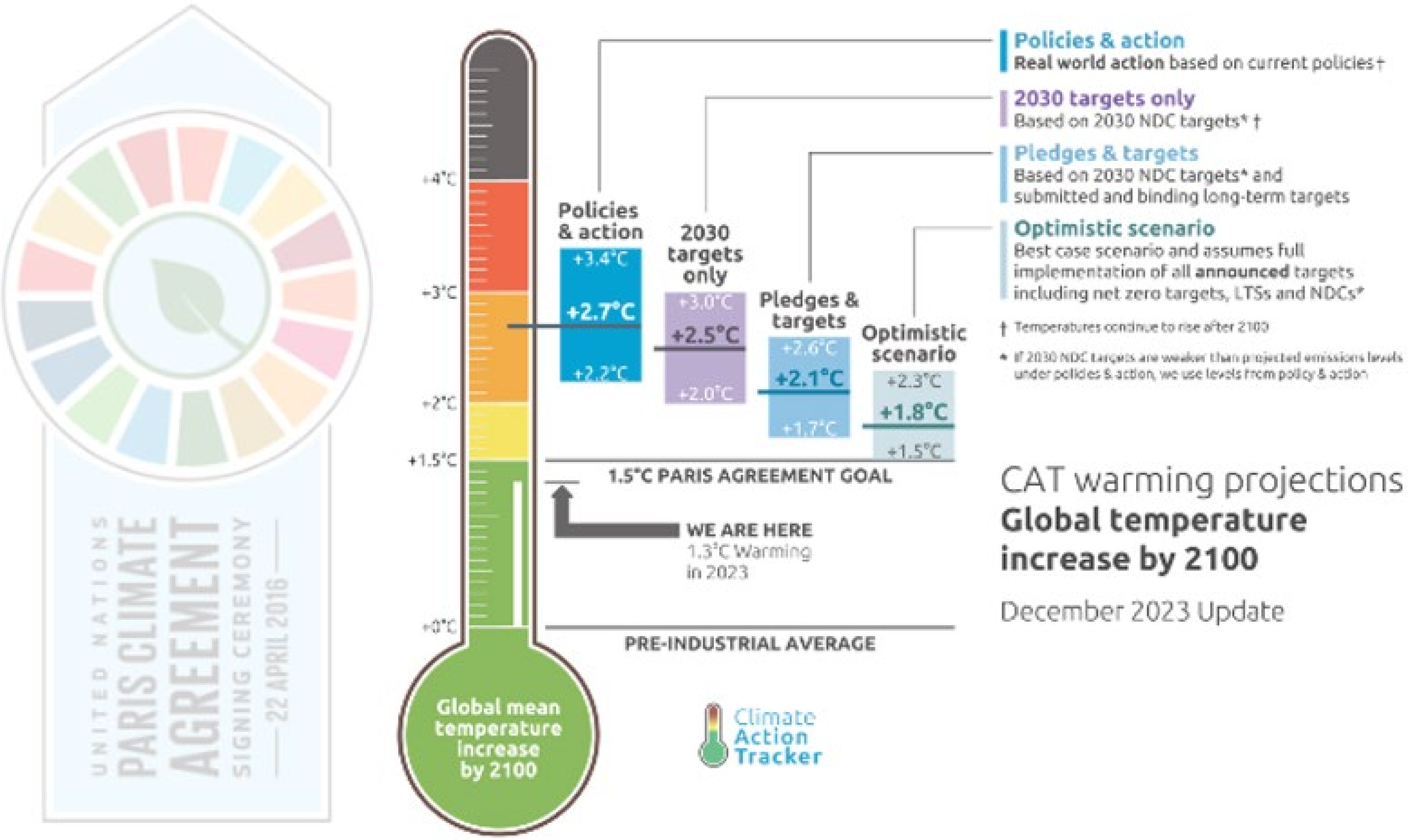
Leveraging the Properties of Concrete in Net-Zero Buildings

1. Communication
2. Quality Control and Quality Assurance
3. Optimization of Concrete Design
4. Alternative Cements
5. Supplementary Cementitious Materials
6. Admixtures
7. Limitation of Ingredients
8. Targets for Carbon Footprint
9. Sequestering CO2 in Concrete
10. Innovation

No. 1:

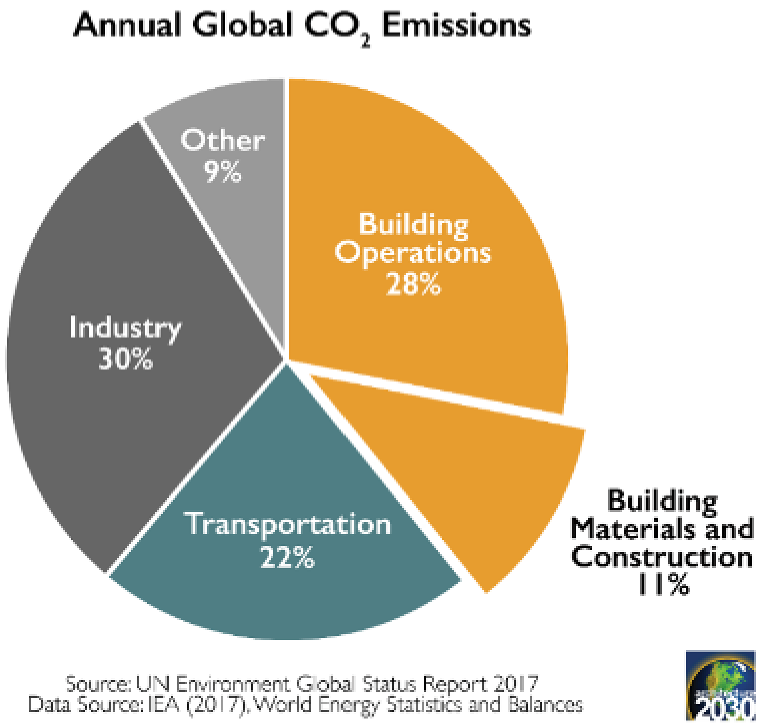
Communicate Carbon Reduction Goals

The Urgent Need to Reduce GHG Emissions



The Concrete Construction Industry Will Play a Pivotal Role in Global Decarbonization

- Embodied carbon from the building materials produce 11% of annual global GHG emissions.
- Concrete, iron, and steel alone produce ~9% of annual global GHG emissions.
- Likely will need to build with more robust materials like concrete.
- How do we minimize environmental impacts?



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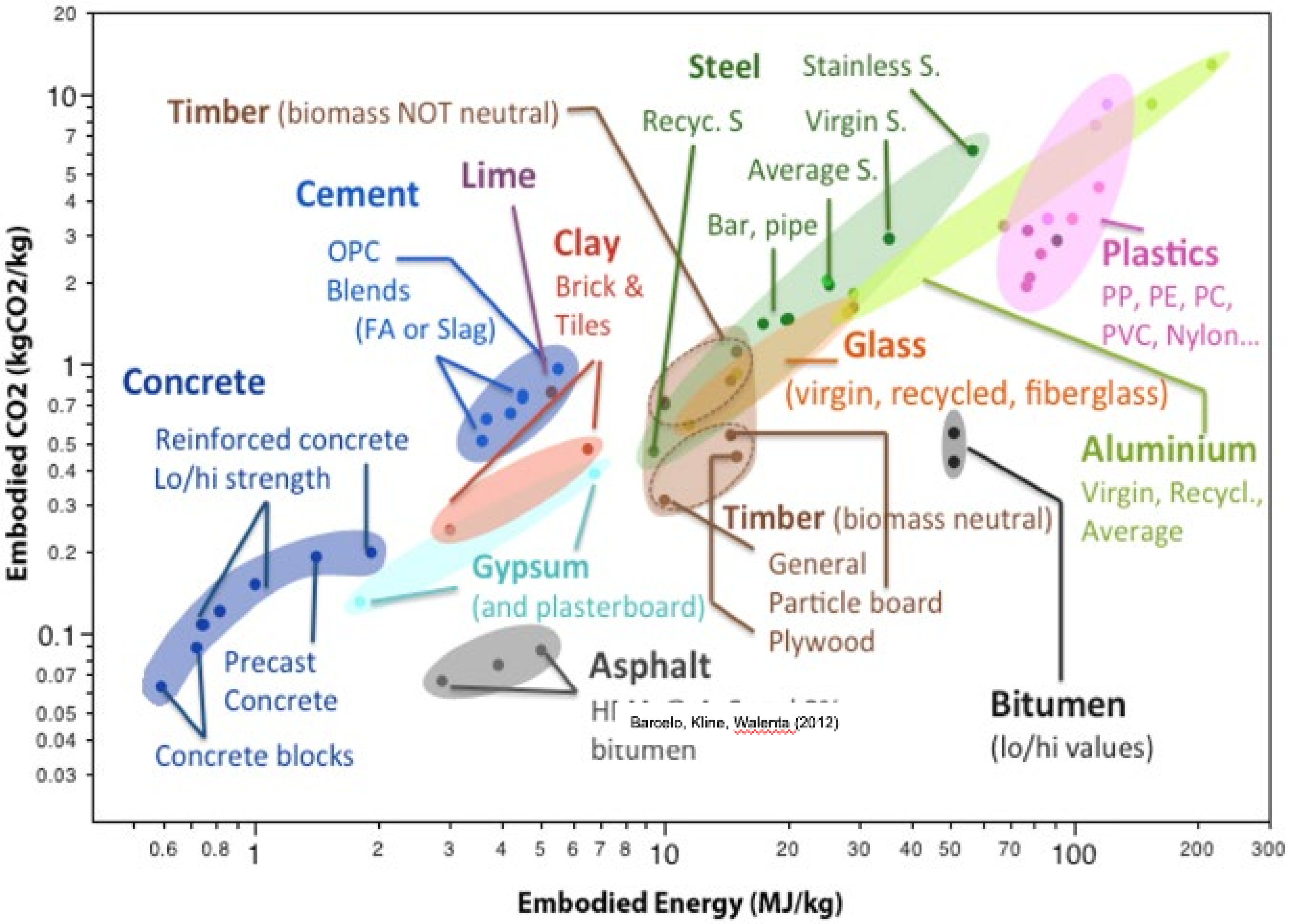
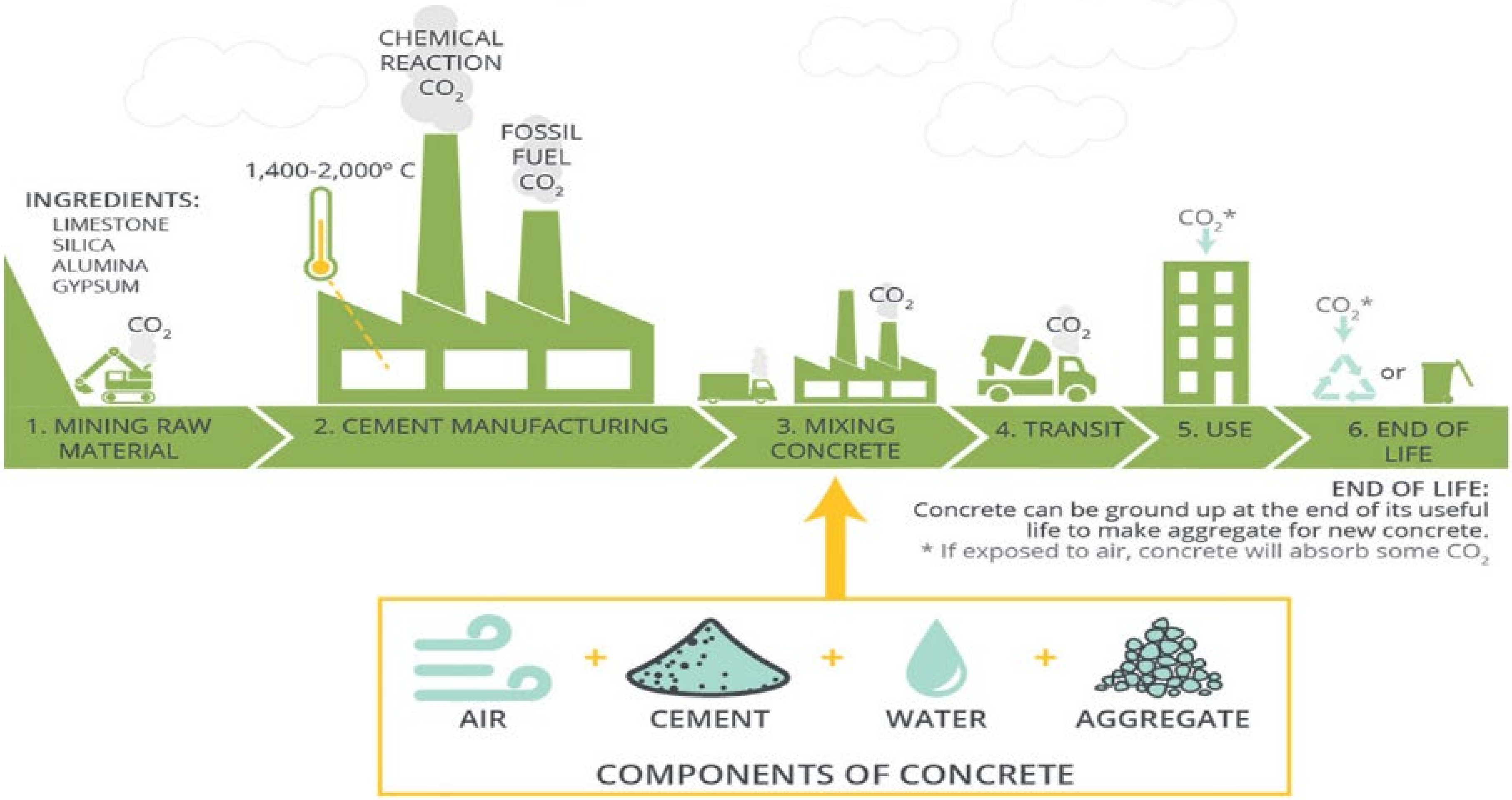
Environmental Impacts on a Per Unit Basis



Carbon Impacts of Concrete



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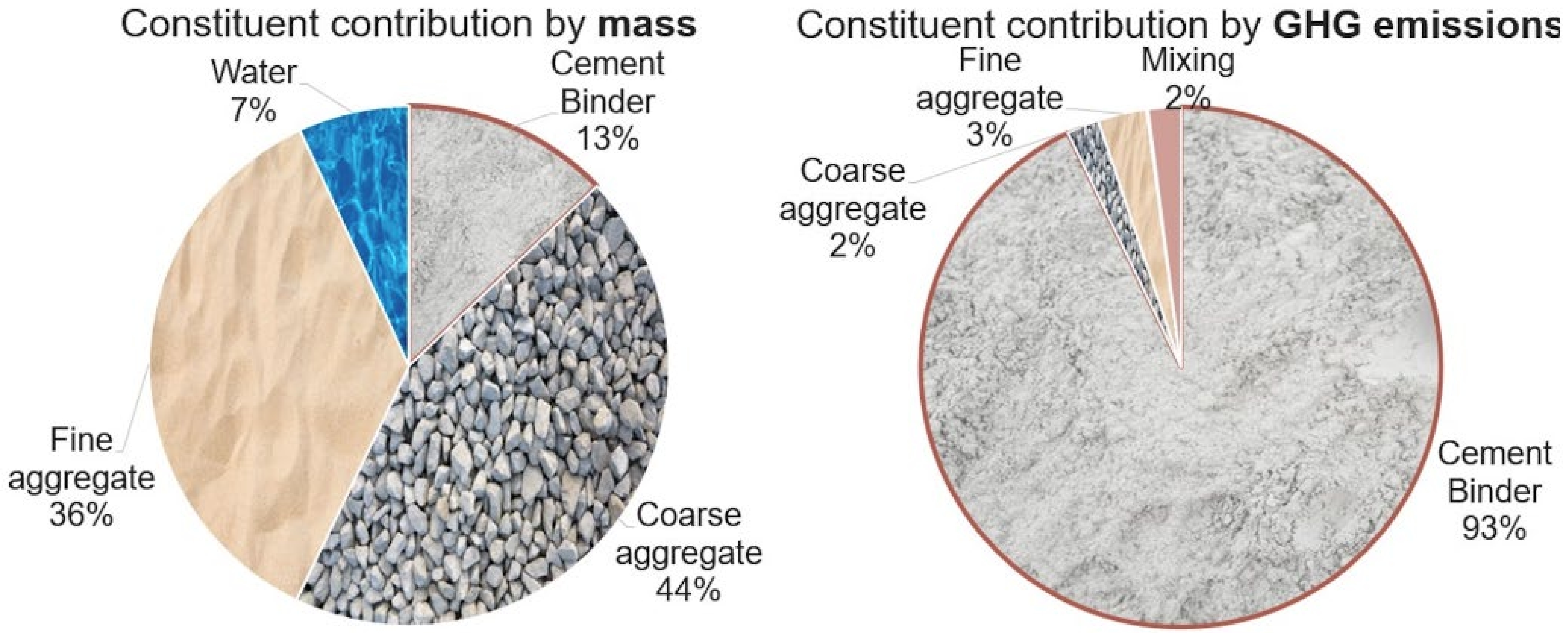
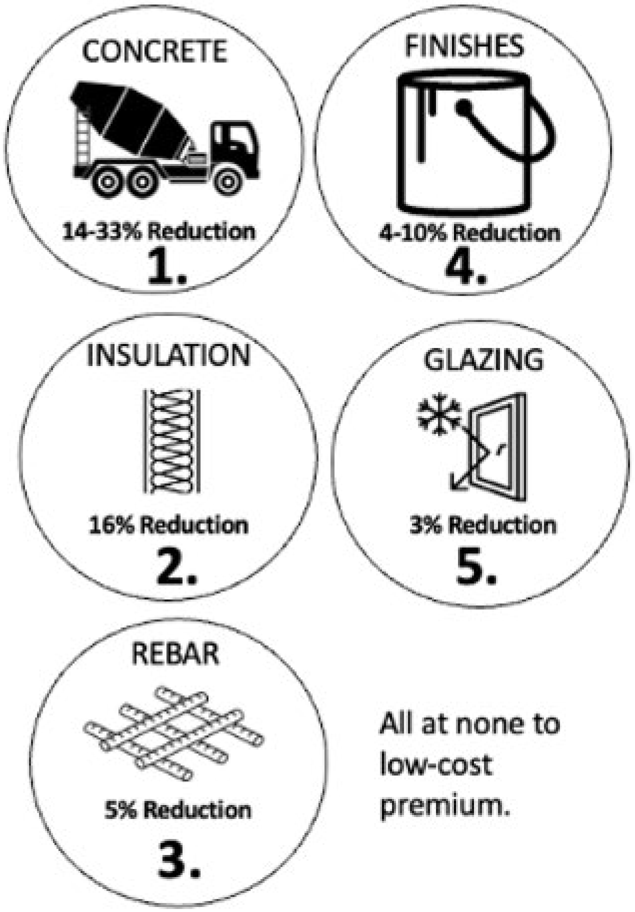
In Traditional Mixtures, Cement Drives Concretes' Greenhouse Gas Impact

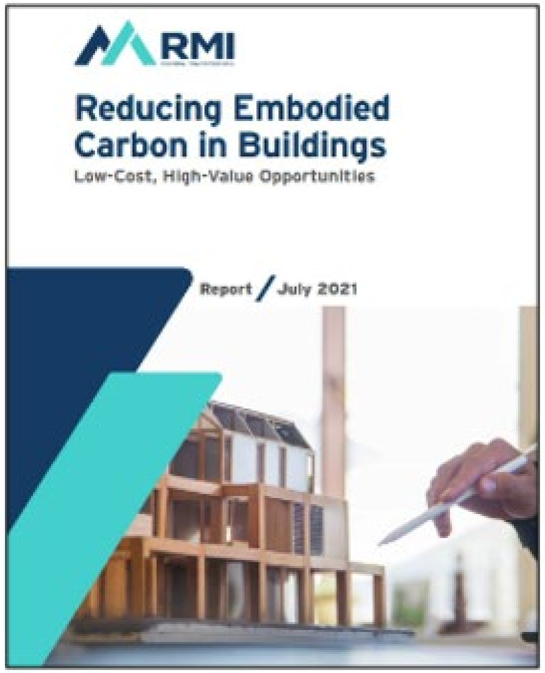


3000 psi mixture with no SCMs

Opportunities for Reduction



All at none to low-cost premium.



RMI Report, Reducing Embodied Carbon in Buildings Low-Cost, High-Value Opportunities July 2021

We are Seeing….

Collaboration during design process

- Early on, in meetings and charettes
- Communication of the problem and possible solutions

Articulation of goals in Concrete Spec

- Ex. This project has a goal of reducing the embodied carbon footprint over a typical project by 30%

Re-Articulation in Prebid Meetings

- Re-state the carbon reduction goals and encourage innovation

No. 2:

Ensure Good Quality Control and Quality Assurance

Manufacturer Qualifications:

- NRMCA Certified Concrete Production Facility
- NRMCA Concrete Technologist Level 2

Installer Qualifications:

- ACI Flatwork Finisher

Testing Agency Qualifications:

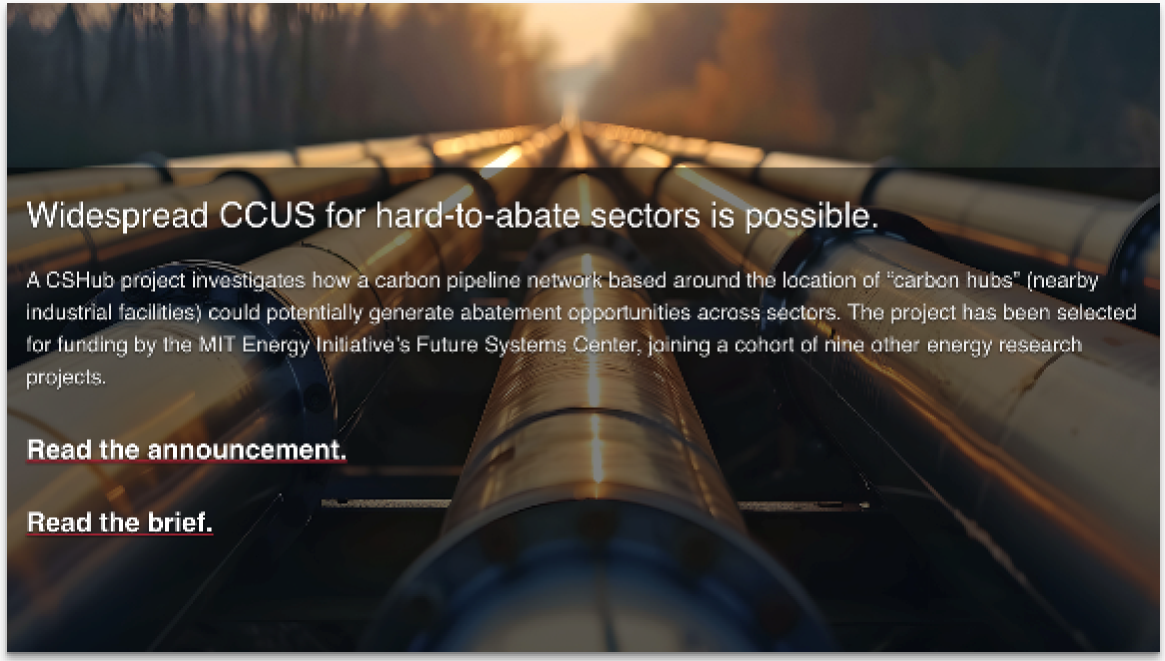
- Meets ASTM C1077
- ACI Concrete Field-Testing Technician Grade I
- ACI Concrete Laboratory Testing Technician Level I
- Results certified by a registered design professional

No. 3:

Optimize Concrete Design

MIT Concrete Sustainability Hub

Home | About Us | Key Impacts | Resources | News | Social Media



The MIT Concrete Sustainability Hub makes key impacts in three areas:

Carbon Neutrality

Carbon neutral concrete is possible. Solutions are available today, and new ones are being developed for the future. One of the major goals of MIT CSHub is to help realize a carbon neutral concrete industry.

Infrastructure

Effective, sustainable infrastructure spending can improve system performance and impact climate change. MIT CSHub investigates how low carbon infrastructure may be built with very finite resources.

Resilience

The risk of hazards like natural disasters and extreme heat is underestimated. Stronger construction to mitigate it is undervalued. MIT CSHub studies how cities can be made more resilient to hazards through investment in stronger, cooler construction.

Concrete Materials:

- **Hydraulic Cement:** ASTM C150, ASTM C595, or ASTM C1157

No. 4:

Use Alternative Cements

ASTM C595		
Type	**Description**	**Notes**
Type IL (X)	Portland-Limestone Cement	Where X can be between 5 and 15% limestone
Type IS (X)	Portland-Slag Cement	Where X can be up to 70% slag cement
Type IP (X)	Portland-Pozzolan Cement	Where X can be up to 40% pozzolan (fly ash is the most common)
Type IT (AX)(BX)	Ternary Blended Cement	Where X can be up to 70% of pozzolan + limestone + slag, with pozzolan being no more than 40% and limestone no more than 15%

No. 4:

Use Alternative Cements

Portland-limestone cement is intended to fully replace ordinary Portland cement, 10% reduction in carbon footprint.

No. 5:

Use Supplementary Cementitious Materials

Many Binders Can Be Used in Concrete

Portland Cement

Natural Pozzolans

Calcined Clay

Fly Ash

Waste

Granulated Slag

Post-Consumer Glass

No. 6:

Use Admixtures

Nearly every concrete made today uses some sort of admixture.

Concrete Materials:

Chemical Admixtures:

1. Air-Entraining Admixture: ASTM C 260/C 260M
2. Water-Reducing Admixture ASTM C 494/C 494M Type A
3. High-Range Water-Reducing Admixture: ASTM C 494/C 494M Type F or G
4. Accelerating Admixture: ASTM C 494/C 494M Type C or E
5. Retarding Admixture: ASTM C 494/ C 494M Type B or D
6. Hydration Control Admixture: ASTM C 494/C 494M Type B or D

No. 7:

Don't Limit Ingredients

All too often, there are seemingly random limits on material ingredients in project specifications that limit the concrete producer's ability to meet performance criteria.

Establish Performance Based Specifications

- **Goal:**
- Prescription → Performance

- **Methods:**

➢ Emphasize ACI 318 Exposure Classes

➢ Alt testing for durability/design
  - **Shrinkage, MOE, RCP, ASR**

➢ Expand acceptable materials

➢ Extended strength development

- ~~Maximum w/cm ratio~~
- ~~Air content of 6% for all concrete~~
- ~~Maximum cement content~~
- ~~Minimum cement content~~
- ~~Maximum fly ash content~~
- ~~Minimum fly ash content~~
- ~~Water: Potable~~

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No. 8:

Set a Carbon Budget

Resist the temptation to set carbon footprint limits for individual classes of concrete.

Establish a Carbon Budget

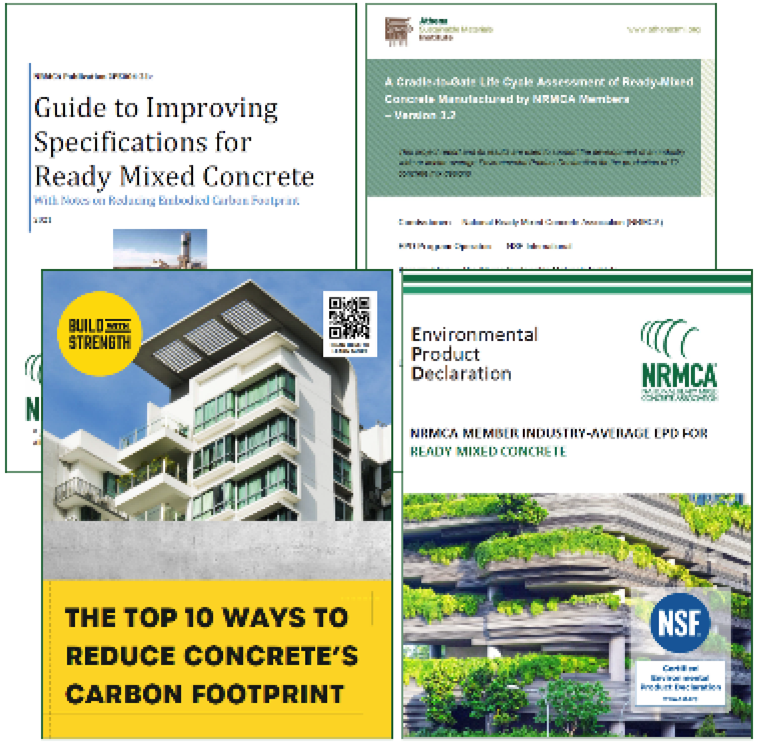
- **Goal:**
- Trigger the use of low carbon materials

- **Method:**

a) Set Baseline

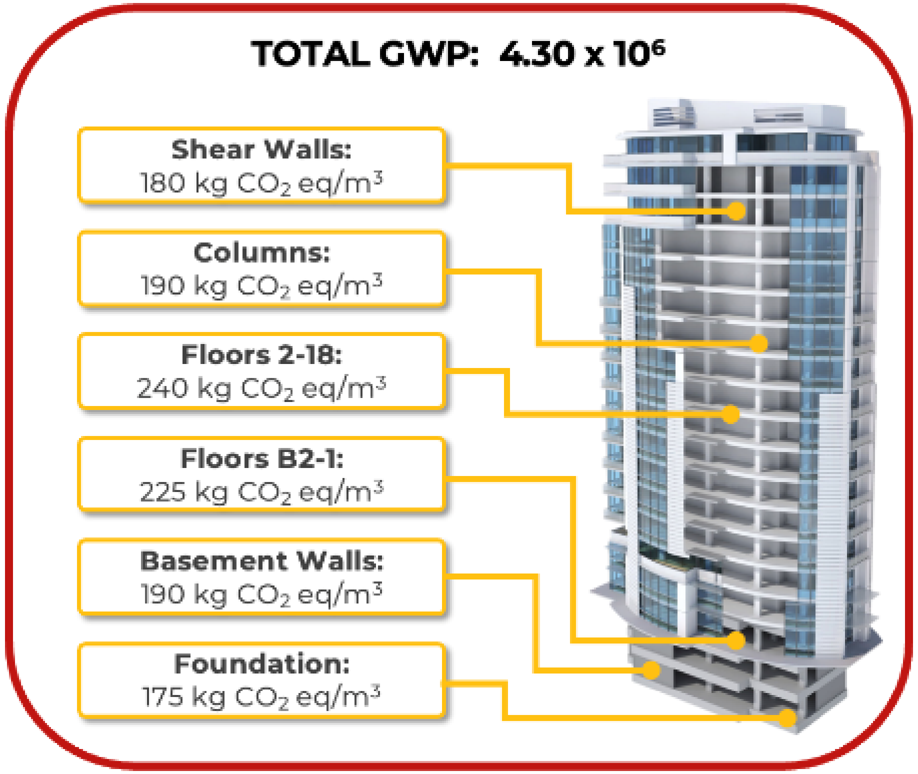
b) Collect EPDs

c) Establish a Carbon Budget



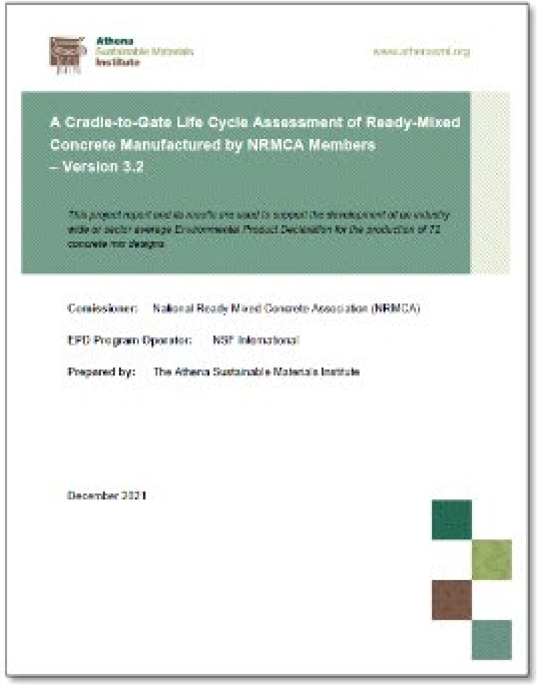
Establish a Carbon Budget

VS



Establish Comparison Between Benchmark and Project

Benchmark Project



Athena Sustainable Materials Institute

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

Commissioner: National Ready Mixed Concrete Association (NRMCA)

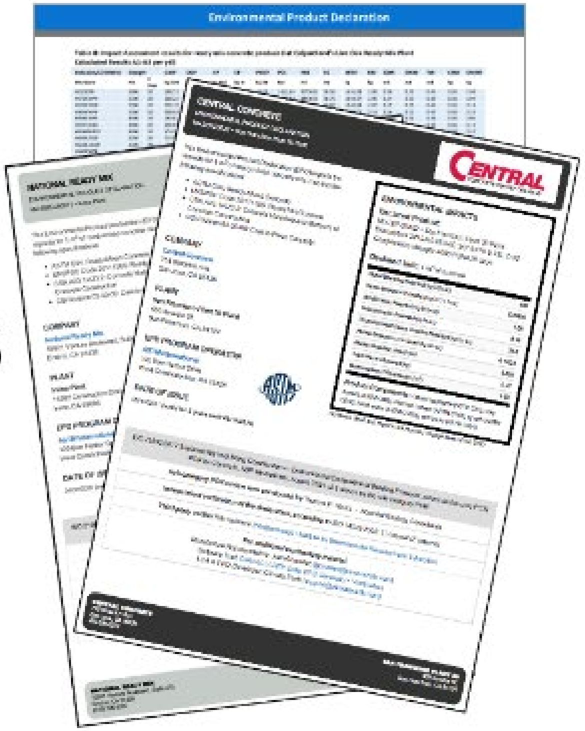
EPD Program Operator: NSF International

Prepared by: The Athena Sustainable Materials Institute

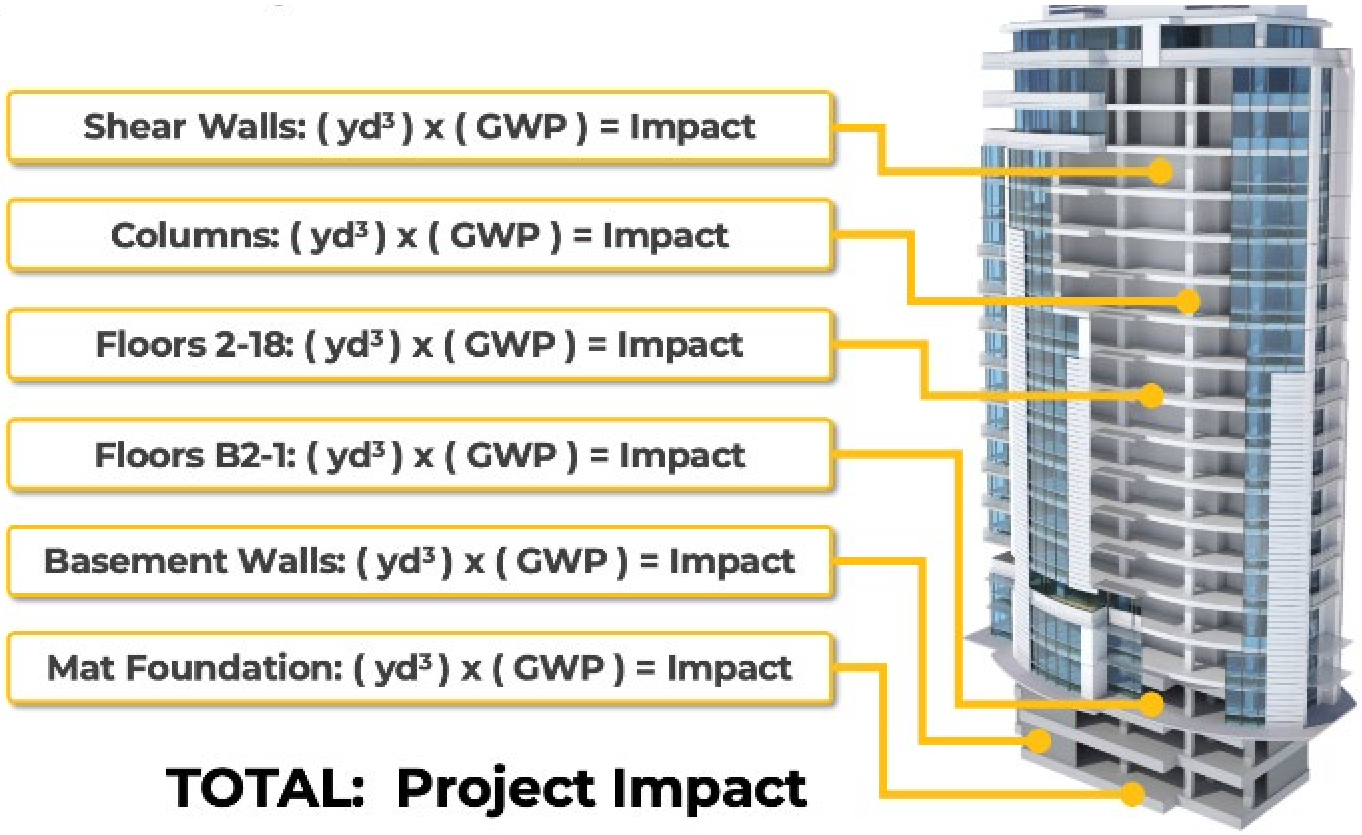
December 2021

VS

Proposed Project



Life Cycle Analysis

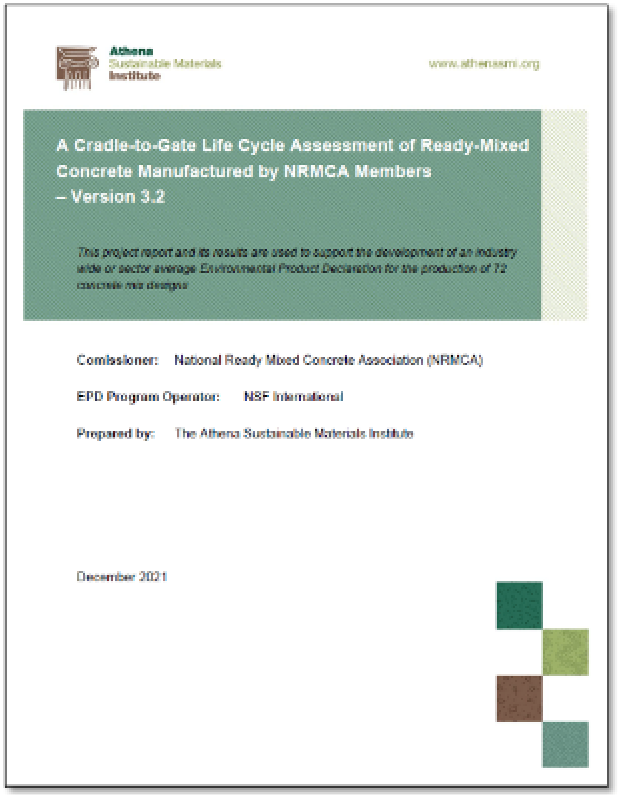


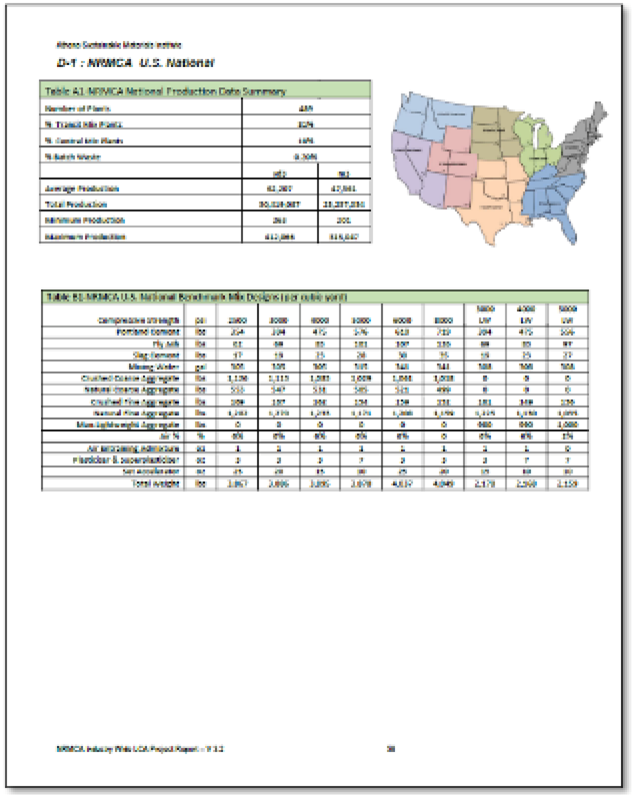
Estimating Quantities and Properties

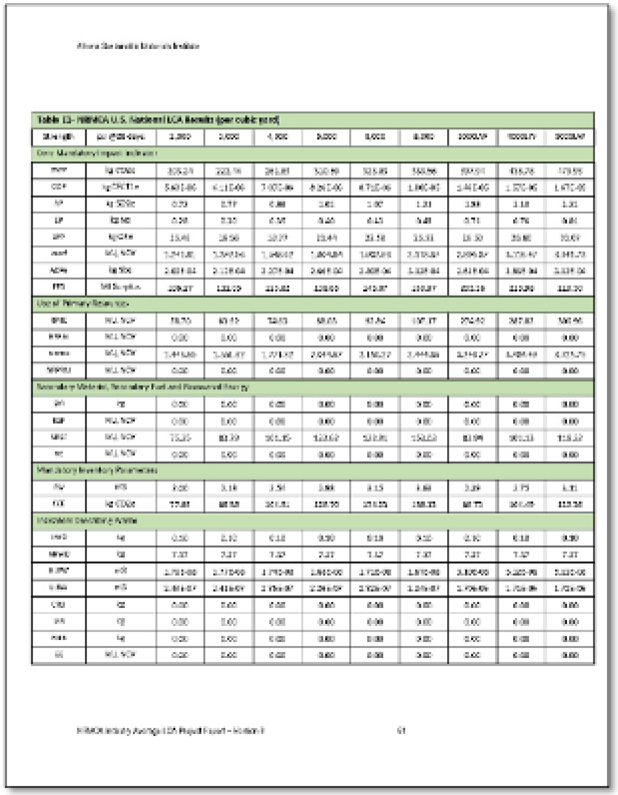
Concrete Element	Concrete Volume (yd^3)	Benchmark Mixes (benchmark)*	Proposed Mixes (IW-EPD)*
Shear Walls	7,630	6,000 psi	6,000 psi 30% slag, 20% fly ash
Columns	366	8,000 psi	8,000 psi 40% fly ash
Floors 2-18	4,533	5,000 psi	5,000 psi 30% slag
Floors B2-1	1,067	5,000 psi	5,000 psi 40% fly ash
Basement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

NRMCA Benchmark Mixes

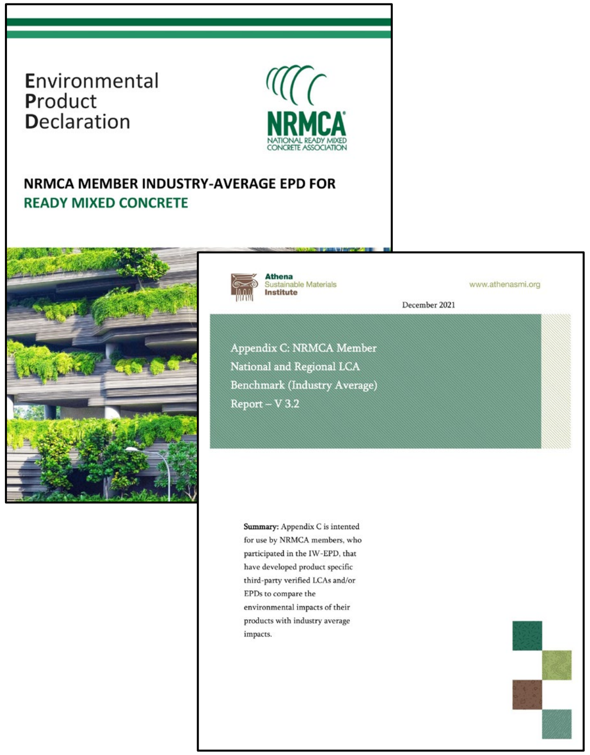






Download at **https://www.nrmca.org/sustainability**

Regional EPDs


Environmental
Product
Declaration

NRMCA
NATIONAL READY MIXED CONCRETE ASSOCIATION

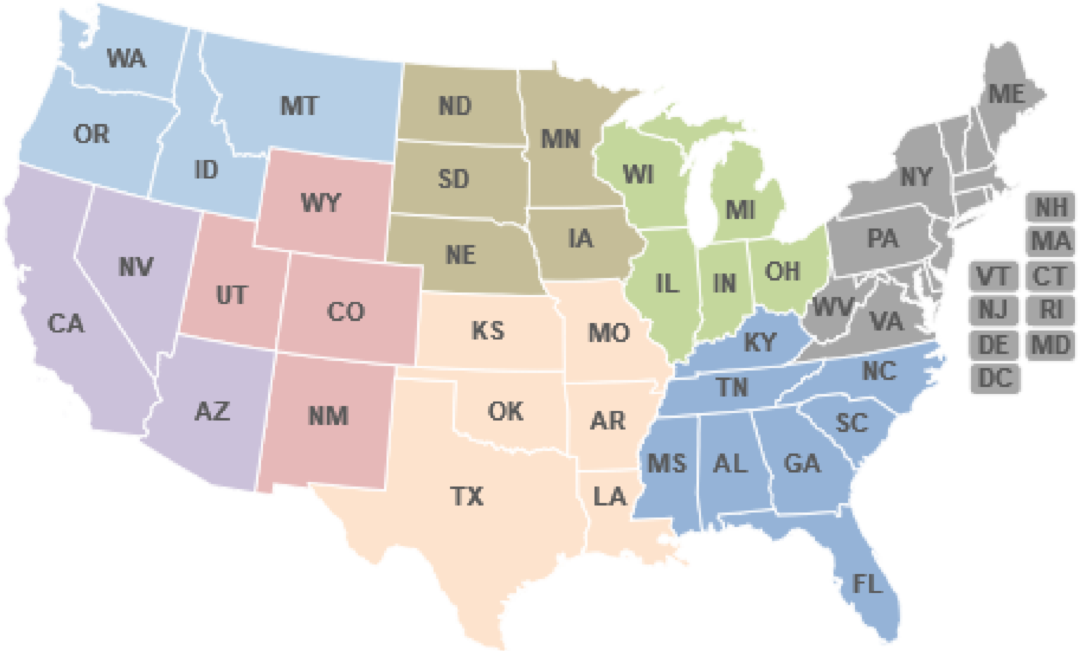
NRMCA MEMBER INDUSTRY-AVERAGE EPD FOR
READY MIXED CONCRETE

Athena Sustainable Materials Institute
www.athenasmi.org
December 2021

Appendix C: NRMCA Member National and Regional LCA Benchmark (Industry Average) Report – V 3.2

Summary: Appendix C is intented for use by NRMCA members, who participated in the IW-EPD, that have developed product specific third-party verified LCAs and/or EPDs to compare the environmental impacts of their products with industry average impacts.

2021 Version 3

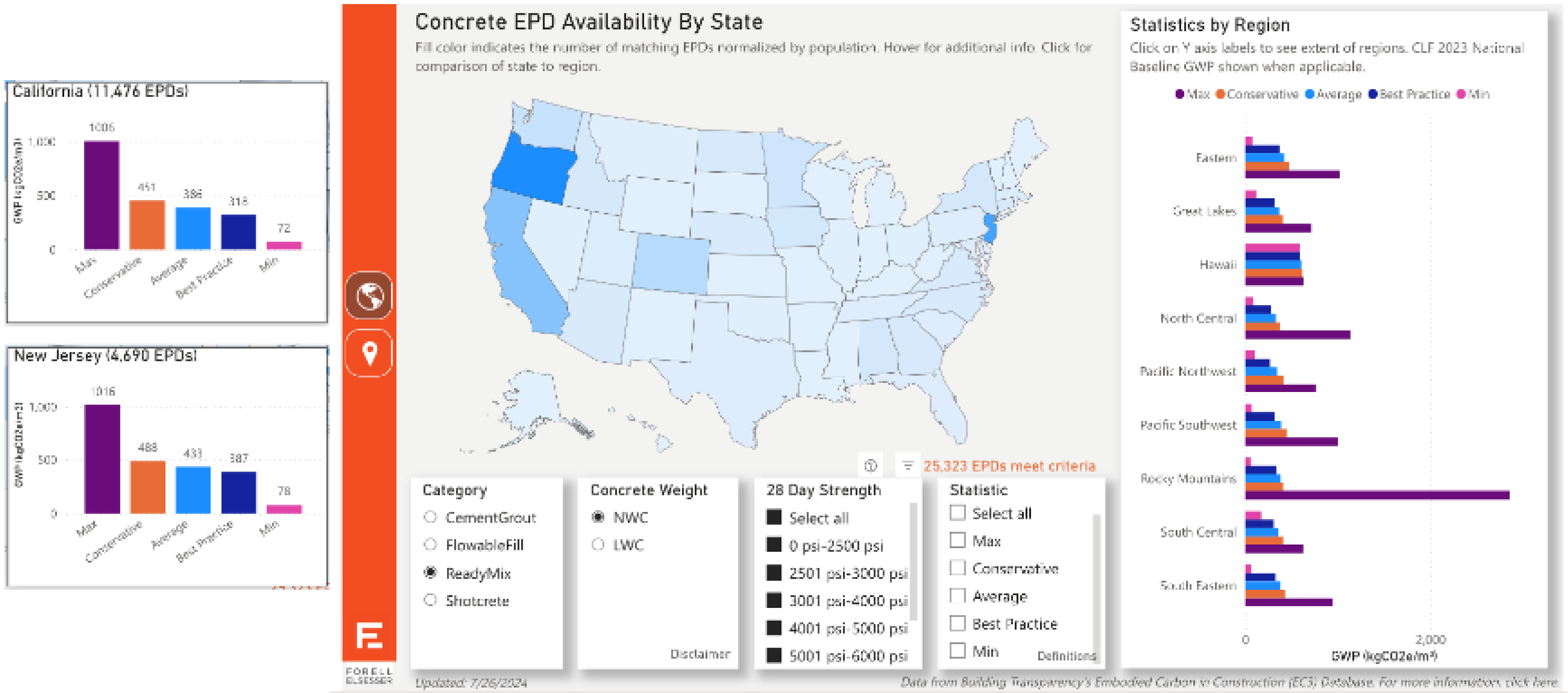


Regional EPDs

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

Regional EPDs

Concrete EPD Availability by State



NRMCA Benchmark Mixes

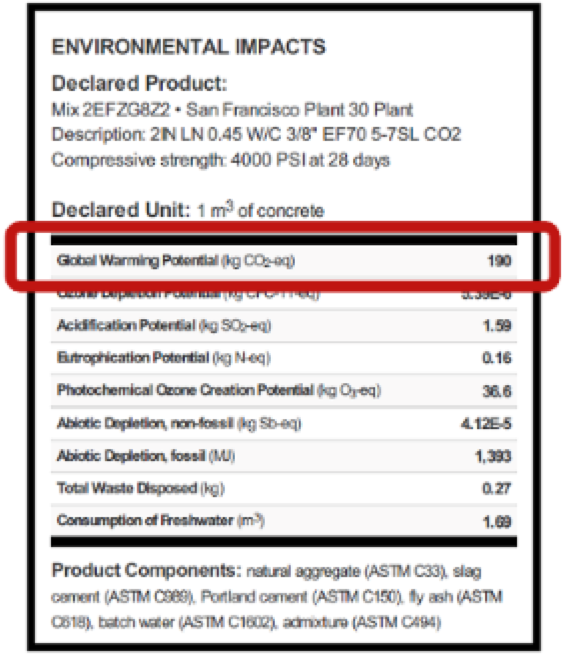
Shear Walls	7,630	6,000 psi	6,000 psi 30% slag, 20% fly ash

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

Collect EPDs

3^{rd} party verified & registered documents that communicate transparency



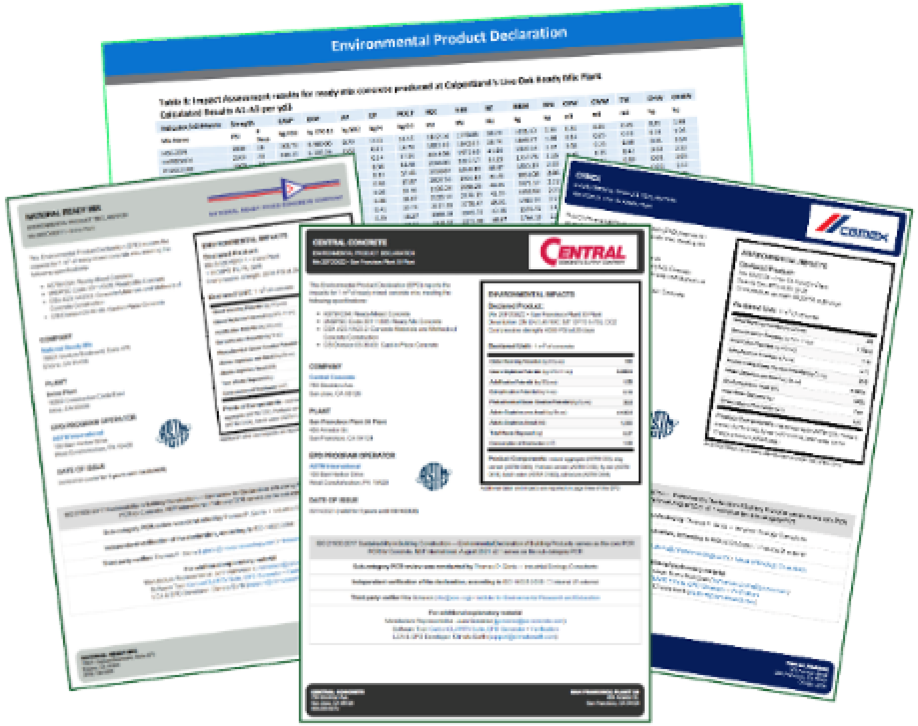
ENVIRONMENTAL IMPACTS

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
Ozone Depletion Potential (kg CFC-11-eq)	3.38E-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)



Compare to NRMCA 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	233.10	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	[illegible]
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

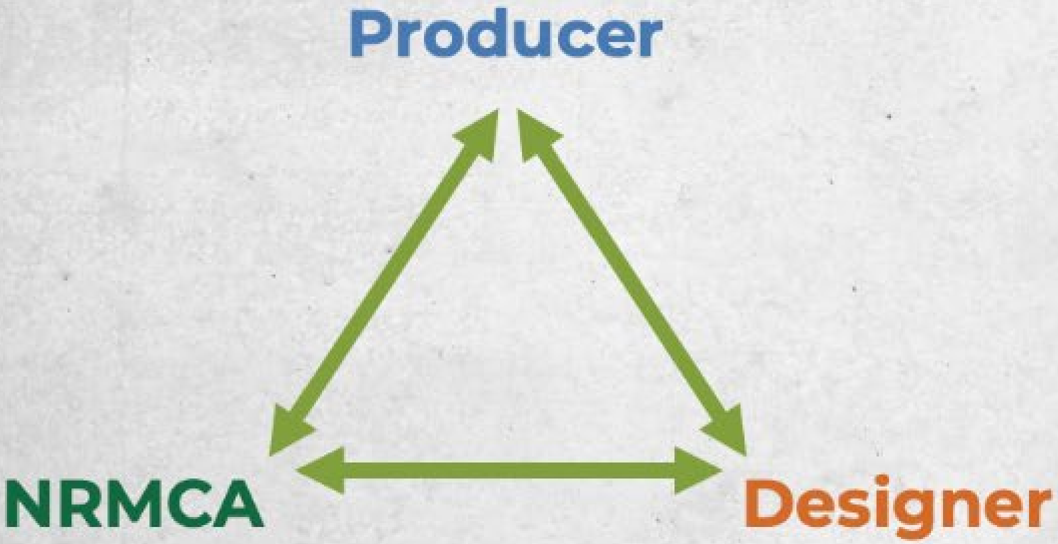
Download at https://www.nrmca.org/sustainability

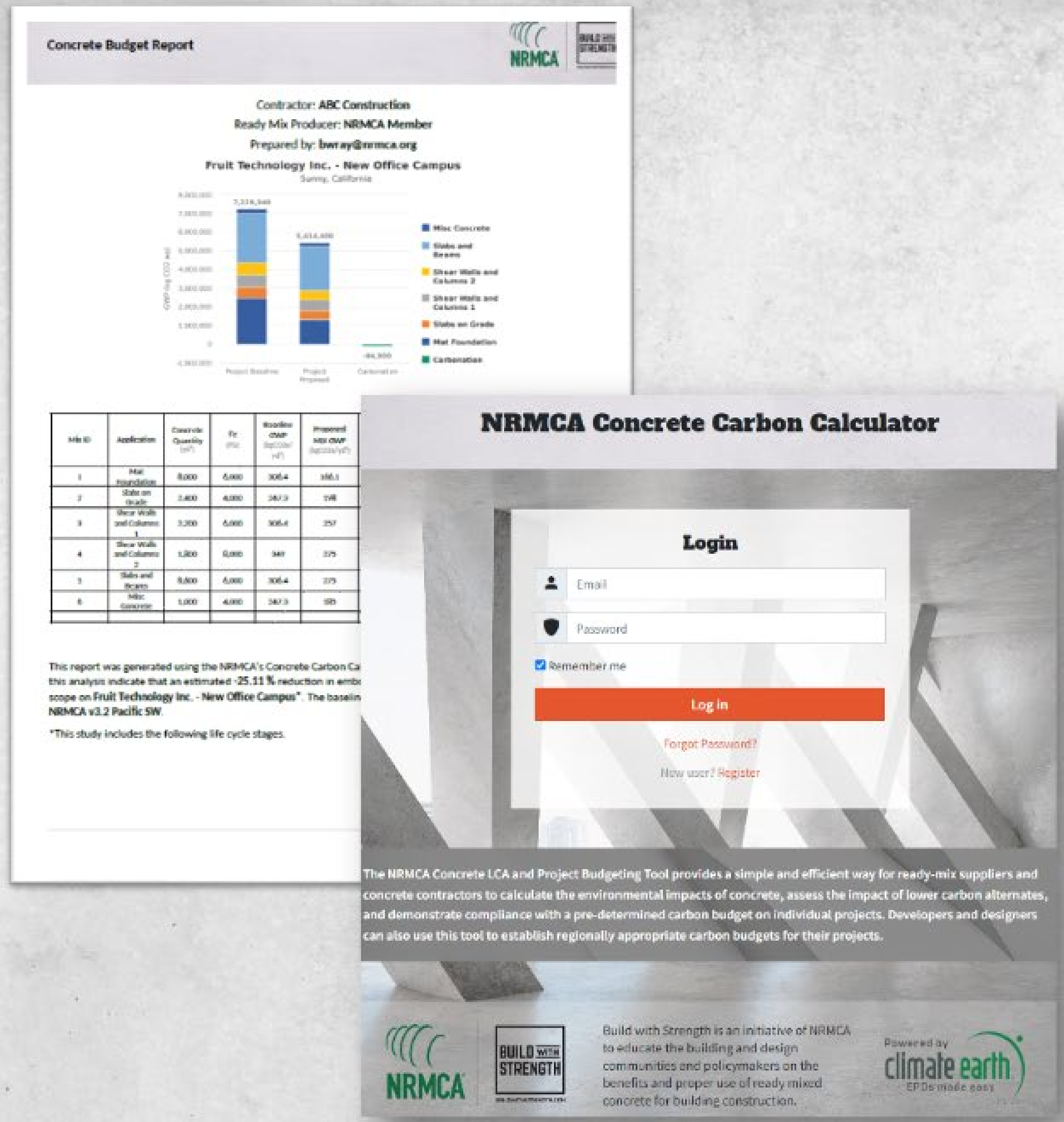
Identify Global Warming Potential

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

*Should be augmented with local data, knowledge, capabilities

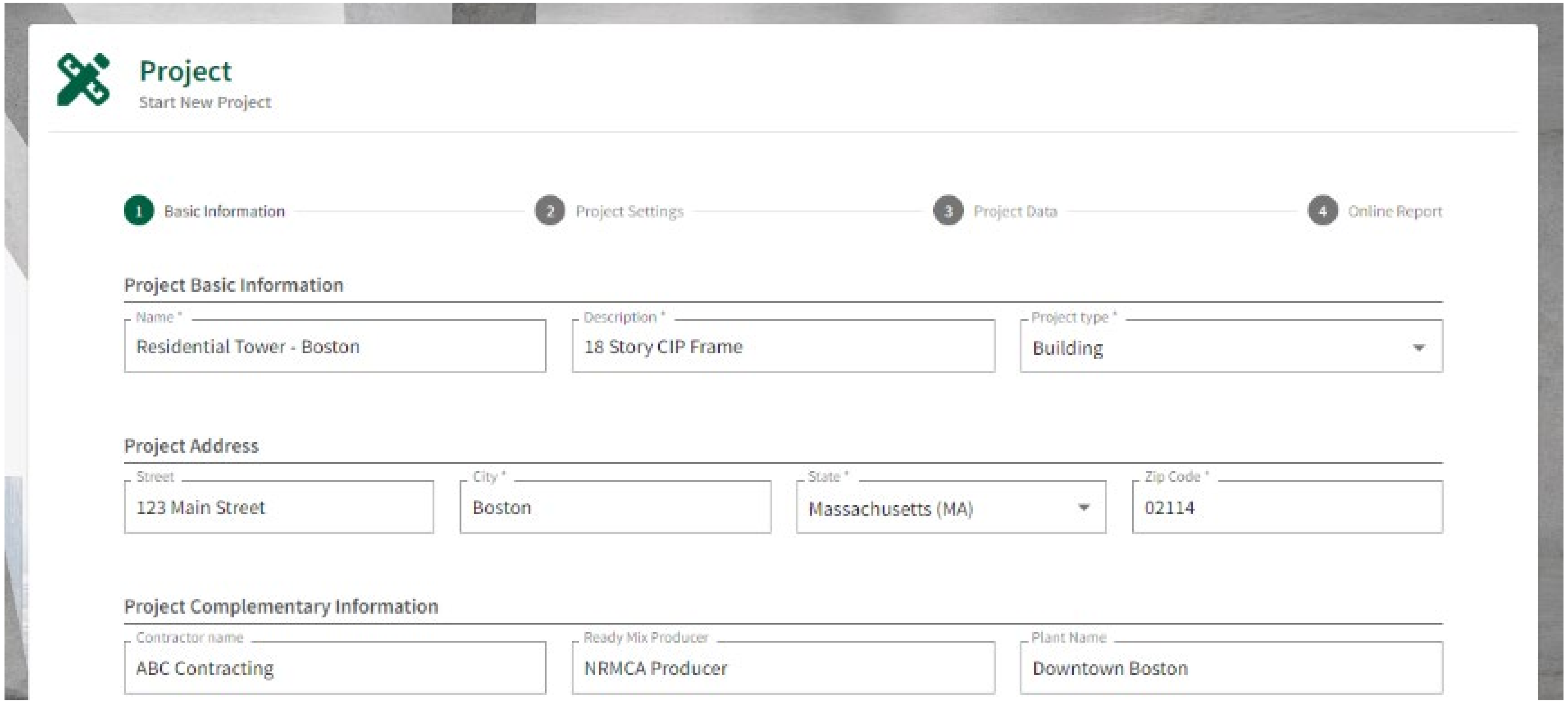
NRMCA Concrete Carbon Calculator



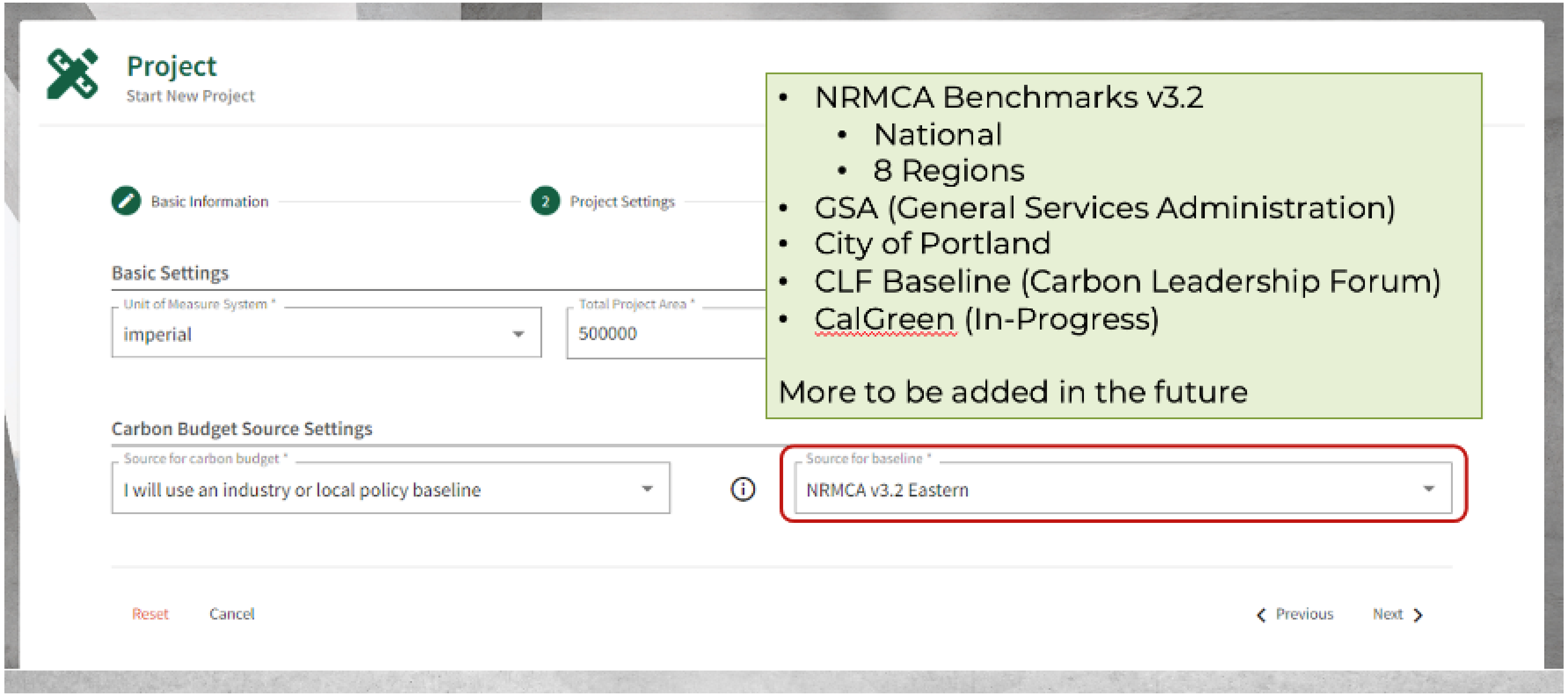


Access at **https://nrmca.climateearth.com/**

NRMCA Carbon Tool



NRMCA Carbon Tool



NRMCA Carbon Tool

Project
Edit Project

Basic Information — 2 Project Settings — 3 Project Data — Online Report

	Mix ID	Strength PSI	Mix Type	Application	Total Volume yd^3	Proposed Mix GWP $kgCO_2e/yd^3$	Carbonation Factor $kgCO_2e/yd^3$	Baseline GWP $kgCO_2e/yd^3$	Baseline GWP Budget $kgCO_2e$/project	Proposed Project GWP $kgCO_2e$/project	Total Achievable Carbonation $kgCO_2e$/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

NRMCA Carbon Tool

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

2 Project Settings — 3 Project D

Application	Total Volume yd³	Proposed Mix GWP kgCO2e/yd³	Carbonation Factor kgCO2e/yd³	Baseline GWP kgCO2e/yd³
Shear Walls	7630	232	-7.6	305.3
Columns	366	303	-17.8	360.5
Floors 2-18	4533	277	-12.4	289
Floors B2-1	1067	249	-17.7	289
Basement V	444	220	-18.6	289
Foundation	3844	166.4	[illegible]	305.3
TOTALS	17,884			

Proposed Mix GWP for 'Mat Foundation'

Important information

This result is NOT an EPD. This GWP was calculated using the same LCI data sources as prescribed in Table A1 of the PCR for Concrete, NSF International, August 2021 v2.1. A3 is assumed to be 9.04 kg CO2eq/m3 per NRMCA's Benchmark Report v3.2. This GWP is strictly an estimate and is based on industry averages, regional data, and average transportation impacts and should be used for estimation purposes only. For more accurate results, it is recommended that a Type III Third-Party Verified Product Specific EPD be developed.

For a more accurate plant specific estimate, use your EPD tool provider's EPD estimator.

Material	Quantity per yd³	UoM
Batch Water	32	GAL
Portland Limestone Cement (Type IL)/ASTM C595 - Domestic	282	LB
Fly Ash	112	LB
Slag Cement/ASTM C989 - Imported	170	LB
Crushed Coarse Aggregate/ Crushed Fine Aggregate	1650	LB
Natural Fine Aggregate	1350	LB
Plasticizer and Superplasticizer	24	FL.OZ

Cancel   Download Mix Design File   Calculate

NRMCA Carbon Tool

For calculating the carbonation potential of each element.

ings — 3 Project Data — Online Report

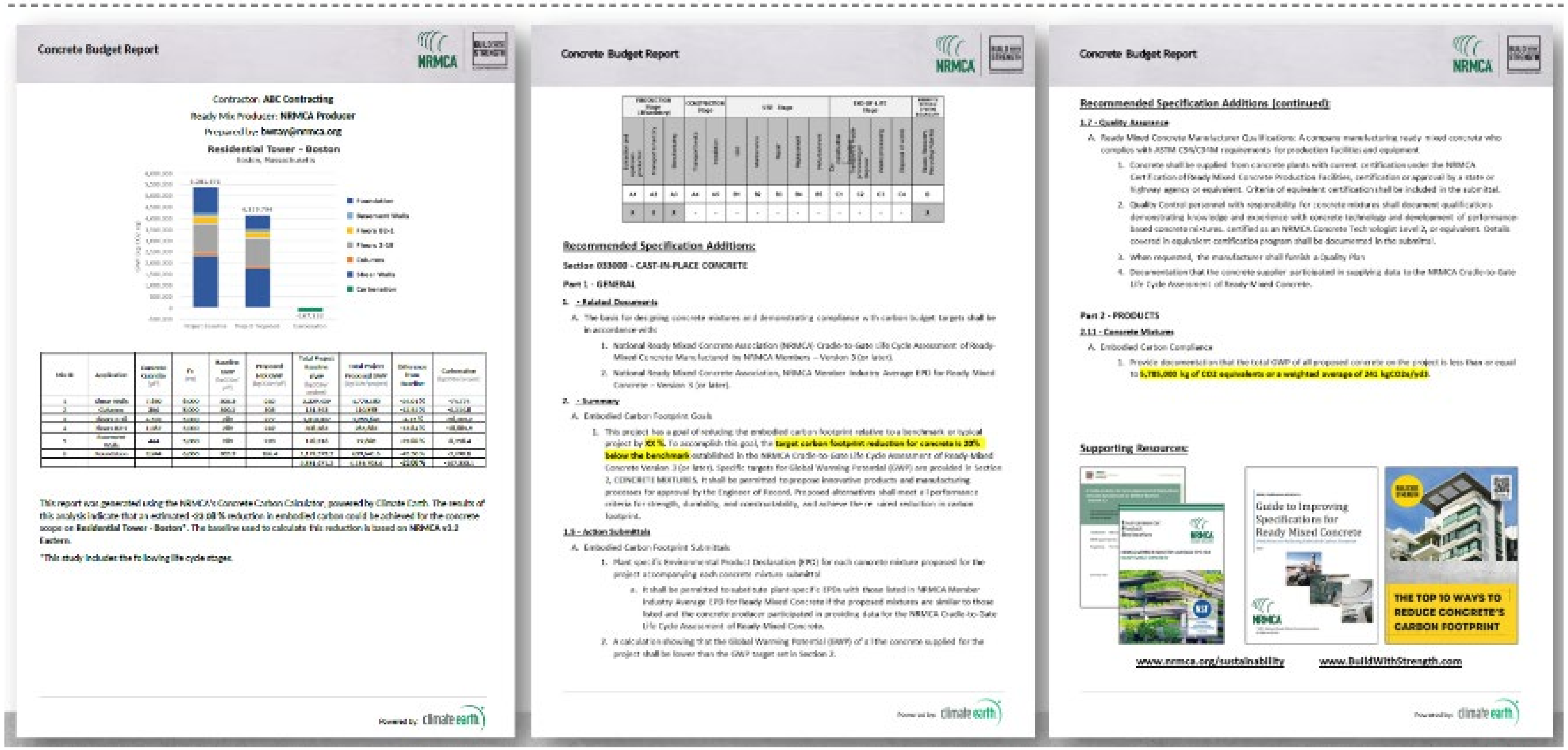
Total Volume yd³	Proposed Mix GWP kgCO2e/yd³	Carbonation Factor kgCO2e/yd³	Baseline GWP kgCO2e/yd³	Baseline GWP Budget kgCO2e/project	Proposed Project GWP kgCO2e/project	Total Achievable Carbonation kgCO2e/project
7630	232	-7.6	305.3	2,329,439	1,770,160	-57,988
366	303	-17.8	360.5	131,943	110,898	-6,515
4533	277	-12.4	289	1,310,037	1,255,641	-56,209
1067	249	-17.7	289	308,363	265,683	-18,886
444	220	-18.6	[illegible]	[illegible]	97,680	-8,258
3844	166.4	-0.7	305.3	1,173,573	639,642	-2,691
17,884				5,381,671	4,139,704	-150,547

Carbonation Factor

- Use type *
- Reference Service Life (RSL) (years) *
- Exposed surface (yd²/yd³) *
- Exposure category *
- Cement content (lb/yd³) *
- Percent clinker in cement (%) *
- Percent limestone in concrete (%) *
- Percent silica fume in concrete (%) *
- Percent fly ash in concrete (%) *

Cancel | Calculate

NRMCA Carbon Tool


Concrete Budget Report

Contractor: ABC Contracting

Ready Mix Producer: NRMCA Producer

Residential Tower - Boston

Concrete Budget Report

Recommended Specification Additions:

Section 033000 - CAST-IN-PLACE CONCRETE

Part 1 - GENERAL

Concrete Budget Report

Recommended Specification Additions (continued):

Part 2 - PRODUCTS

Supporting Resources:

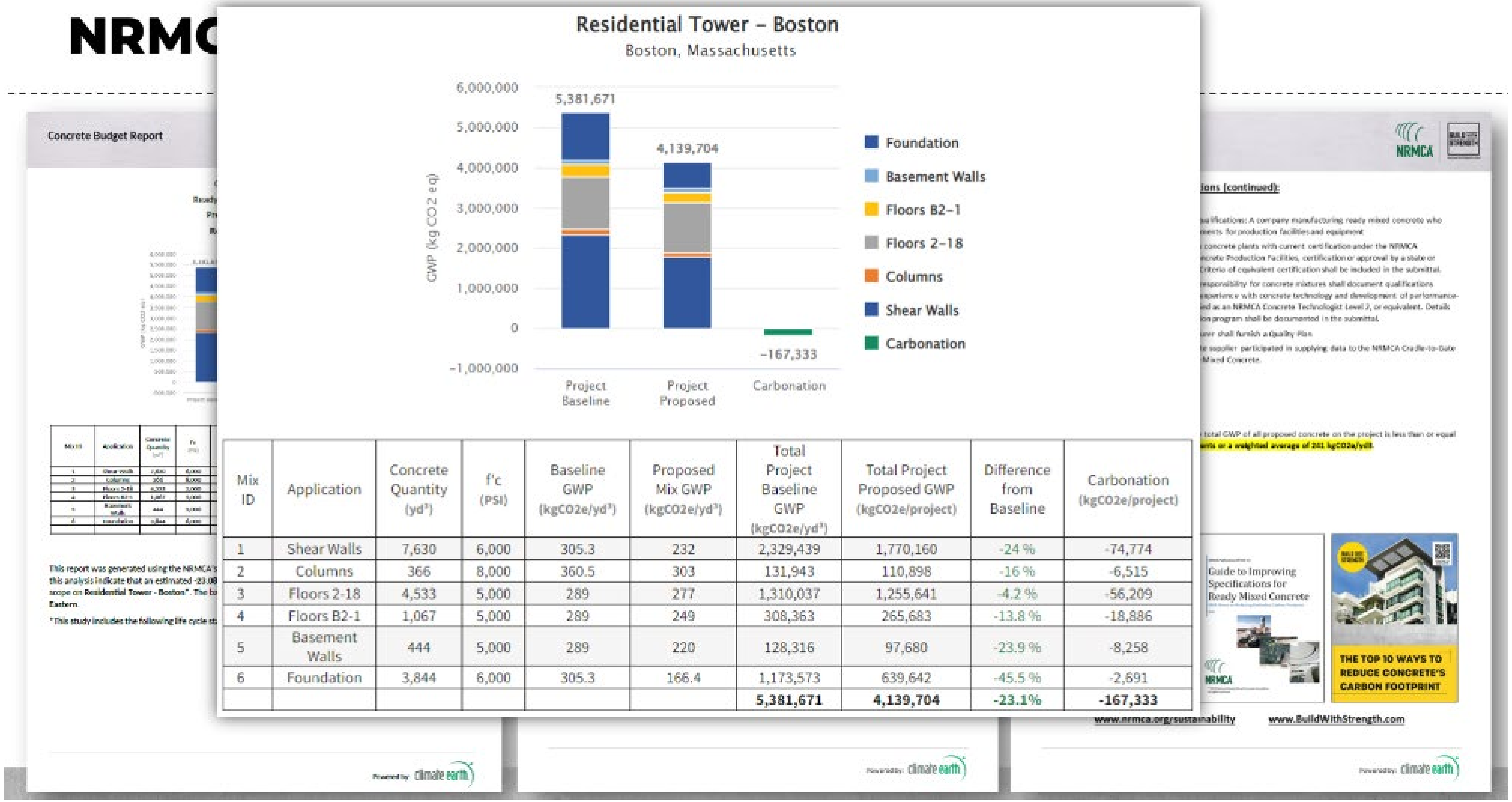
Guide to Improving Specifications for Ready Mixed Concrete

THE TOP 10 WAYS TO REDUCE CONCRETE'S CARBON FOOTPRINT

www.nrmca.org/sustainability

www.BuildWithStrength.com

NRMC



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/yd^3)	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

Set Targets for Carbon Footprint

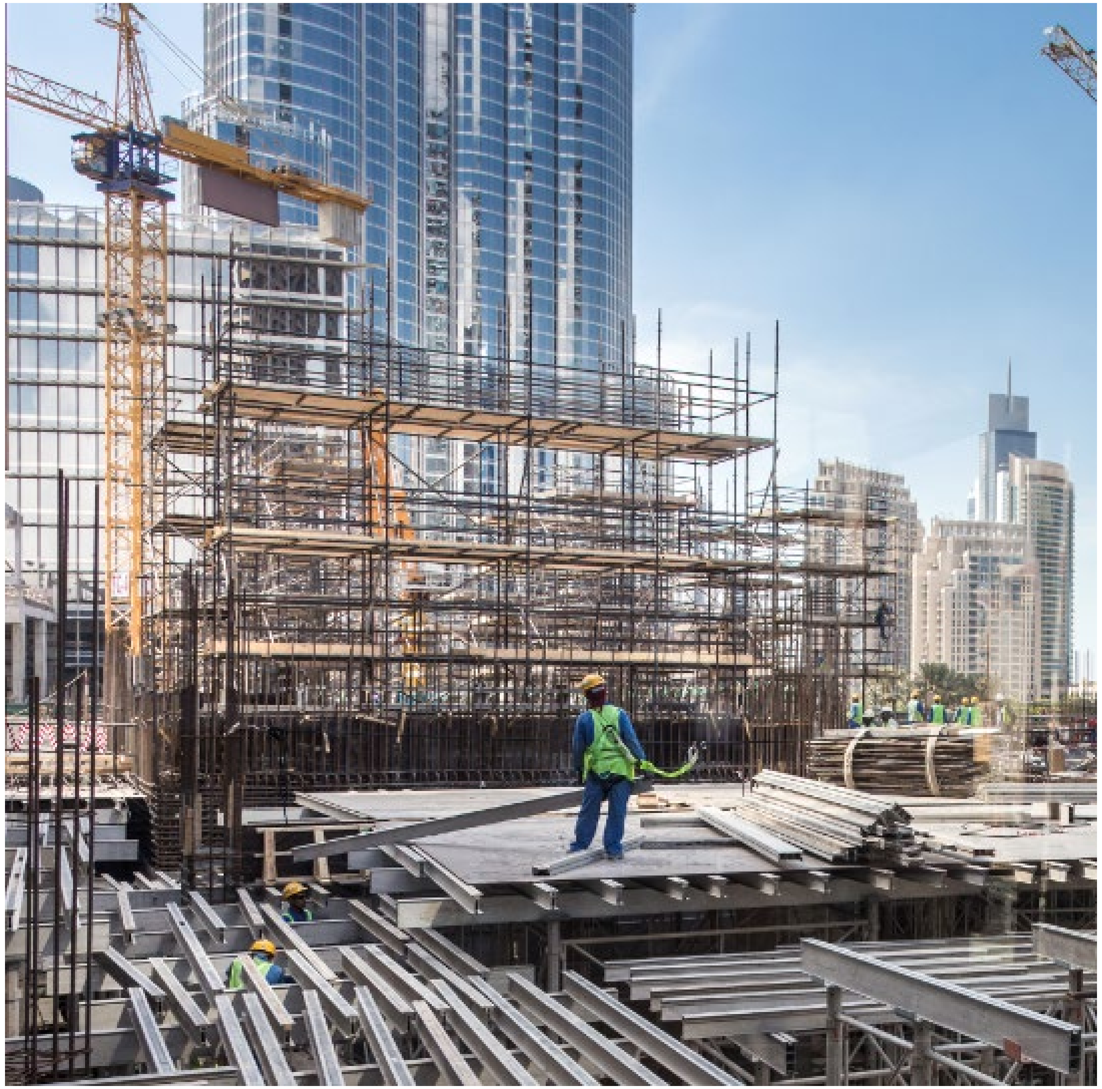
- **<u>Concrete Materials:</u>**

A. Supply concrete mixtures such that the total Global Warming Potential (GWP) of all concrete on the project is less than or equal to **4,300,000 kg** of CO2 equivalents or a weighted average of **240 kgCO2e/yd3**

No. 9:

Sequester Carbon Dioxide w/Carbonation

Carbonation is a naturally occurring process by which CO_2 penetrates the surface of hardened concrete and chemically reacts with cement hydration products to form carbonates.



Concrete Materials:

A. Normal-weight Aggregate: ASTM C33
B. Lightweight Aggregate: ASTM C330
C. Recycled concrete aggregate (crushed concrete) meeting the requirements of ASTM C33 or ASTM C330 may be used in structural concrete up to 10% of the total aggregate.
D. Artificial limestone aggregate meeting the requirements of ASTM C33 or ASTM C330 is permitted.
E. Carbon mineralization by injecting CO2 into concrete during manufacturing or curing in CO2 atmosphere shall be permitted.

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No. 10:

Encourage Innovation

- Ground Glass Pozzolan
- Carbon Storing Aggregate
- Carbon Negative Cement
- Carbon Dioxide infused fly ash
- Biochar
- Limestone Calcined Clay Cement
- Biogenic Limestone Cement
- Geopolymer Cement
- Metamaterial Cement

The Competition Landscape of Low-Carbon Concrete

Concrete Technology Tracker
From istructe.org Jan 2024

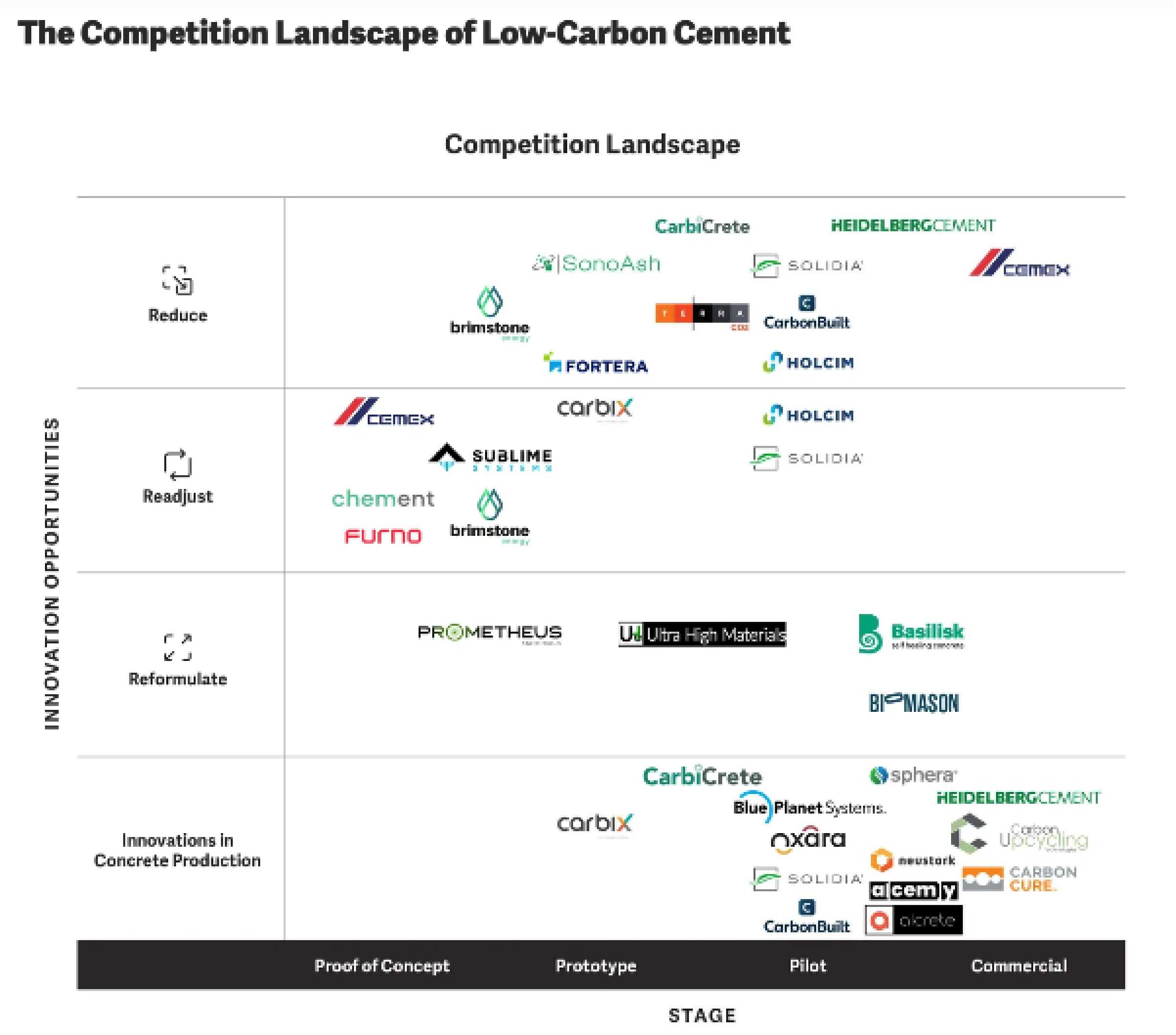
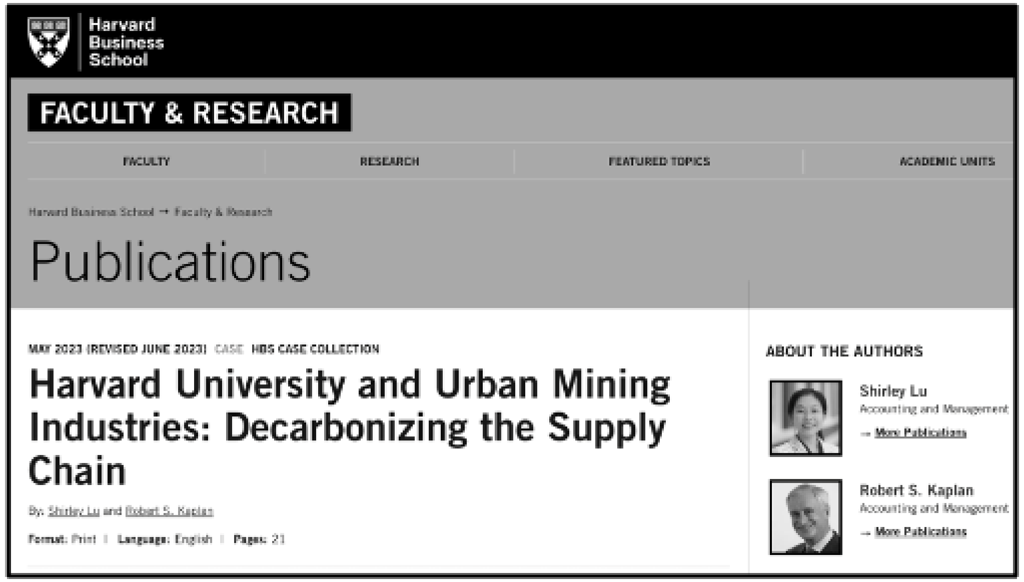


Exhibit 1: Competition landscape across the three Rs of low-carbon cement



Harvard Business School

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Publications

MAY 2023 (REVISED JUNE 2023) CASE HBS CASE COLLECTION

Harvard University and Urban Mining Industries: Decarbonizing the Supply Chain

By: Shirley Lu and Robert S. Kaplan

Format: Print | Language: English | Pages: 21

ABOUT THE AUTHORS

Shirley Lu
Accounting and Management
→ More Publications

Robert S. Kaplan
Accounting and Management
→ More Publications

Is cement the solution to storing renewable energy? Engineers at MIT think so.

Supercapacitors could make powering your home and electric vehicles easier and more sustainable

By Macie Parker Globe Correspondent, Updated August 22, 2023, 9:36 a.m.

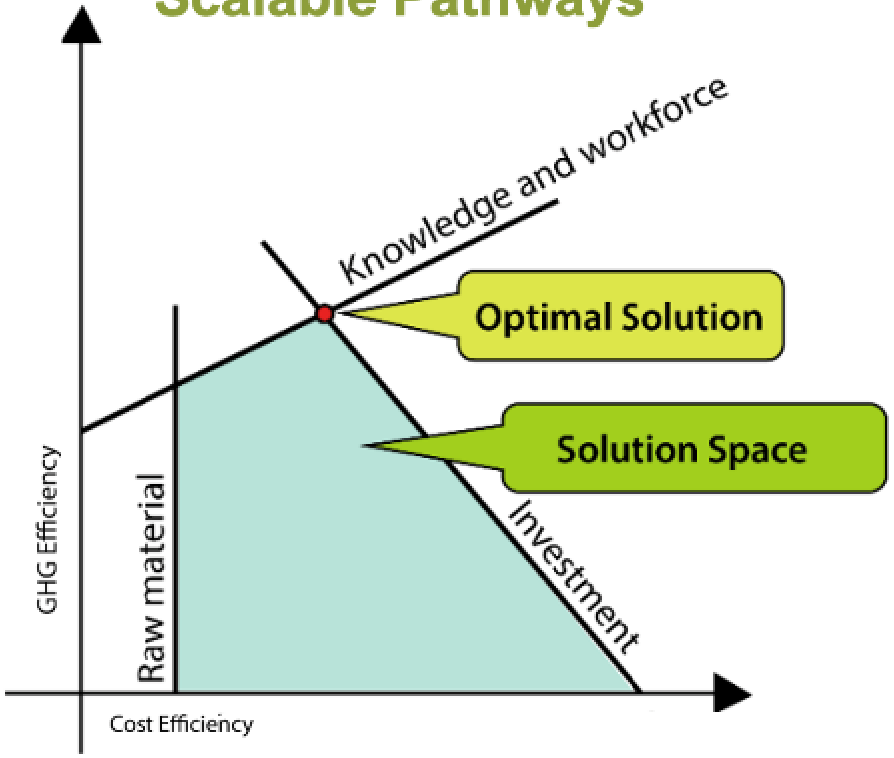
At the Massachusetts Institute of Technology, from left, professor Admir Masic, visiting scholar James Weaver, postdoc Damian Stefaniuk, and professor Franz-Josef Ulm surrounded a supercapacitor, which can store renewable energy using cement, water, and carbon. SUZANNE KREITER/GLOBE STAFF

The Boston Globe

MIT CSHub MIT Concrete Sustainability Hub

Over the last 2 years, more than $500 Million has been invested in lower-carbon concrete startups.

Scalable Pathways

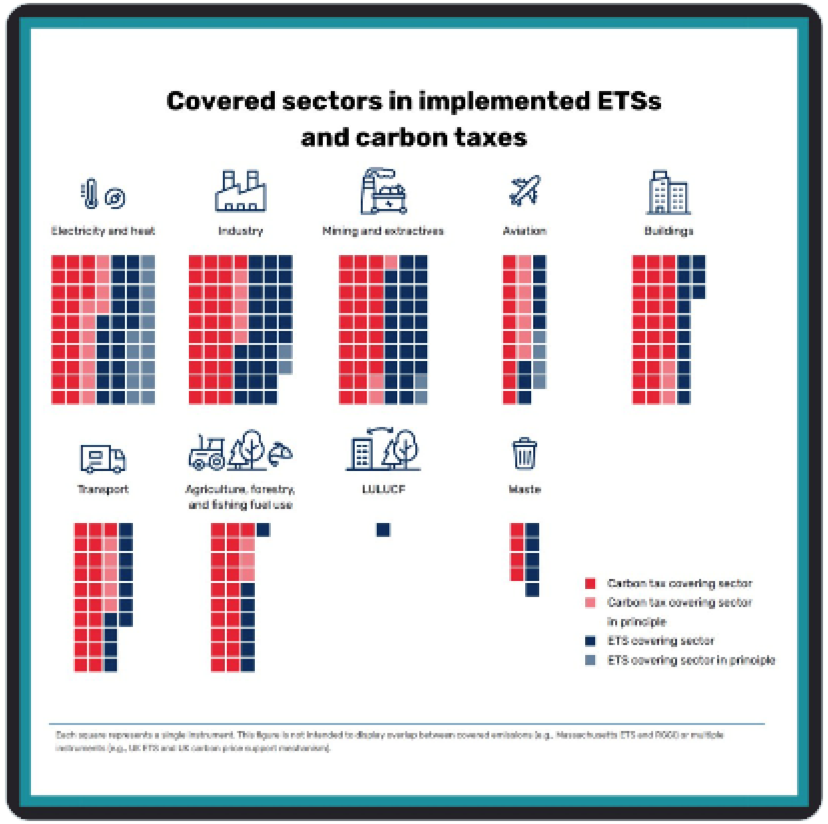


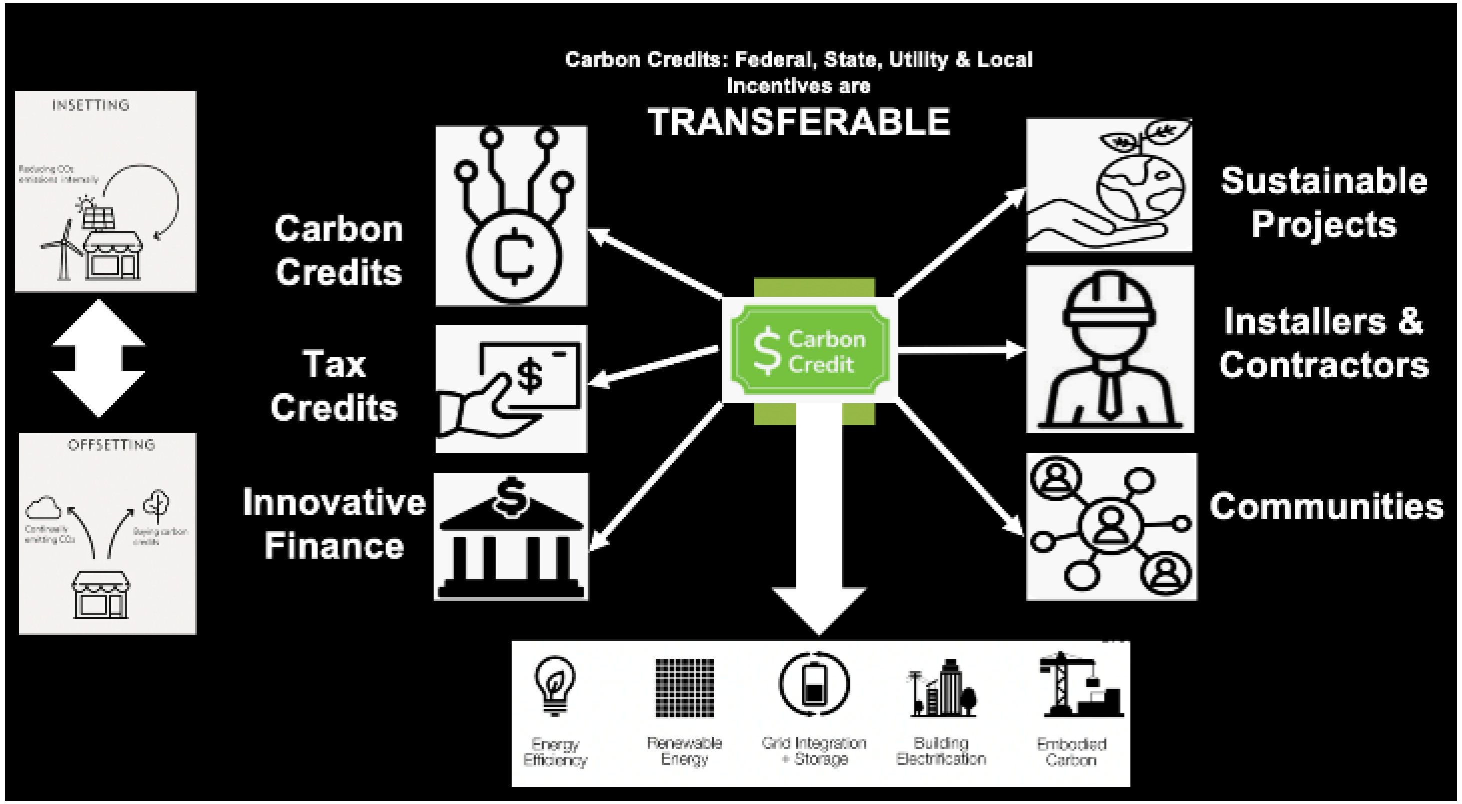
Scalable lower-carbon pathways for concrete must have adequate and distributed raw material supply, align w/existing capital investments, and be understood by the concrete and construction workforce.

MIT Concrete Sustainability Hub

World Bank @WorldBank · 7h

Did you know that a #PriceOnCarbon is increasingly being considered in new sectors such as aviation, shipping and waste? Check out the "State and Trends of Carbon Pricing 2024" report to learn more: wrld.bg/BUtX50SnzCe



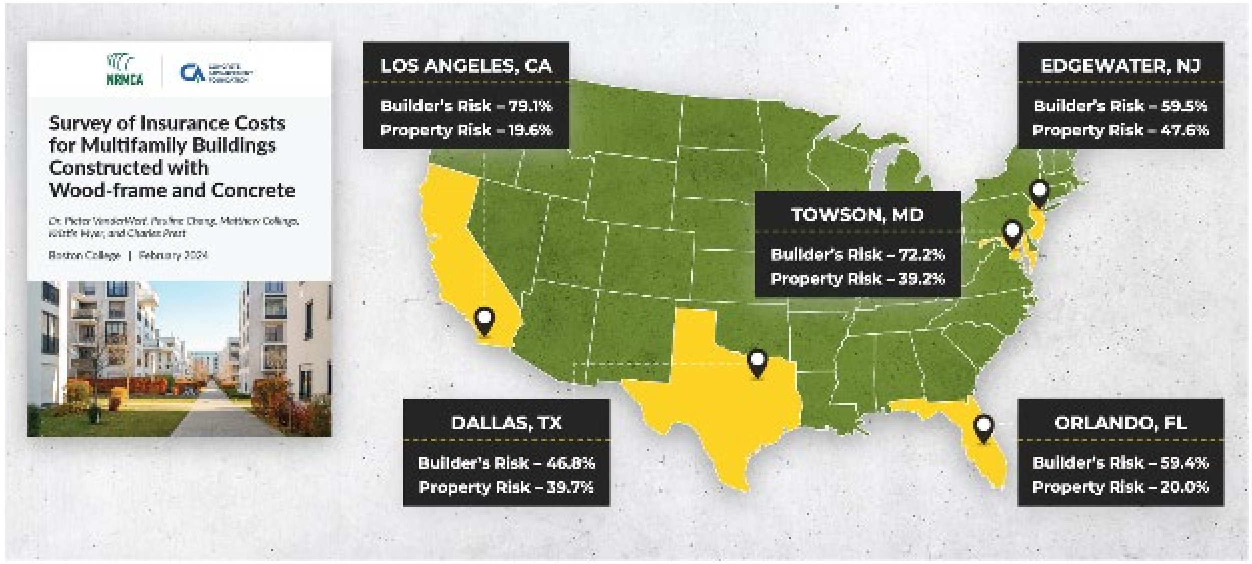


EPA IRA Government Grant

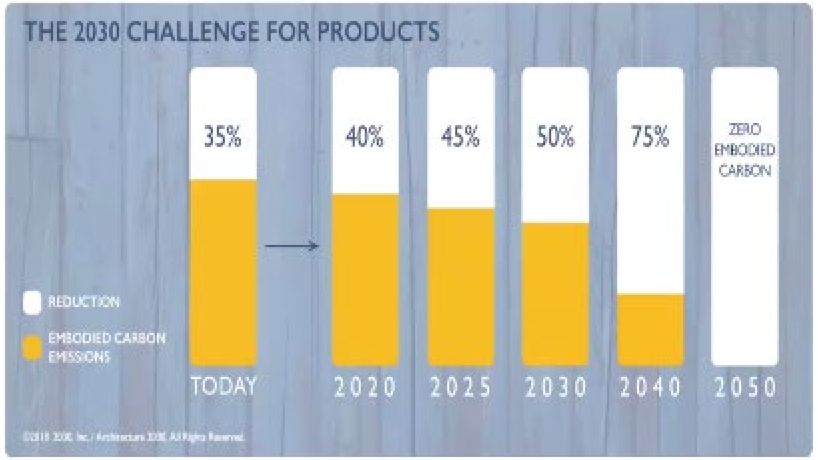
$250M allocated to the Environmental Protection Agency (EPA) to help manufacturers develop Environmental Product Declarations (SEC. 60112)

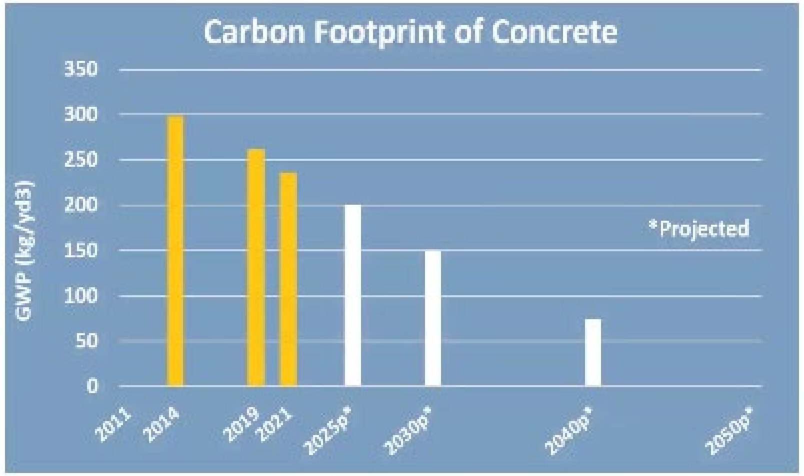
$100M Notice of Funding Opportunity (NOFO) issued in October 2023
Proposals were due January 2023
NRMCA applied to provide funding for producers to publish EPDs
NRMCA was selected for a grant for $9.63M
Public announcement happened on 7-16-2024
Grant will likely start funding in October-December 2024 timeframe

Insurance Costs



Progress to Date





NRMCA Resources

Event Resources

Concrete Design Center

The NRMCA Carbon Calculator Brochure

Concrete's Environmental Impact: What You Need to Know

NRMCA Environmental Product Declaration (EPD) Program Flyer

The Top 10 Ways to Reduce Concrete's Carbon Footprint

Guide to Improving Specifications for Ready Mixed Concrete

Leveraging the Properties of Concrete in Net-Zero Buildings

Frank Mruk, FAIA

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Concrete LC2, designed by Stefan Zwicky in 1980