CONCRETE INNOVATIONS

Specifying Sustainable Concrete

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June 8, 2022

NRMCA

BUILD WITH STRENGTH

Calls for net zero commitments are all the rage

UN CLIMATE PRESS RELEASE / 21 SEP, 2020

Commitments to Net Zero Double in Less Than a Year

22 regions, 452 cities, 1,101 businesses, 549 universities and 45 of the biggest investors

facebook

Ford

LafargeHolcim

architecture 2030

SE2050 COMMITTING TO ZERO

WORLD GREEN BUILDING COUNCIL

NRMCA Sustainability Initiatives

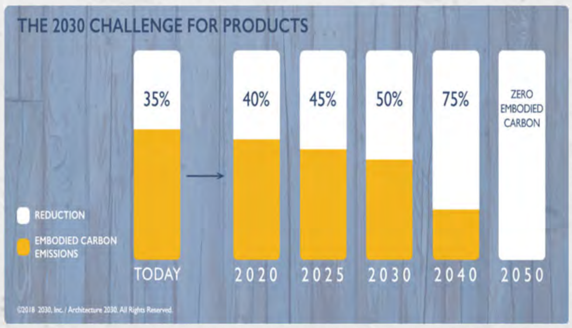
2009 | 2012 | 2014 | 2016 | 2021

ADOPTER architecture 2030 CHALLENGE

NRMCA CERTIFIED EPD

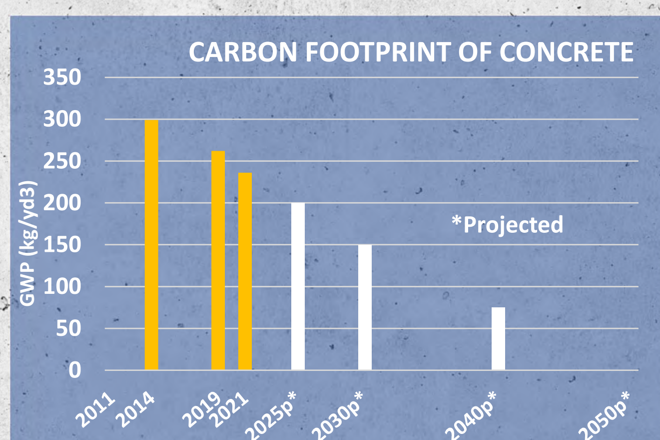
BUILD WITH STRENGTH

Roadmap to Carbon Neutrality
A more sustainable world is Shaped by Concrete



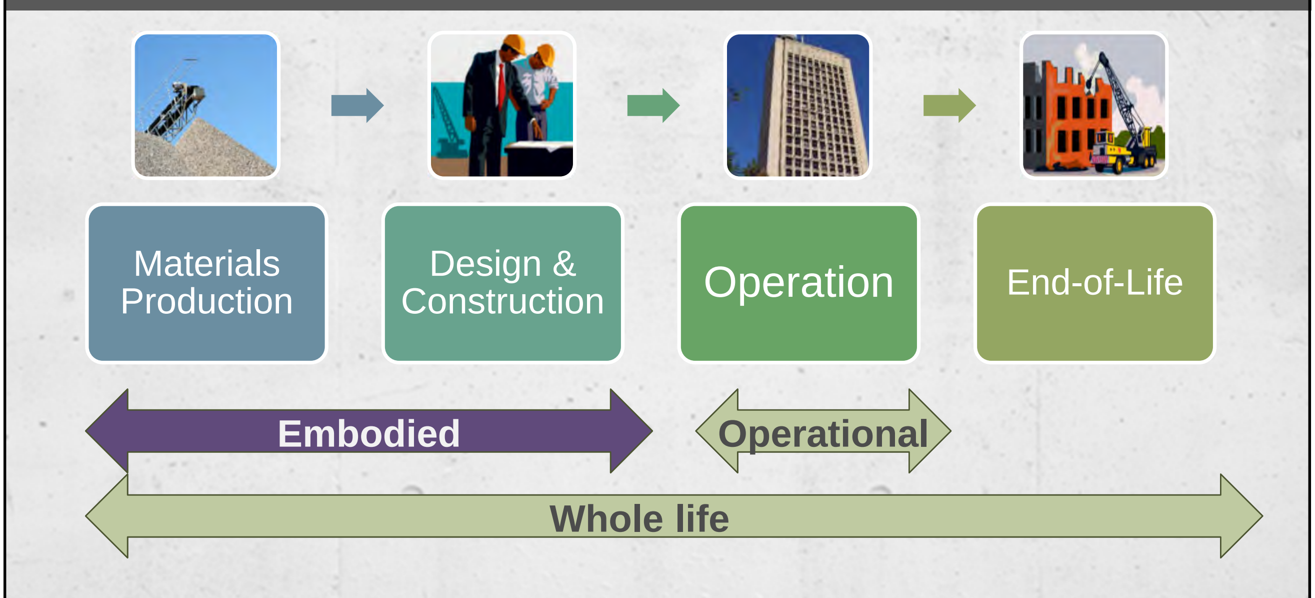
EPD Program Progress

- 21% decrease in embodied CO_2
- 40,000+ concrete EPDs



Green Building Standards & Initiatives

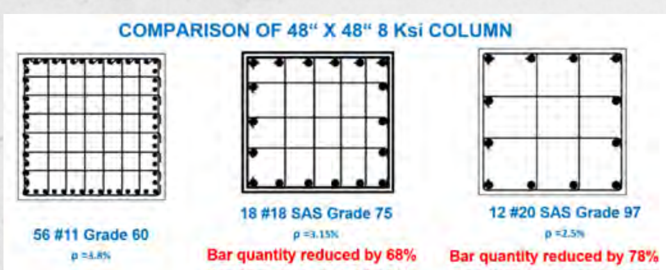
What is embodied vs operational emissions?



Is Concrete Sustainable?

Influence of Design on Embodied Carbon

- Choice of structural system / grid
- Bay size variations
- Section dimensions
  - Concrete strength
  - Rebar Grade

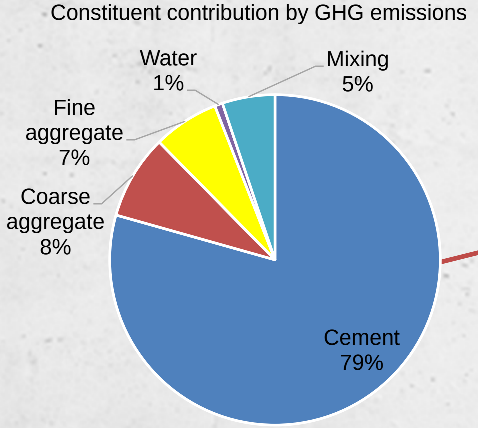


Influence of Project Specifications

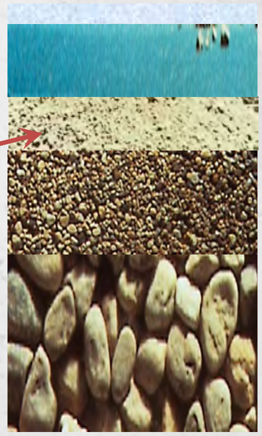
- Sustainability criteria should have minimum impact on performance or service life of concrete
- Specifications should not restrict concrete from being sustainable

Impact of Specifications for Concrete

- Embodied Carbon (GWP) related to design (specified) strength

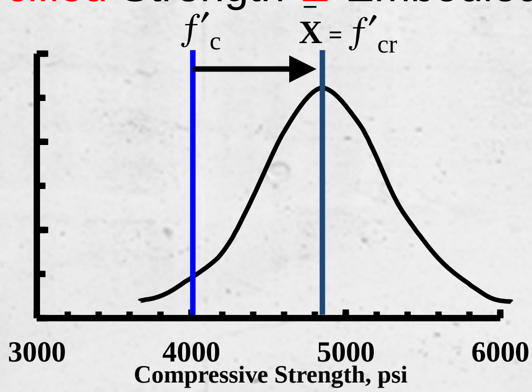


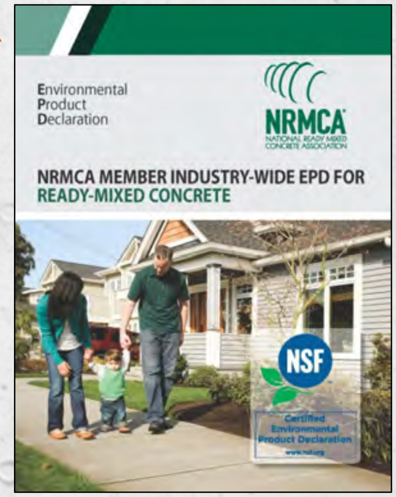
3000 psi mixture with no SCMs



Concrete Strength and Embodied Carbon (GWP)

Specified Strength ▲ Embodied Carbon ▲





Average Strength ▲ Embodied Carbon ▲

Strength ▲ 100 psi (0.7 MPa) GWP ▲ 1.5%

Sustainable Concrete

- Meet traditional performance requirements of the owner, designers, contractor and producer

+

- Minimize Energy and Embodied Carbon (GWP)
- Minimize Potable Water Use
- Minimize Waste
- Increase Use of Recycled Content

Is This Concrete Sustainable?

50% portland cement replacement!
Is this Sustainable Concrete?

Portland cement	208 kg/m³ (3[illegible]0 lb/yd³)
Slag cement	178 kg/m³ (300 lb/yd³)
Silica fume	[illegible] kg/m³ (50 lb/yd³)
Coarse aggregate	[illegible]068 kg/m³ (1800 lb/yd³)
Fine aggregate	712 kg/m³ (1200 lb/yd³)
Water	178 kg/m³ (300 lb/yd³)
Air content	6%

Not Sure

High Early Strength Concrete

Mass Concrete

Prescriptive Specifications

2.1.2 Water-Cement Ratio

Maximum water-cement ratio (w/c) for concrete shall be 0.40 by weight, for all work.

segregation or bleeding. The cementitious materials content of concrete shall be at least 675 pounds per cubic yard. Except that concrete to be placed by tremie the cementitious materials content shall be at least 725 pounds per cubic yard.

c. Fly Ash: Fly Ash shall have a high fineness and low carbon content and shall exceed the requirements of ASTM-C-618, "Specification for Fly Ash and Raw or Calcined Natural for Use in Portland Cement Concretes" for Class F, except that the loss of ignition shall be less than 3% and all fly ash shall be a classified processed material. Fly ash shall be obtained from one source for the concrete delivered to the project. Complete chemical and physical analysis of the fly ash shall be submitted to the Architect prior to use. Concrete mixes proportioned with fly ash shall contain not less than 10% nor more than 20% by weight of cement to fly ash.

Most Common Prescriptive Requirements

Prescriptive Requirement	Frequency Seen
Restriction on SCM quantity	85%
Max w/cm (when not applicable)	73%
Minimum cementitious content	46%
Restriction on SCM type, characteristics	27%
Restriction on aggregate grading	25%

References

ACI Concrete International Aug 2015

nrmca.org/p2p

STRUCTURE Magazine, April 2019

www.structuremag.org

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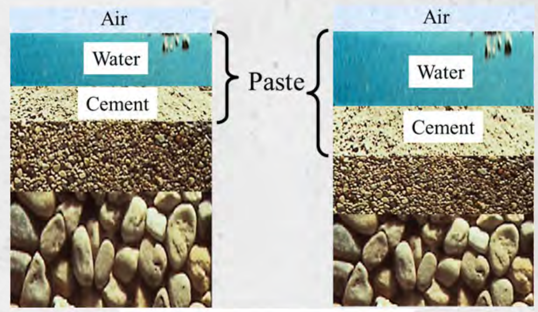
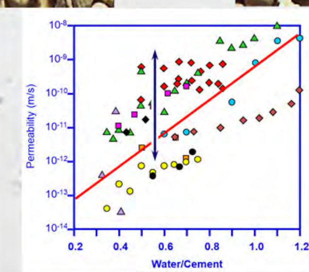
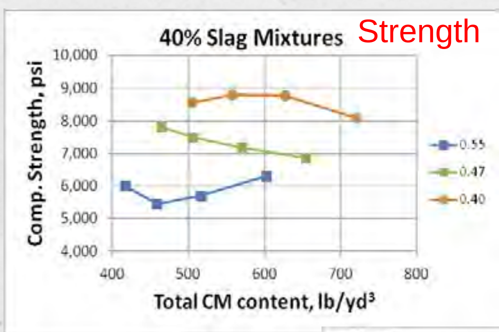
Specifying Water-Cement Ratio

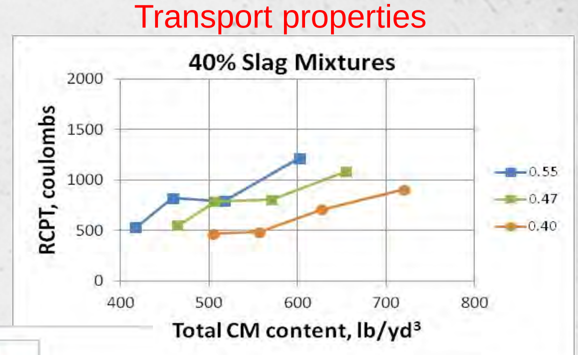
- Paste volume impact
- No “credit” for SCMs
- May not assure intent
- Lower is not always better
  - Impacts sustainability
  - Impacts constructability
  - Associated impact on performance



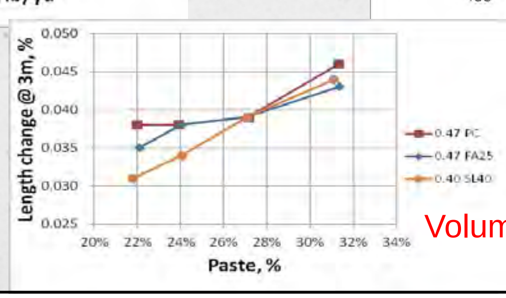


Effect of CM content





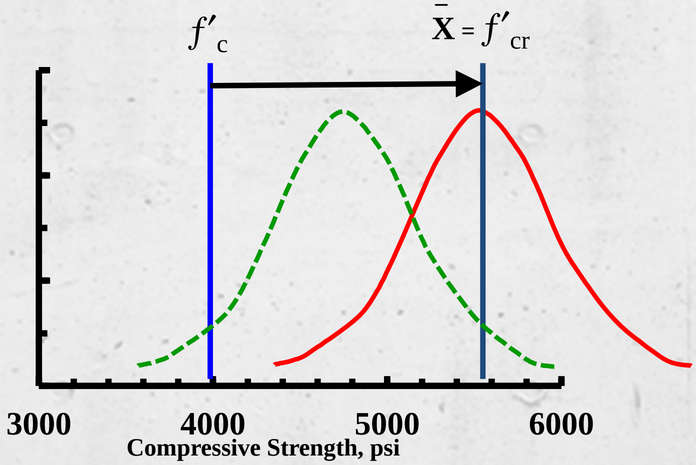
Strength/Workability
Higher Cementitious



Durability / Cracking
Lower Cementitious

Impact of Prescriptive Specifications

Max w/cm or min cementitious content



1MPa = 145 psi

Are we Significantly Over-designed?

- Typical "overdesign" ~15%> f'_c

w/cm	f'_c	Non Air	Air-Ent
0.40	5000	37%	23%
0.45	4500	34%	21%
0.50	4000	30%	18%
0.55	3500	29%	14%
		33%	**19%**

Impact of Prescription

hanley wood UNIVERSITY

BUILD WITH STRENGTH

SPECIFYING SUSTAINABLE CONCRETE (PRINT COURSE)

Concrete is used in nearly every structure we build today, including buildings, bridges, homes and infrastructure. With ... READ MORE

AVERAGE RATING ★★★★★

ENROLL

COURSE CREDITS

AIA 1 LU | Elective, PDH Potential 1 Hour, Canada Potential 1 Learning Credits

Ref: Lemay, Lobo, Obla, Hanley Wood University, 2019

www.nrmca.org/sustainability

Impact of Prescription

Specification Provision	Impact of provision		
	Sustainability	Performance	Cost
Restrictions on characteristics of aggregates	↓	↔	↑
Invoking a minimum content for cementitious materials	↓	↕	↑
Prescriptive requirements toward green building credit	↑	↕	↕
Restriction on SCM characteristics	↓	↓	↑
Restriction on quantity of SCM	↓	↓	↑

Ref: Lemay, Lobo, Obla, Hanley Wood University, 2019

Impact of Prescription

Table 1. Impact of Prescriptive Specification on Sustainability, Performance and Cost

Specification Provision	Impact		
	Sustainability	Performance	Cost
1. Restrictions on type and source of cement	↓	↕	↑
2. Not permitting cements conforming to ASTM C1157 and ASTM C595	↓	⇔	⇔
3. Restriction on cement alkali content	↓	⇔	↑
4. Restriction on type and source of aggregates	↓	⇔	↑
5. Restrictions on characteristics of aggregates	↓	⇔	↑
6. Minimum content for cementitious materials	↓	↕	↑
7. Restriction on quantity of SCM	↓	↓	↑
8. Restriction on type and characteristics of SCM	↓	↓	↑
9. Restriction on type or brands of admixtures	⇔	↓	↑
10. Same class of concrete for all members in a structure	↓	⇔	↑
11. Requiring higher strength than required for design	↓	⇔	↑
12. Invoking maximum w/cm when not applicable or one that is not compatible with the design/specified strength.	↓	⇔	↑
13. Requiring a high air content or requiring air content for concrete not exposed to freezing and thawing	↓	↓	↑
14. Restricting the use of a test records for submittals	↓	↓	↑
15. Restriction on changing proportions when needed to accommodate material variations and ambient conditions	↓	↓	↑
16. Requirement to use potable water	↓	↕	↑
17. Not permitting recycled aggregates and materials	↓	↕	↕
18. Not requiring accredited testing labs	↓	⇔	↑
19. Specific limitations on slump	↓	↓	↕

7. Quantity of SCM: Some specifications place limits on the quantity of SCMs. Often, the use of more than one type of SCM is prohibited. This prevents optimizing concrete mixtures for performance and durability. The only building code restriction is for exterior concrete subject to application of deicing chemicals. Maximum limits on the quantity of SCM increases cost and does not support sustainable development. Increasingly, projects seeking green certification impose prescriptive requirements on concrete mixtures such as minimum replacement for cement or minimum recycled content. These requirements can often impact the performance of fresh and hardened concrete properties, such as setting characteristics, ability to place and finish and rate of development of in-place properties. In the long run, this may impact the quality of construction or the service life of the structure. The implication to initial cost may be reduced, but it could cost more in the long term. Alternatives to limiting quantities of SCM to lower environmental impact are discussed later.

To Achieve Optimized Performance

- Quality of paste
  - Supplementary cementitious materials
  - Admixtures
- Quantity of paste - minimize
  - Cementitious materials
  - Control of water
  - Aggregate grading
- Improved Quality Control
- Specific durability issues – ASR, sulfate resistance
- Constructability

← Strength
Permeability

← Shrinkage
Thermal effects
Permeability

The specification should not restrict achieving these goals

Performance Alternatives

- Permeability
  - RCP - ASTM C1202 (1500 coulombs?)
  - Bulk resistivity - ASTM C1876 (120 ohm.m?)
  - Surface resistivity - AASHTO T 358
- Shrinkage
  - ASTM C157 (0.05%)
  - Define specimen size; duration of curing and drying
- ASR – ASTM C1293; ASTM C1567

ACI 318-19 – Durability Requirements

Chapter 19

19.3.1.1

19.3.1 *Exposure categories and classes*

19.3.1.1 The licensed design professional shall assign exposure classes in accordance with the severity of the anticipated exposure of members for each exposure category in Table 19.3.1.1.

The **licensed design professional shall assign** exposure classes in accordance with the severity of the **anticipated exposure** of members **for each exposure category** according to Table 19.3.1.1

Exposure Categories Durability (ACI 318)

Table 19.3.2.1—Requirements for concrete by exposure class

Exposure class	Maximum w/cm[1,2]	Minimum f_c', psi	Additional requirements			Limits on cementitious materials
			Air content			
F0	N/A	2500	N/A			N/A
F1	0.55	3500	Table 19.3.3.1 for concrete or Table 19.3.3.3 for shotcrete			N/A
F2	0.45	4500	Table 19.3.3.1 for concrete or Table 19.3.3.3 for shotcrete			N/A
F3	0.40[3]	5000[3]	Table 19.3.3.1 for concrete or Table 19.3.3.3 for shotcrete			26.4.2.2(b)
[redacted]			Cementitious materials[4] — Types			Calcium chloride admixture
			ASTM C150	ASTM C595	ASTM C1157	
S0	N/A	2500	No type restriction	No type restriction	No type restriction	No restriction
S1	0.50	4000	II[5][6]	Types with (MS) designation	MS	No restriction
S2	0.45	4500	V[6]	Types with (HS) designation	HS	Not permitted
S3 Option 1	0.45	4500	V plus pozzolan or slag cement[7]	Types with (HS) designation plus pozzolan or slag cement[7]	HS plus pozzolan or slag cement[7]	Not permitted
S3 Option 2	0.40	5000	V[8]	Types with (HS) designation	HS	Not permitted
[redacted]						
W0	N/A	2500	None			
W1	N/A	2500	26.4.2.2(d)			
W2	0.50	4000	26.4.2.2(d)			
[redacted]			Maximum water-soluble chloride ion (Cl^-) content in concrete, percent by mass of cementitious materials[9,10]		Additional provisions	
			Nonprestressed concrete	Prestressed concrete		
C0	N/A	2500	1.00	0.06	None	
C1	N/A	2500	0.30	0.06		
C2	0.40	5000	0.15	0.06	Concrete cover[11]	

Requirements for Concrete (partial)

Concrete Mixtures				
Members	**Exposure**	**f'_c load/dur**	**w/cm**	**NMSA**
Pool and deck	F2, S0, W1, C1	4,000 / 4,500	0.45	¾-in.
Interior slabs and beams	F0, S0, W0, C0	4,000 / n/a	n/a	¾-in.
Interior columns	F0, S0, W0, C0	8,000 / n/a	n/a	¾-in.
Balconies	F3, S0, W0, C2	4,000 / 5,000	0.40	¾-in.
Exterior walls	F1, S0, W0, C1	3,500 / 3,500	0.55	1-in.
Foundation	F0, S1, W0, C1	3,000 / 4,000	0.50	1-in.
Parking Slabs	F0, S1, W0, C2	3,000 / 5,000	0.40	¾-in.

- Specify Exposure Class (ACI 318)
- Can test age >28 days?
- Performance criteria (permeability, shrinkage, etc.)

Evolution to Performance

- Identify Exposure Classes

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

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Evolution to Performance

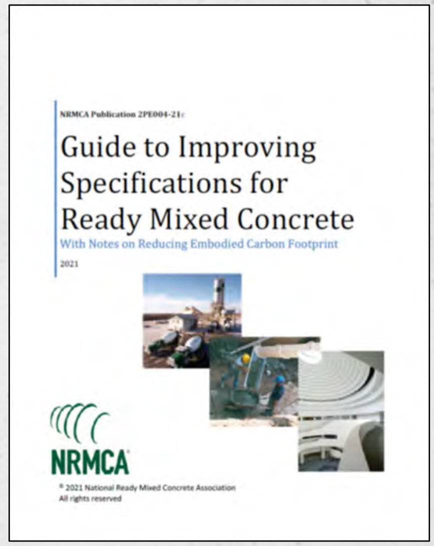
- Performance requirements as applicable

Member	RCP, C1202	Shrinkage, C157	Freeze Thaw		ASR	MOE, C469	Thermal Control Plan	Density	Other
			C666	C457					
Footings					X				
Foundations					X		X		
Slabs on Grade		X			X				
Exterior Slabs	X		X						
Interior Slabs		X						X (LW)	
Frame Members						X			
Interior Columns						X			
Exterior Columns									
Interior Walls									
Exterior Walls					X				
Slab Toppings					X				

Specifications for Sustainability

General Guidelines

- Address prescriptive limits
- Do not restrict use of materials
  - Blended cements
  - SCMs and admixtures
  - Recycled materials
- Avoid specifying means and methods
- Address performance requirements
  - By application
- Consider innovation



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Factors Impacting Strength / GWP

Increases Strength & GWP

- Prescriptive requirements
- Early age strength
- Quality control
  - standard deviation
  - overdesign
- Quality Assurance
  - acceptance testing

Decrease GWP @ target strength

- Paste volume
- Use of SCMs / admixtures
- Later strength age requirement

Designer

- Optimizing design
- Use anticipated strength to advantage

Factors Impacting Embodied Carbon

- Typically higher
  - Early strength – PT, formwork removal
  - Self-consolidating concrete
  - Workability for Placement
  - Slabs – finishing
  - Higher air content
- Can be lower
  - Later age strength
  - Mass concrete
  - Performance-based – shrinkage, permeability, modulus…

Specifications for Sustainability

- Avoid GWP limits for each mixture
- Establish carbon budget for all concrete
  - Percent reduction from benchmark OR Max GWP for all concrete

Member	*Mix ID*	*Durability Exposure*				*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)*
		F	*S*	*W*	*C*								
Footings													250
Foundation Walls													250
Slabs-on-grade													250
Exterior slabs													[illegible]
Suspended slabs (interior)													[illegible]
Suspended slabs (exterior)													[illegible]
Frame members													300
Columns (interior)													300
Columns (exterior)													300
Walls (interior)													250
Concrete toppings													250

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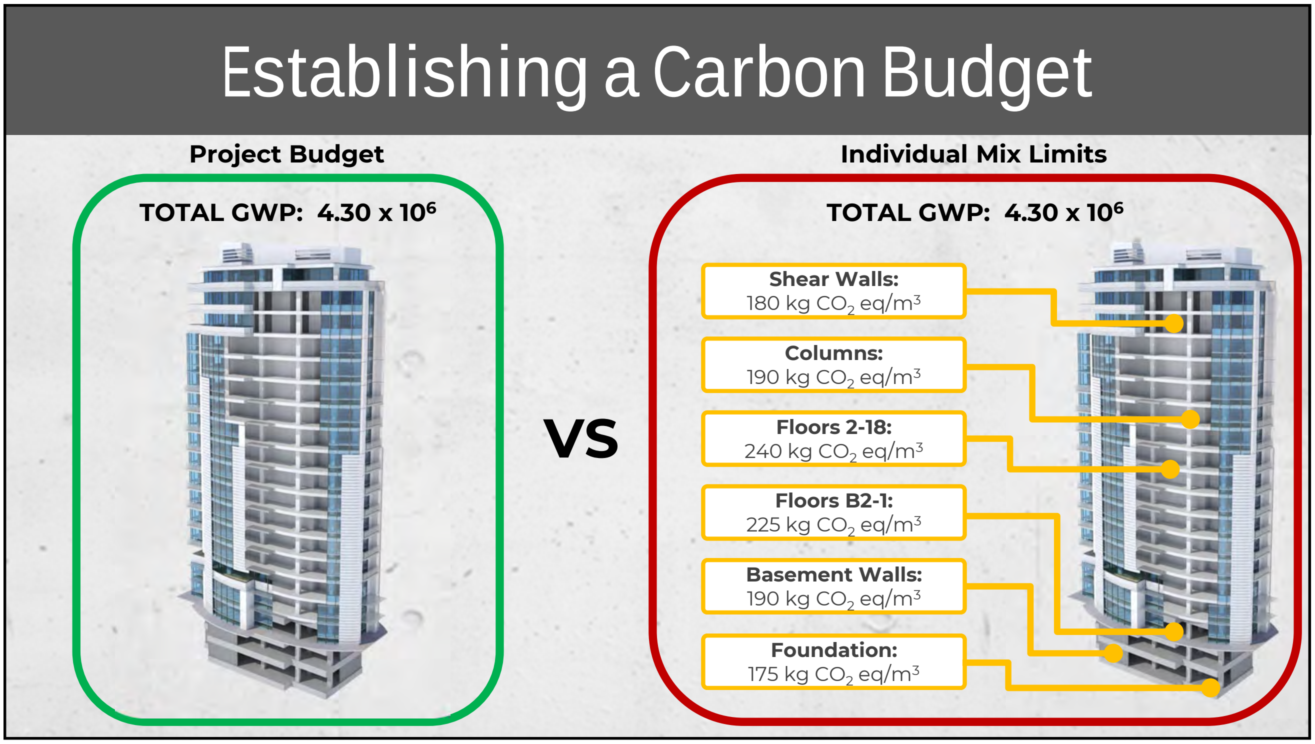
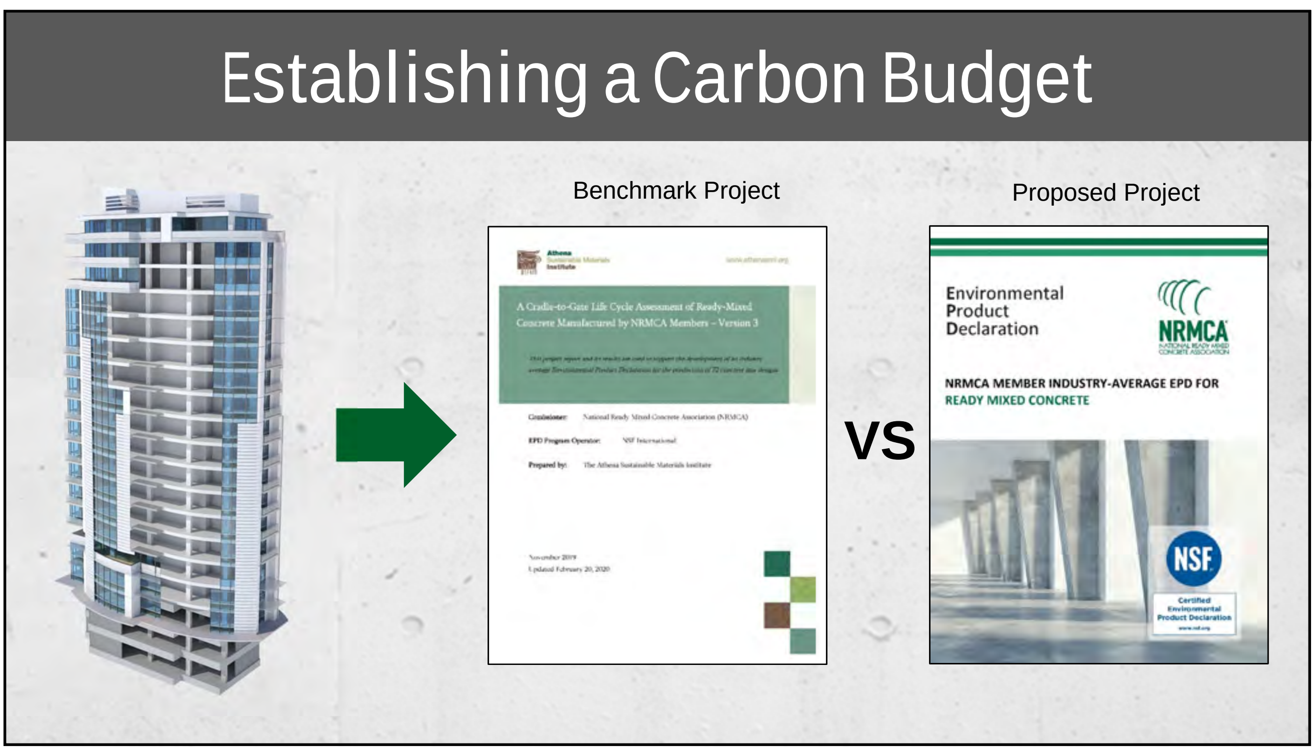
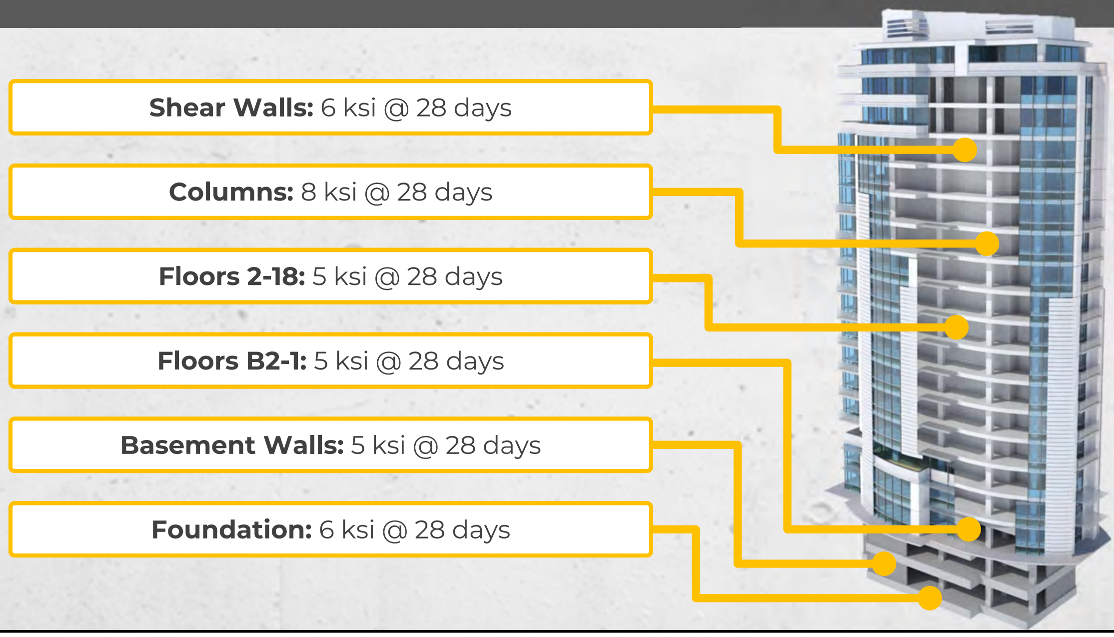

Establishing a Carbon Budget
Project Budget
TOTAL GWP: 4.30 x 10⁶
VS
Individual Mix Limits
TOTAL GWP: 4.30 x 10⁶
Shear Walls: 180 kg CO2 eq/m3
Columns: 190 kg CO2 eq/m3
Floors 2-18: 240 kg CO2 eq/m3
Floors B2-1: 225 kg CO2 eq/m3
Basement Walls: 190 kg CO2 eq/m3
Foundation: 175 kg CO2 eq/m3


Establishing a Carbon Budget
Benchmark Project
A Cradle-to-Gate Life Cycle Assessment of Ready-Mixed Concrete Manufactured by NRMCA Members – Version 3
VS
Proposed Project
Environmental Product Declaration
NRMCA
NRMCA MEMBER INDUSTRY-AVERAGE EPD FOR READY MIXED CONCRETE
NSF

Example: Proposed Building in Northeast U.S.



Estimating Quantities and Properties of Concrete

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 40% slag, 30% fly ash
Foundation	2,844	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/association-resources/sustainability/epd-program/

Environmental Product Declaration (EPD)

3rd party verified & registered documents that communicate transparency

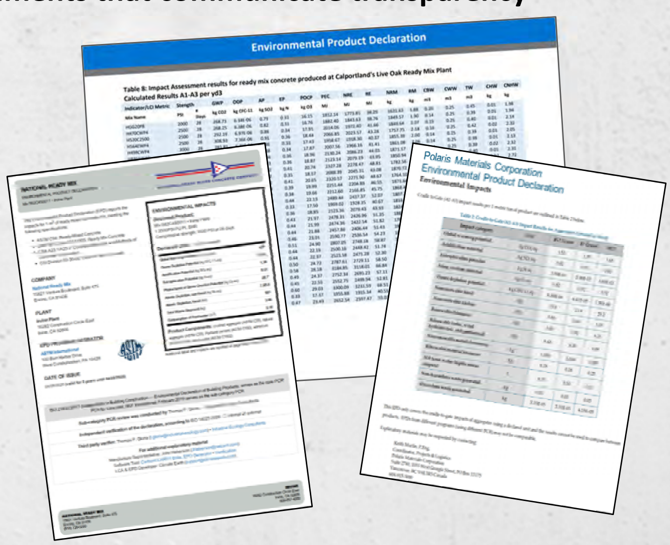
ENVIRONMENTAL IMPACTS

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

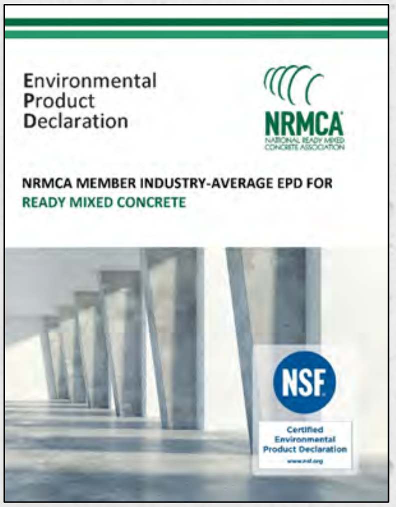
Declared Unit: 1 m^3 of concrete

Global Warming Potential (kg CO_2-eq)	190
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)

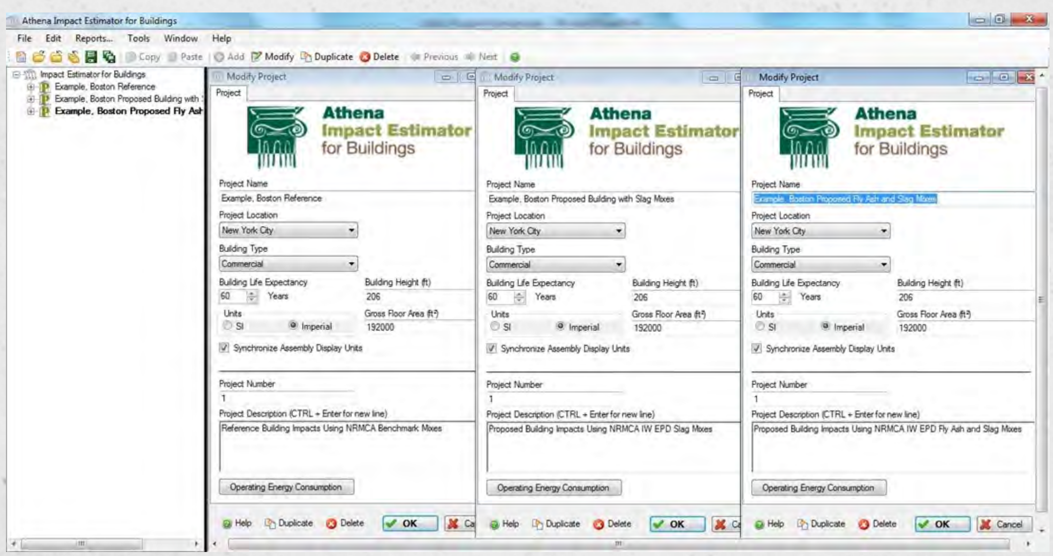


NRMCA Proposed Industry Wide EPD Mixes



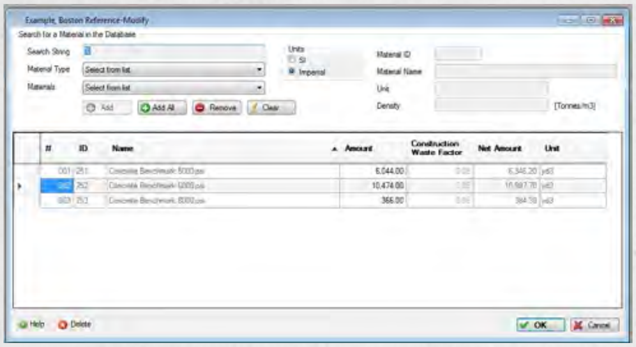
Download at https://www.nrmca.org/association-resources/sustainability/epd-program/

Athena Impact Estimator (incudes NRMCA mixes)

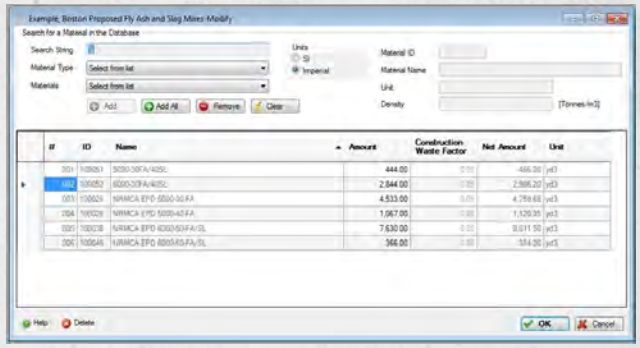


Defining Benchmark and Proposed Project in Athena IE

Reference Mixes (benchmark)



Proposed Project Mixes (IW-EPD)



Final Results

Project	GWP (kg/yd³)	GWP Reduction
Benchmark Mixes	6.14×10^6	0
Proposed with Fly Ash and Slag Mixes	3.92×10^6	-36%
Establish Carbon Budget	4.30×10^6	-30%*

* ~5% tolerance should be achievable

Proposed Specification Language

Option 1

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 CO_2 equivalents as calculated using the Athena Impact Estimator for Buildings Software available at www.athenasmi.org.

Option 2

Supply concrete mixtures such that the total Global Warming Potential (GWP) of all concrete on the project is 30% or more below the GWP of a benchmark building using Benchmark mixes as established by NRMCA and available for download at www.nrmca.org. Submit a summary report of all the concrete mixtures, their quantities and their GWP to demonstrate that the total GWP of the building is 30% or more below the GWP of the benchmark project. Contractor may use the Athena Impact Estimator for Buildings software available at www.athenasmi.org or other similar software with the capability of calculating GWP of different mix designs.

Summary

- Carbon Footprint Reduction
  - Minimize prescriptive limits
  - Performance-based requirements
  - Permit innovative products and processes
- Define project goals for sustainability
- Communicate and partner early with all project stakeholders
  - Consider potential impact on cost


CONCRETE INNOVATIONS
Questions?
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