National Concrete Bridge Council

2026 NCBC WEBINAR SERIES

Silica Fume: A Lever to Lowering Global Warming Potential and Increasing Service Life for Sustainable Infrastructure

November 18, 2026

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www.nationalconcretebridge.org

National Concrete Bridge Council

NCBC Webinar Series 2027

Dates for 2027 TBD

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Industry Events 2026

Dec 1-2, 2026: World Bridge Engineering Conference, Miami, FL

Jan 10-14, 2027: TRB Annual Meeting, Washington, DC

Jan 18–21, 2027: World of Concrete, Las Vegas

February 3–5, 2027: The Precast Show, Salt Lake City

March 7–10, 2027: NRMCA Convention, Louisville, KY

March 21-24, 2027: ACI Convention, Las Vegas, NV

April 1-2, 2027: NCBC Extending Spans Workshop, Orlando, FL

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PCI has met the standards and requirements of the Registered Continuing Education Program. Credit earned on completion of this program will be reported to RCEP at RCEP.net.

A certificate of completion will be issued to each participant. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the RCEP.

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Photo: HNTB, © Core-Visual as seen in *ASPIRE* Summer 2023.

Julie K. Buffenbarger



- Senior Scientist and Sustainability Principal for Beton Consulting Engineers
- Technical Engineer for St. Mary's Cement
- Expert in sustainability, durability, service life, and concrete mixture design with 32 years experience
- Active in ASTM and ACI Fellow
- Serves on responsibility, sustainability, material, and code committees advocating for the use of low carbon and sustainable concrete.

1:00 – 2:00 PM ET

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Silica Fume: A Lever to Lowering Global Warming Potential and Increasing Service Life for Sustainable Infrastructure

Julie K. Buffenbarger, FACI, LEED AP
Senior Scientist & Sustainability Principal
Beton Consulting Engineers, Hinckley, Ohio



SFA
SILICA FUME ASSOCIATION

Learning Objectives

After this webinar, participants will be able to:

- Describe how silica fume is used in the industry to reduce portland cement consumption.
- Recognize how silica fume impacts the total life cycle of a structure
- Understand EPDs and allocation methods in comparing materials
- Realize how durability is a large driver in the sustainability of structures
- Evaluate project profiles of silica fume projects and GWP profiles











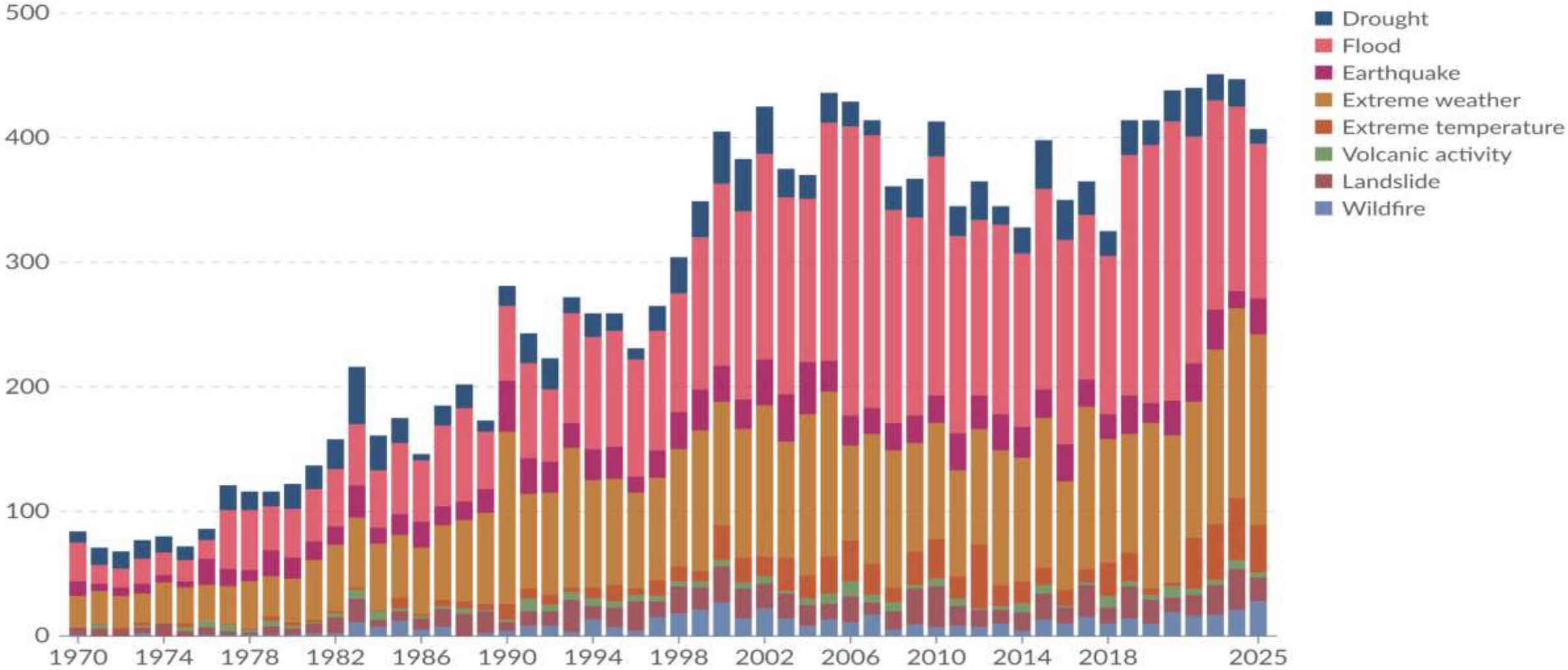




Global reported natural disasters by type 1970 to 2025

Our World in Data

The annual reported number of natural disasters, categorized by type. Note that this largely reflects increases in data reporting, and should not be used to assess the total number of events.



Data source: EM-DAT, CRED / UCLouvain (2026)

OurWorldinData.org/natural-disasters | CC BY

Note: Data includes disasters reported up to October 2026. The latest year may be incomplete due to reporting delays.

Annual economic damages from all natural disasters as a share of GDP

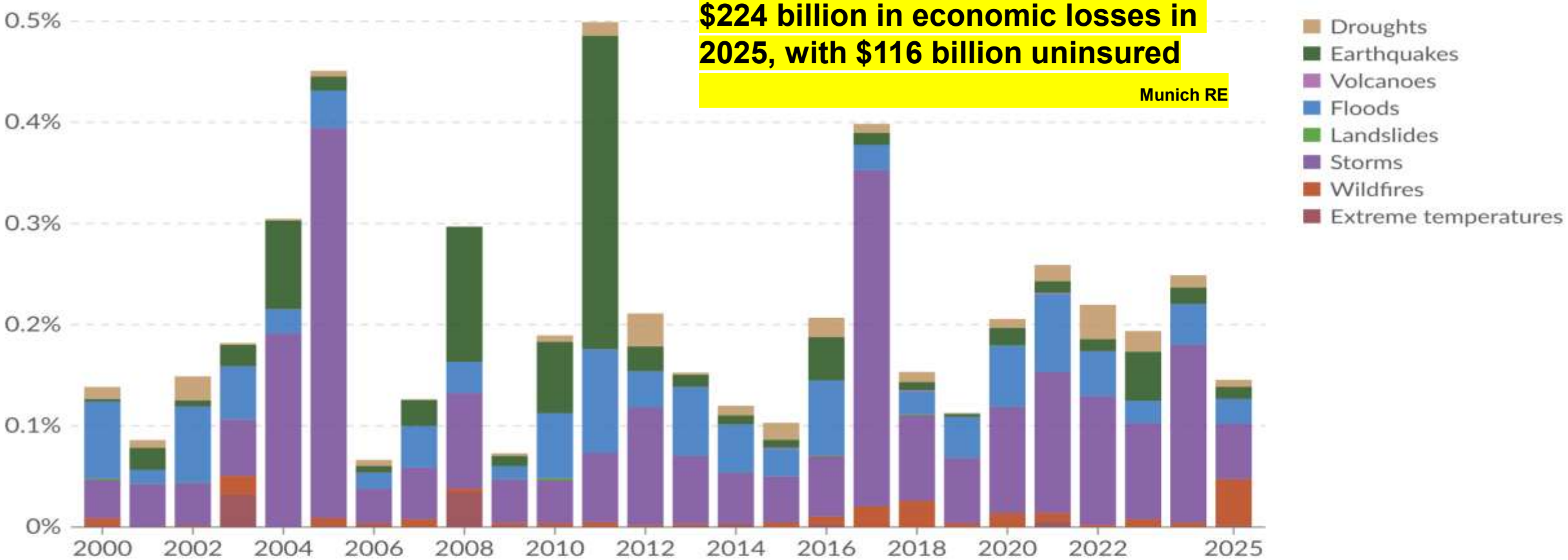
Our World in Data

World, 2000 to 2025

Damages are expressed as a share of gross domestic product (GDP). Disasters include events such as earthquakes, volcanoes, droughts, wildfires, storms, and floods.

$224 billion in economic losses in 2025, with $116 billion uninsured

Munich RE



Data source: EM-DAT, CRED / UCLouvain (2026); National statistical organizations and central banks, OECD national accounts, and World Bank staff estimates (2026)

Note: Based on recorded events; coverage is more limited before the year 2000. Longer historical trends may partly reflect reporting improvements. The latest year may be incomplete due to reporting delays.

OurWorldinData.org/natural-disasters | CC BY

Natural and Manmade Disasters

- **Measurable Impacts**
  - Damage to Infrastructure
  - Economic Costs
  - Loss of Lives



- **Implications beyond Measurable Impacts**
  - Loss of Elements of Social Capital
    - Identity
    - Culture
    - Historical
    - Community



Concrete Growth: Infrastructure and Housing

GWP is Increasing due to concrete volume

Growth in societal need for infrastructure is expected:

- **Megatrends of population growth and urbanization**
- **Necessity of concrete for new construction (lower GWPs)**
- **Requirements for infrastructure resilience and climate adaptation.**

A forecast has been made of what the total need for concrete might be through 2050, assuming current practice.

This forecasted an increase from the current 18.2 bn yd^3 (14.0 bn $m^{3)}$ of concrete to approximately 26 bn yd^3 (20 bn m^3) in 2050. The CO_2 emissions associated with this volume of concrete have also been calculated, assuming current practice, and amount to 3.8 Gt CO_2 emissions.

GCCA 2022

Functionally Deficient Bridges

U.S. Bridge Inventory, by Rating					
		2024	2025	Change 24 to 25	% Change 24 to 25
Good	44.1%	274,835	272,774	-2,061	-0.7%
Fair	49.1%	306,245	309,716	3,471	1.1%
Poor (Structurally Deficient)		42,067	41,677	-390	-0.9%
	6.8%				
Total Number of Bridges		623,147	624,167	1,020	0.2%
Does not include Guam and U.S. Virgin Islands					

NBI database finds that 35 percent of all U.S. bridges—nearly 220,300 spans—require major repair work or replacement.

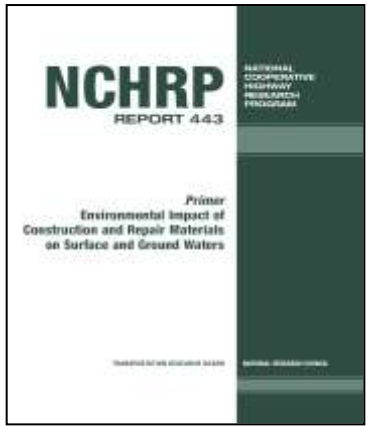
Infrastructure investments of a half-century ago are straining to support modern population levels and commercial activities they were not designed to accommodate and are sorely inadequate relative to the natural and man-made hazards they face.

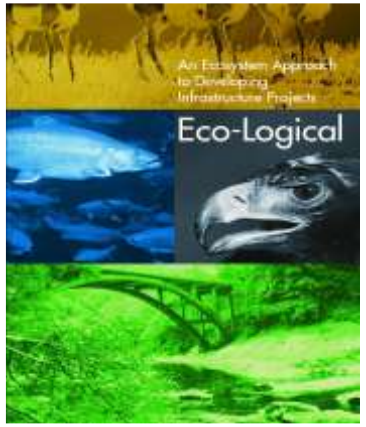
American Road & Transportation Builders Association, June 2025
ASCE 2025 Infrastructure Report Card, 2025

Infrastructure Goals of FHWA & AASHTO

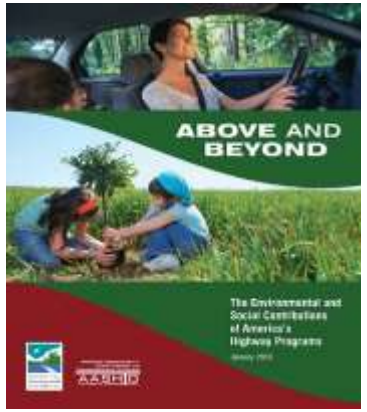
Enable the delivery of safe, environmentally-friendly bridge infrastructure, and provide a high level of service.

- Long-Term Infrastructure Performance
- Durable Infrastructure Systems
- Accelerated Construction
- Environmentally Sensitive Infrastructure
- Performance-Based Specifications
- Comprehensive and Integrated Infrastructure Asset Management
- Core Infrastructure R&D Facilities, Capabilities, and Functions







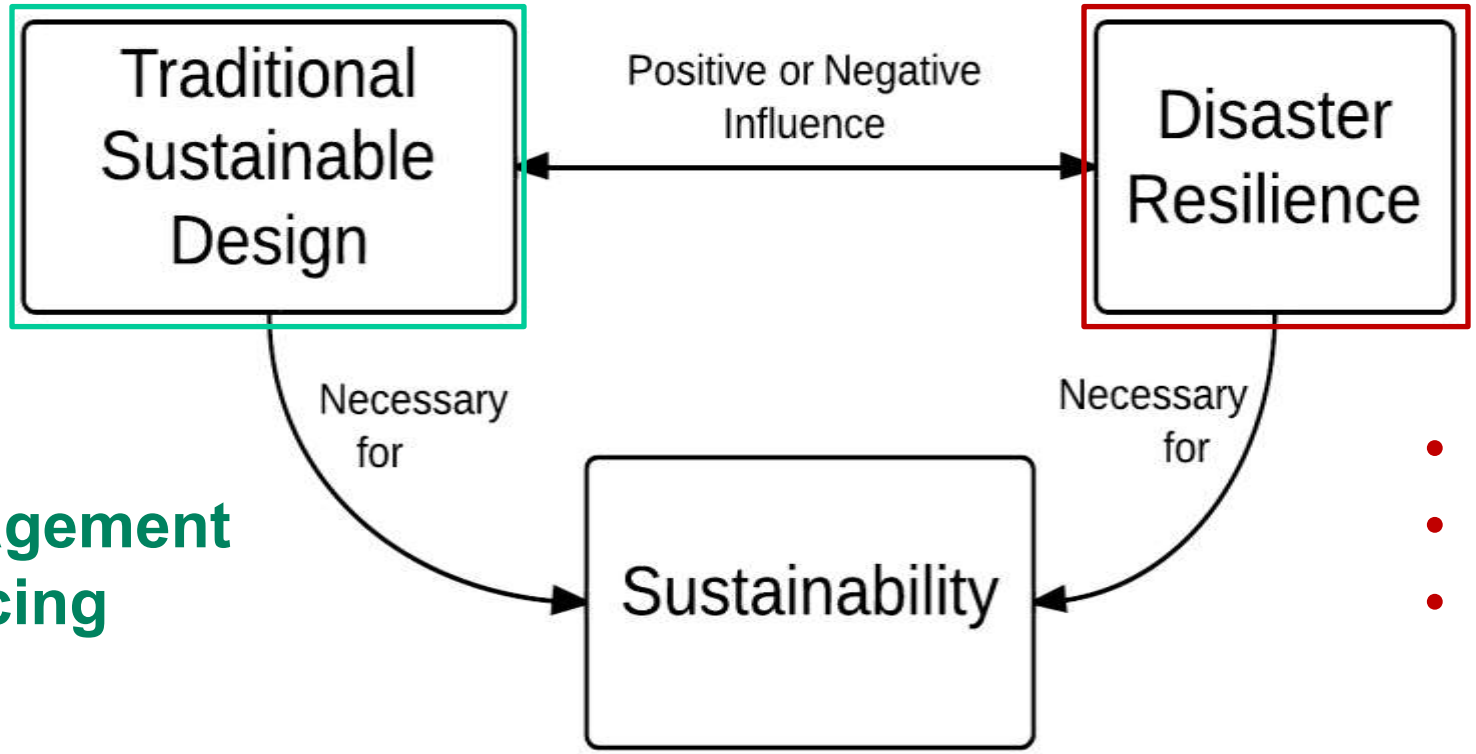




Institute for Sustainable Infrastructure

INVEST
ECONOMIC • SOCIAL • ENVIRONMENTAL

Traditional Sustainable Design, Disaster Resilience and Sustainability



- GWP (CO_2)
- Water Management
- Local Sourcing

- Durability
- Robustness
- Service Life

SEI Sustainability Committee

Sustainability vs. Resilience

Typical sustainability assessments usually concern "ordinary events" that have relatively high probabilities and low impacts (e.g., day-to-day maintenance and operations).

Resilience assessments usually concern "extraordinary events" that have relatively low probabilities and high impacts (e.g., the possible loss of a building in an earthquake).

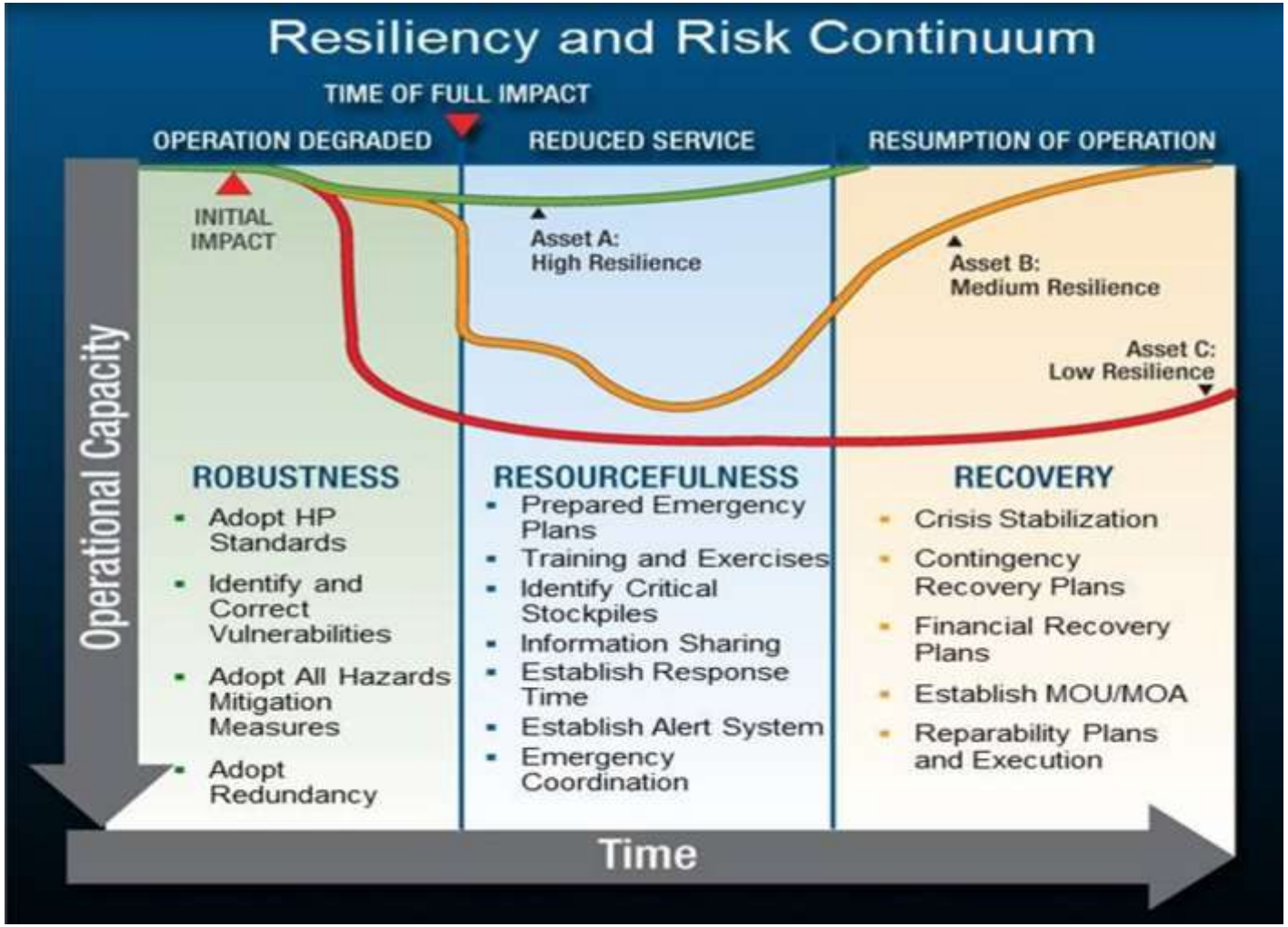
Impact →	1	2	3	4	5
Probability ↓	Negligible	Minor	Moderate	Significant	Severe
(81-100)%	Low Risk	Moderate Risk	High Risk	Extreme Risk	Extreme Risk
(61-80)%	Minimum Risk	Low Risk	Moderate Risk	High Risk	Extreme Risk
(41-60)%	Minimum Risk	Low Risk	Moderate Risk	High Risk	High Risk
(21-40)%	Minimum Risk	Low Risk	Low Risk	Moderate Risk	High Risk
(1-20)%	Minimum Risk	Minimum Risk	Low Risk	Moderate Risk	High Risk

			Probability				
			Frequent	Likely	Occasional	Seldom	Unlikely
			A	B	C	D	E
SEVERITY	Catastrophic	I	1	2	6	8	12
	Critical	II	3	4	7	11	15
	Moderate	III	5	9	10	14	16
	Negligible	IV	13	17	18	19	20
			Risk Levels				

Rodriguez and Perez, 2014

Resilience

- Increase a structure's ability to withstand at least some of the impacts of an event
- Provide a minimum level of functionality immediately after the event
- Shorten the time required for a structure to return to normal functioning following an event; and then
- Improve in the face of future hazard event through post-event investments that further calibrate design performance.



Linkov, et al., 2014

M. Kennett, Resilient Buildings Workshop, November 2012.

Community Resilience and Functional Resilience are Linked

Resilience: Ability to assure public safety, and recover quickly and efficiently

- People
- Social Institutions, Buildings and Supporting Lifeline Infrastructure



Vulnerability and Resilience at Different Levels

Vulnerability		Resilience
Resistance		Recovery
Force Bound		Time Bound
Safety		Bounce Back
Mitigation		Adaptation
Institutional		Community- Based
System		Network
Engineering		Culture
Risk Assessment		Vulnerability and Capacity Analysis
Outcome		Process
Standards		Institution

Vulnerability focuses on the property of resisting the stress caused by a natural hazard and Resilience is more concerned about human capacity to recover from a disaster within a short time with no outside assistance.

What is the Risk?

A measure of the expected loss due to uncertainty.

(Risk) = (Hazard) x (Vulnerability) x (Consequences)

1. **Hazard – probability that it will occur.**
2. **Vulnerability – probability of damage or loss given the hazard**
3. **Consequences – loss or consequence if the hazard is successful in causing damage.**

For climate adaptation it can be re-expressed as:

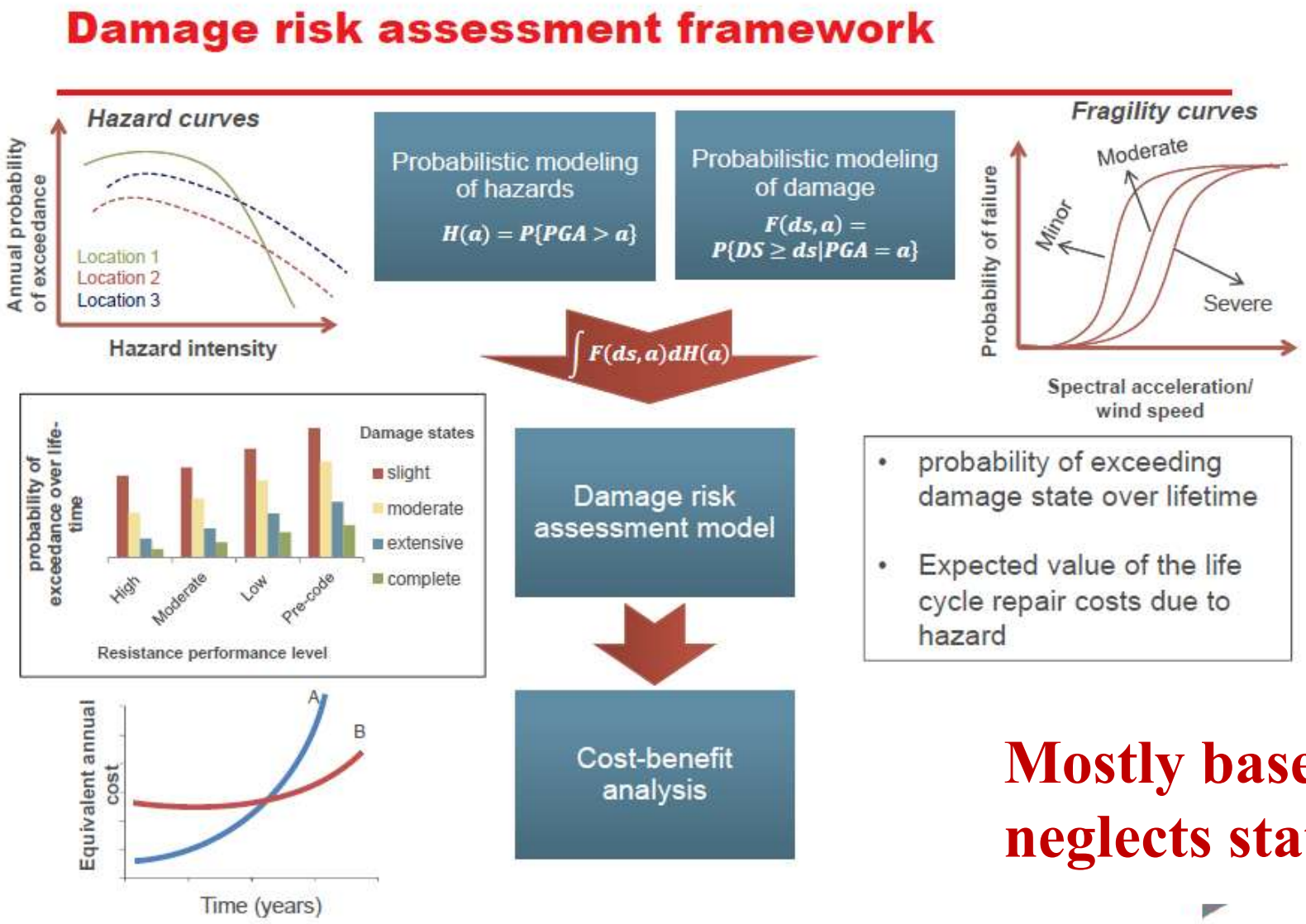
$$\mathbf{E(L) = \Sigma}\ \{Pr(C)_{climate\ scenario}\ Pr(H|C)\}_{Hazard}\ _{*}\ \{Pr(D|H)_{fragility} Pr(L|D)\}_{vulnerability}\ *\ \{L\}_{loss}$$

$$(\Delta R\ _{Reduction\ of\ risk}) = \Delta R\ * E(L)_{expected\ loss} + \Delta Bco\ _{benefits\ gained}$$

(Reduction of Risk caused by climate adaptation)

L = Loss (economic or physical), E=Expected Value, B=Benefit, Pr(D|H) = Fragility

Fragility Curves (Probability of Structural Damage)

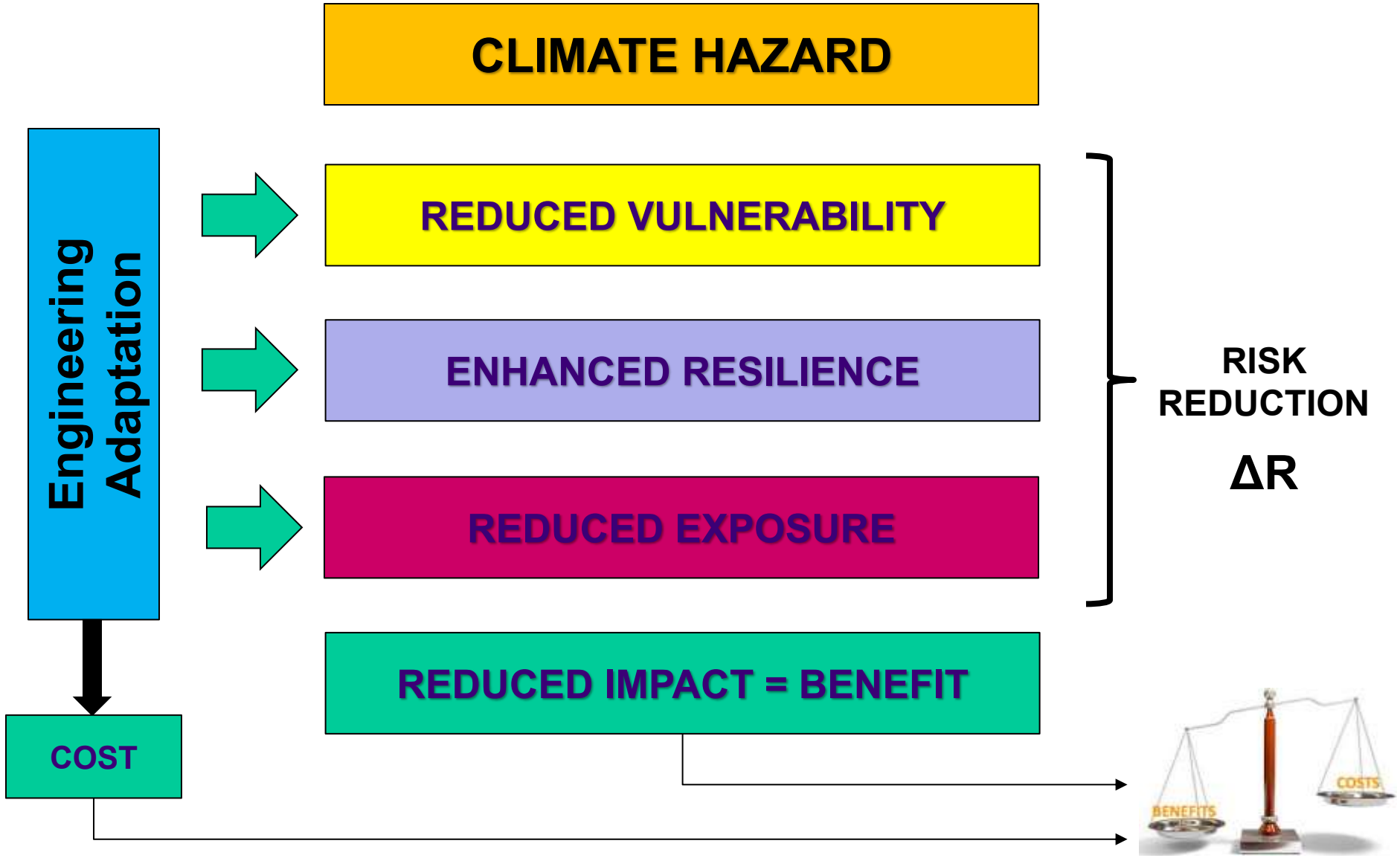




Sanibel Bridge – Hurricane Ian

Mostly based on historical data and neglects statistical uncertainties.

Risk Assessment: A Balance

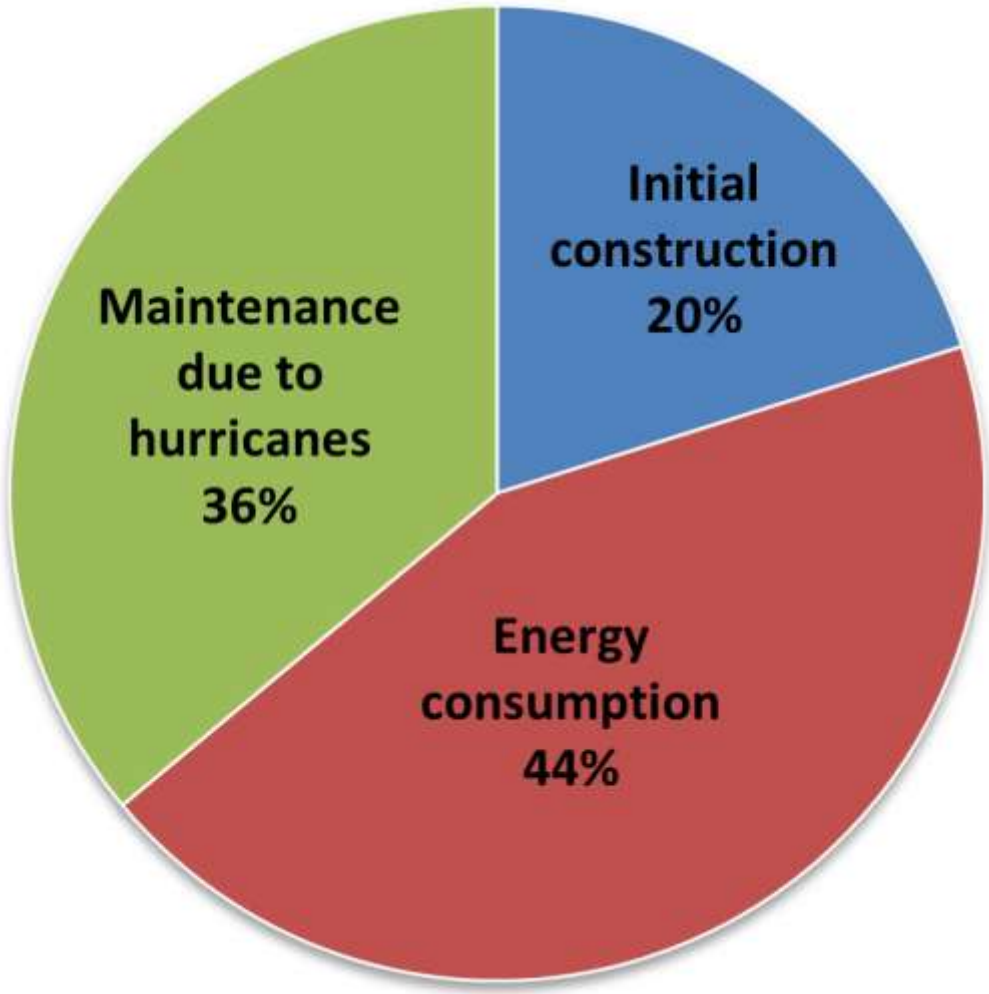


Stewart & Bastidas-Artega, 2019

Quantifying Life Cycle Costing & Resilience

How to quantify and incorporate different performance metrics into the process of comparative cost assessment.

- Resilience of the Built System
- Resilience to the Hazard
- Frequency and Intensity of Hazard?
  - Probability of Risks



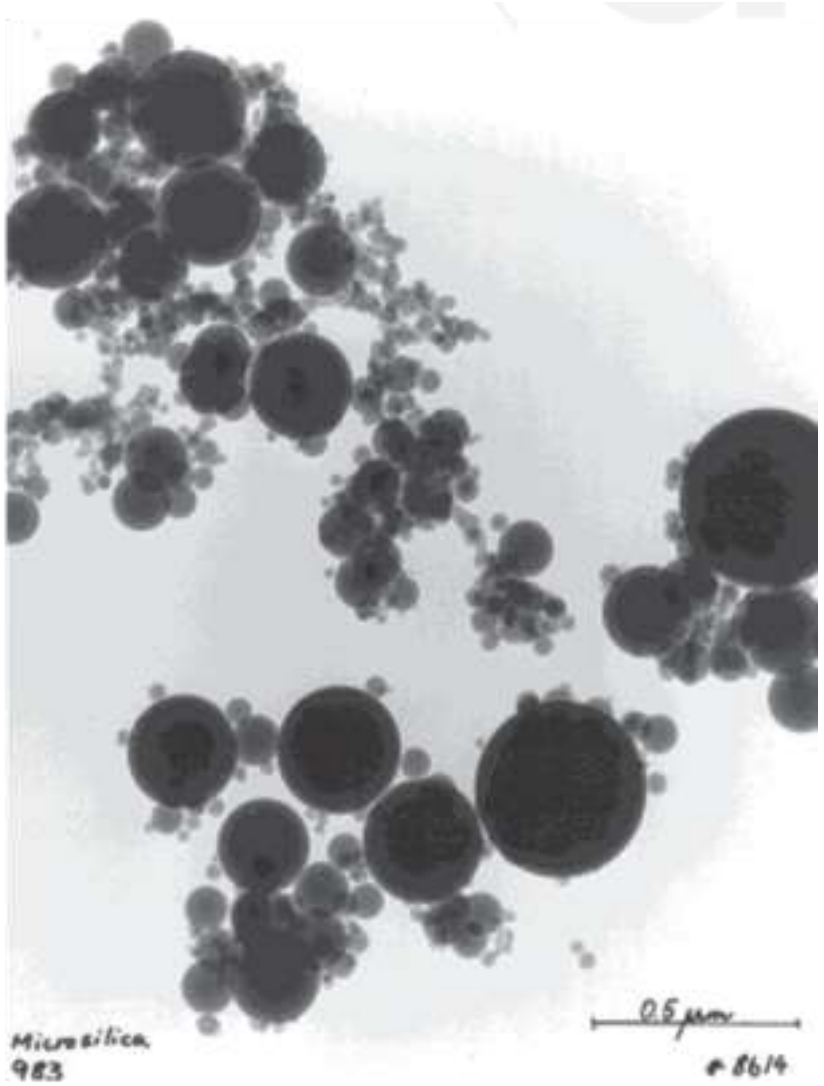
Silica Fume: A Key to Success

What is Silica Fume?

- Silica fume is also referred to as condensed silica fume and microsilica.

- Very fine pozzolanic material, composed mostly of amorphous silica produced by electric arc furnaces as a by-product of the production of elemental silicon or ferro-silicon alloys (ASTM C125).

- 4.0×10^{-6} to 8.0×10^{-6} in. (0.1 to 0.2 μm) in diameter.



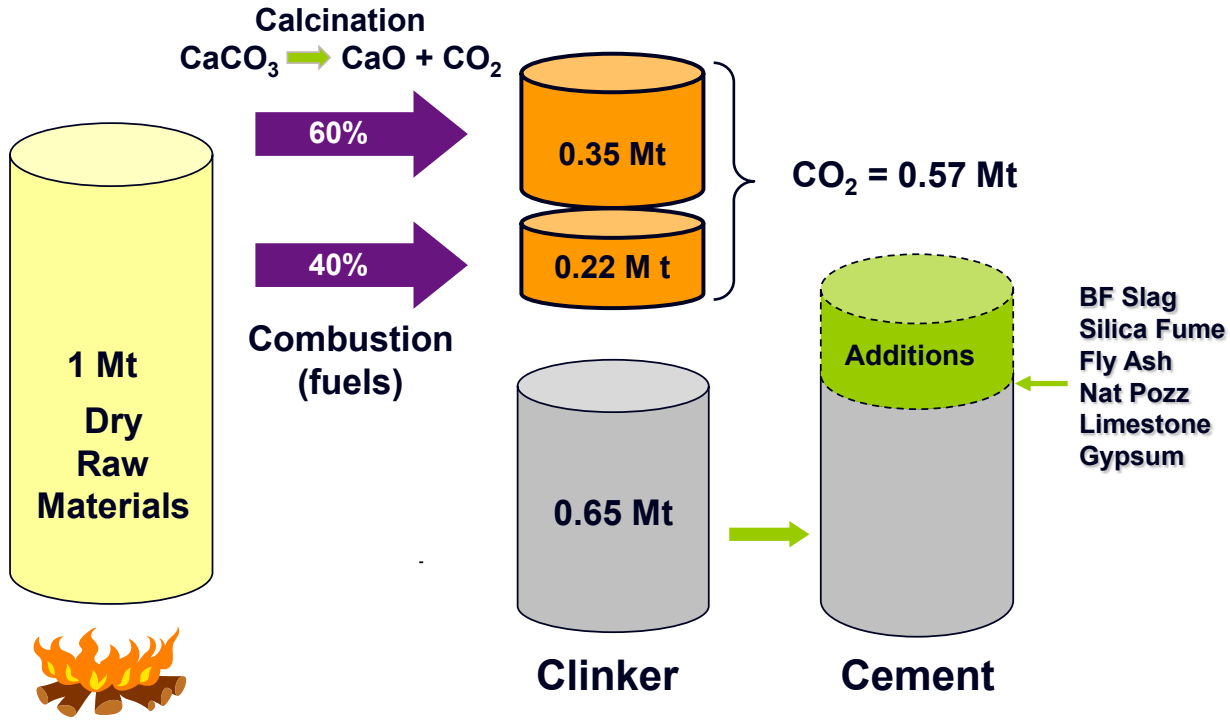
Elkem ASA Materials

Blended Cements: Use of SCMs to Reduce CO_2

The CO_2 generated in the production of portland cement clinker **can be minimized** by incorporating Supplemental Cementitious Materials (SCMs)

- As raw material substitute for limestone
- As a direct substitute for portland cement in concrete

CO_2 Emissions



Note: assume that 0.88t CO_2 /t of clinker

CO_2 Reduction

Every ton of limestone replaced in the raw mix by SCMs reduces CO_2 by approximately 0.53 ton per ton of clinker

Every ton of clinker replaced by SCMs reduces CO_2 by approximately 0.88 ton

ASTM C595 Blended Cements

COMPOSITIONAL REQUIREMENTS FOR ASTM C595/C595M BLENDED HYDRAULIC CEMENTS (BY MASS OF BLENDED CEMENT)

	LIMESTONE (L)	POZZOLAN (P)	SLAG (S)	SUM (L + P + S)
Type IL	>5% and ≤15%	—	—	—
Type IP	≤15%	>0% and ≤40%	—	—
Type IS	≤15%	—	>0% and ≤95%	—
Type IT	≤15%	≤40%	*	≤70%
Type IT(S≥70)	≤15%	*	≥70%	≤95%
Type IC	≤30%	*	*	≤70%

Type IT – Portland cement + 2 of (pozzolans or slag cement) + limestone (optional).

Type IC – Portland cement + 1 or more of (pozzolan, slag cement, limestone).

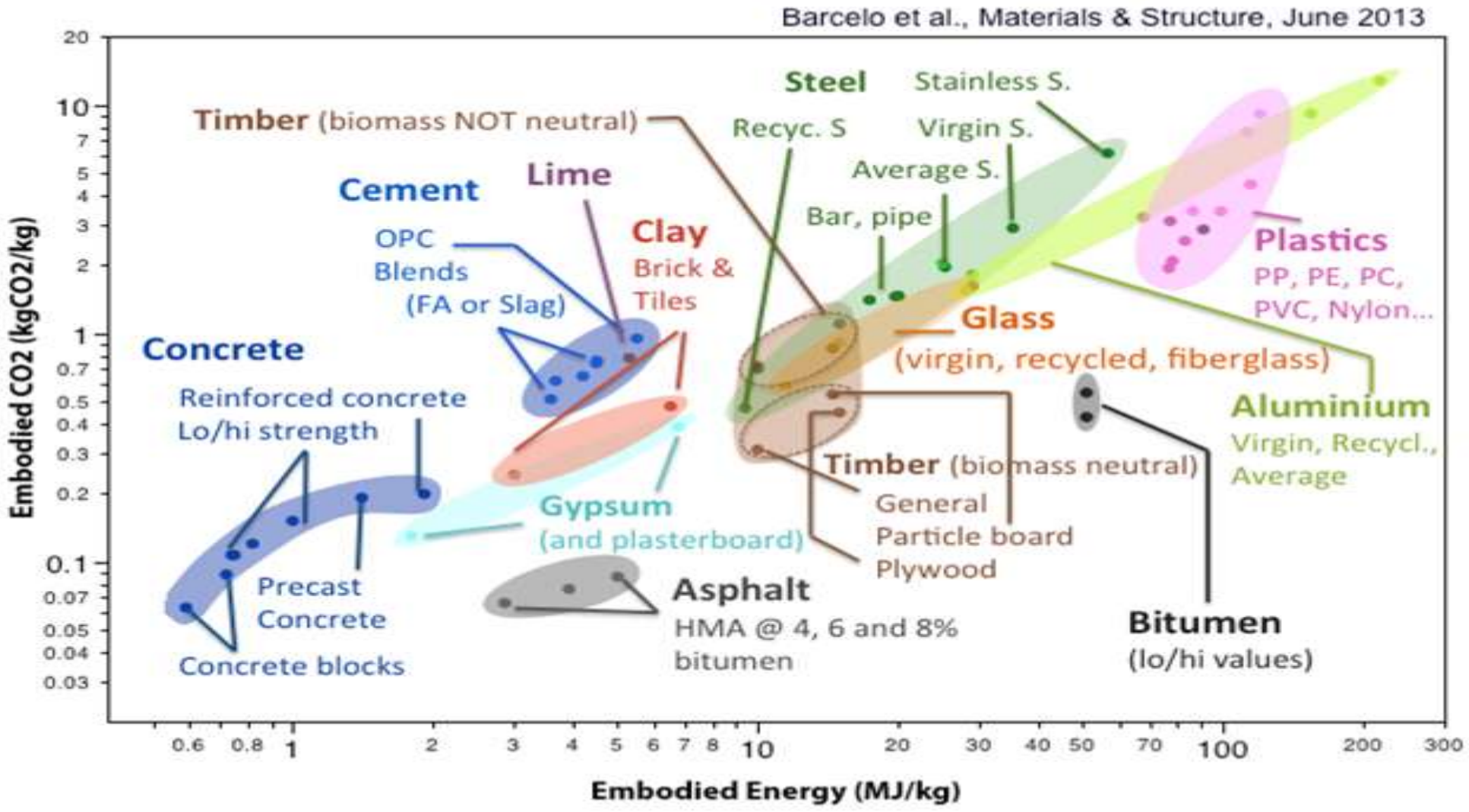
Type IS and Type IT cements with 70% or more slag cement my also contain hydrated lime.

** No stated maximum but must satisfy limit on total limestone, pozzolan and slag cement.*

Successful implementation of blended cements requires lab testing to understand how different cements affect concrete properties, with adjustments made to concrete mixtures and construction methods as needed.

Giannini, 2026

Embodied Energy – CO_2



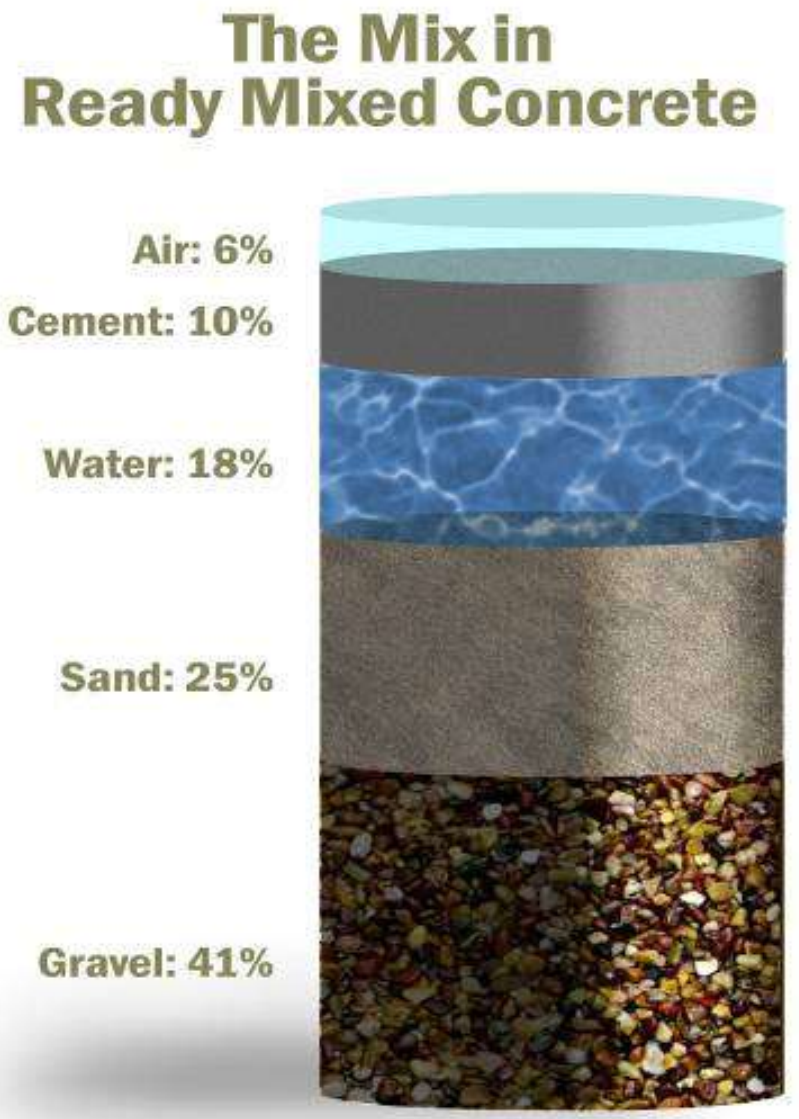
Concrete manufacturing and CO_2 Production

Small percentage of embodied energy (direct and indirect energy through the whole building lifecycle) in concrete

170 to 505 lb (100-300 kg) of embodied CO_2 per cubic yard (cubic meter)

Concrete uses 7 to 15% cement by mass

- This can be reduced with the use of SCMs in concrete mixture designs
- Replacements are based upon durability and performance requirements



SCMs in Concrete

An inorganic material that contributes to the properties of a cementitious mixture through hydraulic or pozzolanic activity, or both.

- **Slag Cement**
- **Fly Ash**
- **Silica Fume**

Property	Class C Ash	Class F Ash	Slag Cement	Silica Fume
Initial Set Time	+	+	+	–
Strength Gain (early)	+	–	–	+
Strength Gain (late)	0	+	+	< >
Setting Time	+	+	+	–
Heat of Hydration	–	–	–	+
Plastic Shrinkage Cracking	< >	< >	< >	+
Permeability	–	–	–	–
ASR Mitigation	< > or 0	+	< > or +	+
Sulfate Attack Mitigation	0	+	< > or +	+

+ indicates increase, – indicates decrease, 0 indicates no change, and < > indicates the effect varies depending upon the characteristics of the SCM or the replacement level

After Kosmatka and Wilson 2011, *Design and Control of Concrete Mixtures: The Guide to Applications, Methods, and Materials*

FHWA 2016

Blend can be complementary in performance!!!

ASTM C125

Energy Savings and CO_2 Emissions Avoidance from Portland Cement Manufacture

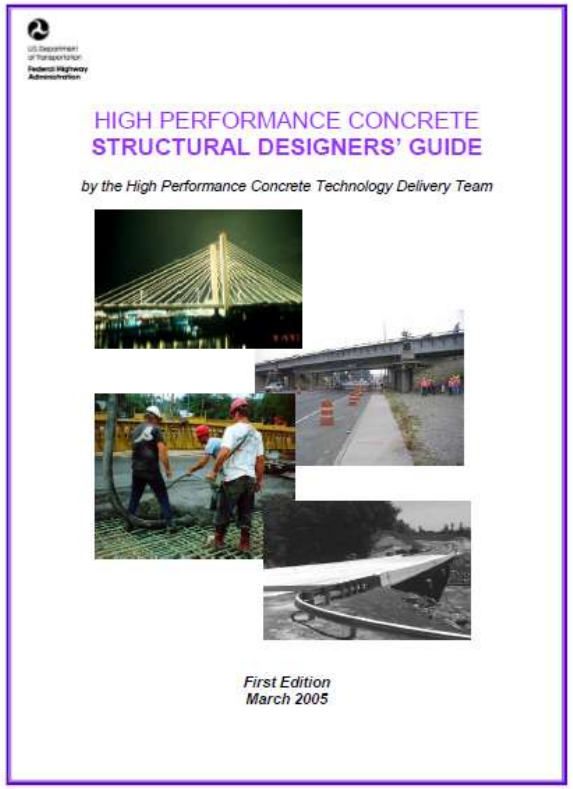
	Concrete industry use of SCMs					
	Silica fume		Slag cement		Fly ash	
Industry-reported use in 2023, MMT	0.9	Emissions avoidance, MMT	4.0	Emissions avoidance, MMT	10.8	Emissions avoidance, MMT
	Emissions avoidance with concrete industry use of SCMs, per metric ton					
Avoided CO_2, metric ton	0.700	0.63	0.669	2.68	0.700	7.56
Avoided NO_x emissions, kg	28.44	0.03	2.02	0.01	2.13	0.02
Avoided SO_x emissions, kg	42.560	0.04	1.61	0.01	1.67	0.02
Avoided CO emissions, kg	2.28	0.00	0.62	0.00	0.65	0.01
	Energy savings with concrete industry use of SCMs, per metric ton					
Energy savings, GJ	32.92	0.03	4.22	0.02	4.70	0.05
Energy savings, 1000 kW/h	9.14	8.23	1.17	4.69	1.30	14.09
Energy savings, USD	$146.29	$131.66	$187.61	$750.42	$208.72	$2254.14

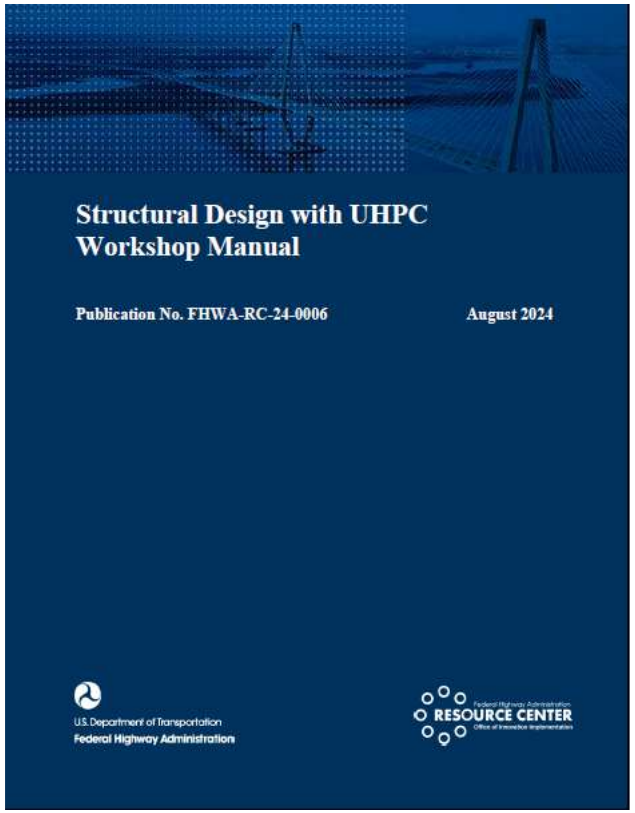
Notes: 1 metric ton = 1.1 short tons; 1.0 GJ/h = 277.8 kW/h; Average kW/h = $0.16 USD in 2023 (EIA 2023). 2023 Industry data from ACAA (2024), Skyway Slag Cement (2024), and Anonymous (2025).

Updated from Buffenbarger 2013

High-Performance & Ultra High-Performance Concrete

- Silica fume can assist in meeting performance and uniformity requirements that cannot always be achieved routinely using conventional constituents and normal mixing, placing, and curing practices.

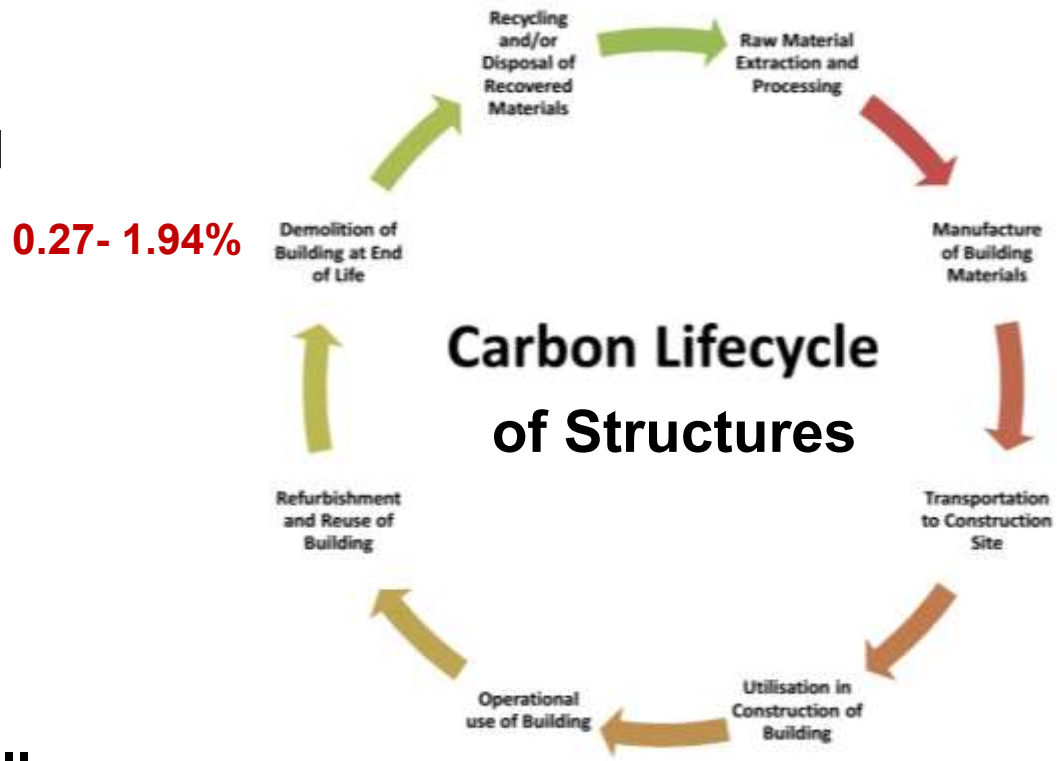




How Silica Fume Impacts the Total Life Cycle of a Structure?

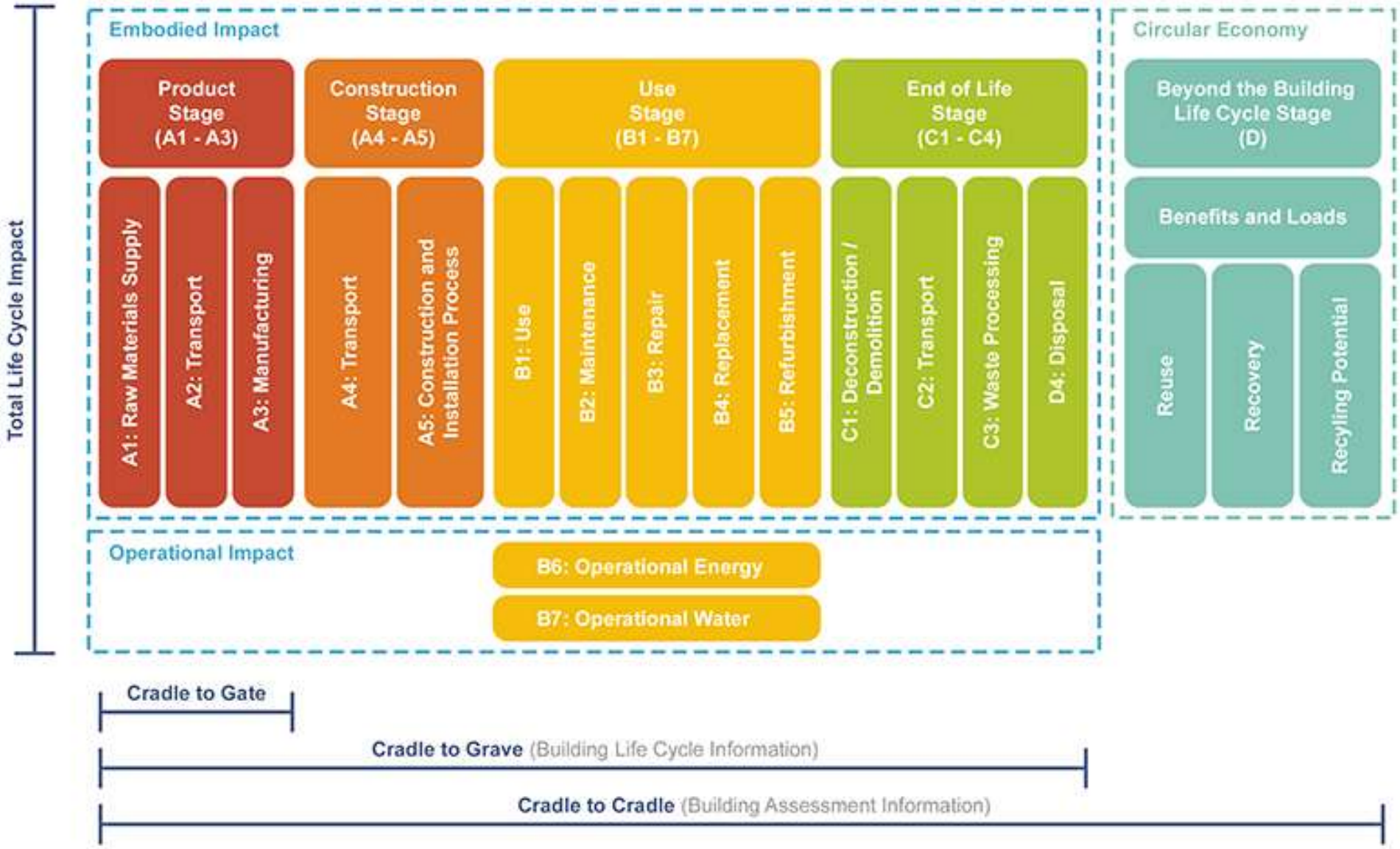
Environmental Burdens from Construction

- **Ecosystem**
  - Degradation of habitats
  - Altered ecosystems
  - Reduction in biodiversity due to land use
- **Embodied Carbon**
  - 10-80 years "pay back" of carbon loading (upfront vs. life cycle)
- **Waste Generation**
  - 1.3 billion tons of construction and demolition waste is generated annually worldwide.
  - Demolition of existing structures produces 90% of construction debris.



Lu & Wang, 2019

Whole Structure Lifecyle



Overbey 2021

BUY CLEAN…..NET ZERO



Net-Zero Emissions Procurement by 2050

+ Launch a Buy Clean initiative for low-carbon materials.

Production of high-volume materials associated with the construction of buildings and infrastructure, especially concrete and steel, is a major source of global GHG emissions. Reducing these emissions, referred to as "embodied" emissions because they are emitted during the manufacture of purchased products, is a critical piece of reducing emissions in the Federal supply chain.

- In February 2022, the Biden Administration launched its Federal Buy Clean Initiative and Task Force that will promote use of construction materials with lower embodied emissions and pollutants across their lifecycle—including each stage of the manufacturing process. Learn more about the Federal Buy Clean Initiative.

Concrete and Steel

The new Buy Clean Executive Order means that from January 1, 2023, the United States federal purchasing agencies are required to obtain EPDs for concrete building materials used on federal projects.

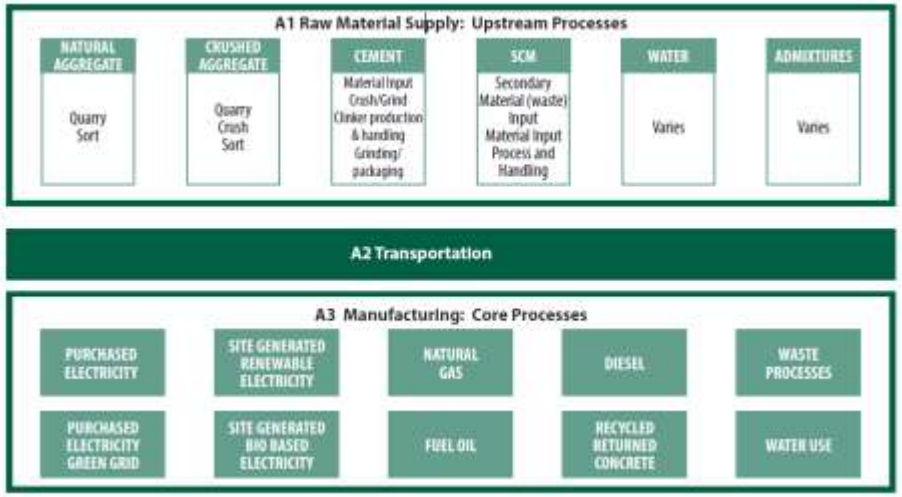
Environmental Product Declarations

An Environmental Product Declaration (EPD) is an independently verified and registered document that transparently reports the life-cycle environmental impact of a product.

An EPD is built upon a Life Cycle Assessment (LCA) and follows international standards ISO 14025, ISO 14040/14044, and EN 15804.

- Carbon footprint (embodied greenhouse gas emissions)
- Resource and energy use (renewable vs. non-renewable)
- Water consumption and water deprivation potential
- Waste generation and emissions to air, water, and soil

What Does an EPD Measure?



Building Life Cycle Information Modules
(x: Included in LCA; mnd: Module Not Declared)

Product stage			Construction Process stage		Use stage							End-of-life stage			
Raw Material supply	Transport	Manufacturing	Transport	Construction/Installation	Use	Maintenance	Repair	Replacement	Refurbishment	Operational Energy Use	Operational Water Use	De-Construction/ Demolition	Transport	Waste processing	Disposal
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4
x	x	x	mnd	mnd	mnd	mnd	mnd	mnd	mnd	mnd	mnd	mnd	mnd	mnd	mnd

What metrics are measured for the manufacturing process?

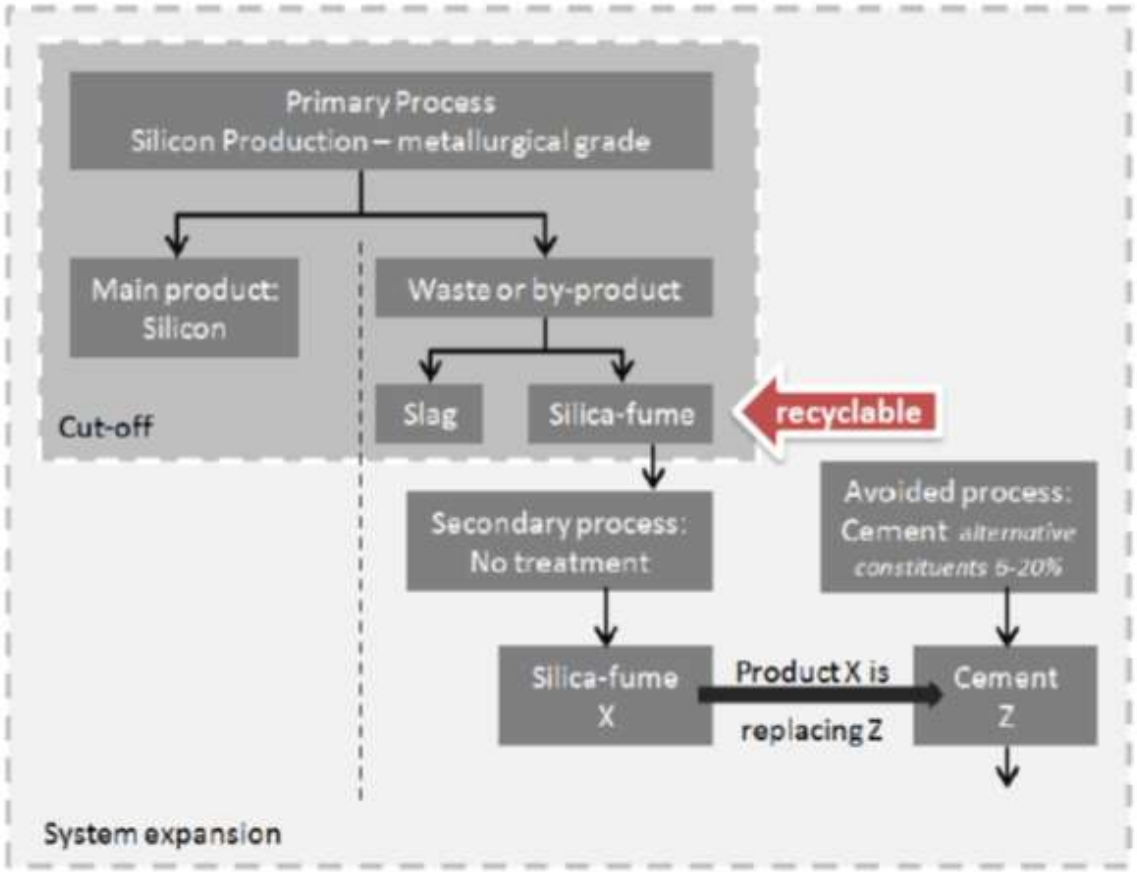
Core Mandatory Impact Indicator	Abbreviation	Unit	Method/Source
Global warming potential	GWP	kg CO2e	TRACI 2.1 V1.02
Depletion potential of the stratospheric ozone layer	ODP	kg CFC11e	TRACI 2.1 V1.02
Acidification potential of soil and water sources	AP	kg SO2e	TRACI 2.1 V1.02
Eutrophication potential	EP	kg Ne	TRACI 2.1 V1.02
Photochemical smog creation potential	POCP	kg O3e	TRACI 2.1 V1.02
Abiotic depletion potential (ADPfossil)*	ADPf	MJ, NCV	CML-IA Baseline V3.02
Abiotic depletion potential (ADPelements)*	ADPe	kg Sbe	CML-IA Baseline V3.02
Use of Primary Resources			
Renewable primary energy carrier used as energy*	RPRE	MJ, NCV	CED V1.10 NCV
Renewable primary energy carrier used as material*	RPRM	MJ, NCV	LCI Indicator
Non-renewable primary energy carrier used as energy*	NRPRE	MJ, NCV	CED V1.10 NCV
Non-renewable primary energy carrier used as material*	NRPRM	MJ, NCV	LCI Indicator

Indicator	Description	Unit	Method / version
GWPT	Global warming potential - total	kg CO2 eq	IPCC AR5, 100-year
GWPF	Global warming potential - fossil	kg CO2 eq	IPCC AR5, 100-year
GWPB	Global warming potential - biogenic	kg CO2 eq	IPCC AR5, 100-year
GWPL*	Global warming potential - land use and land-use change	-	-
ODP	Ozone depletion potential	kg CFC-11 eq	TRACI 2.2
AP	Acidification potential	kg SO2 eq	TRACI 2.2
EPM	Eutrophication potential - marine	kg N eq	TRACI 2.2
EPF	Eutrophication potential - freshwater	kg P eq	TRACI 2.2
SFP	Smog formation potential	kg O3 eq	TRACI 2.2
ADPf	Abiotic depletion potential - fossil resources	MJ	CML-IA baseline / CML 3.1
ADPe*	Abiotic depletion potential - elements	kg Sb eq	CML-IA baseline / CML 3.1; NSF 1112-26 Annex A Table 10 factors for applicable mineral flows
RPRE*	Renewable primary energy used as an energy carrier	MJ	LCI / ISO 21930
RPRM*	Renewable primary resources used as material	MJ	LCI / ISO 21930
NRPRE*	Non-renewable primary energy used as an energy carrier	MJ	LCI / ISO 21930
NRPRM*	Non-renewable primary resources used as material	MJ	LCI / ISO 21930

Newer EPDs

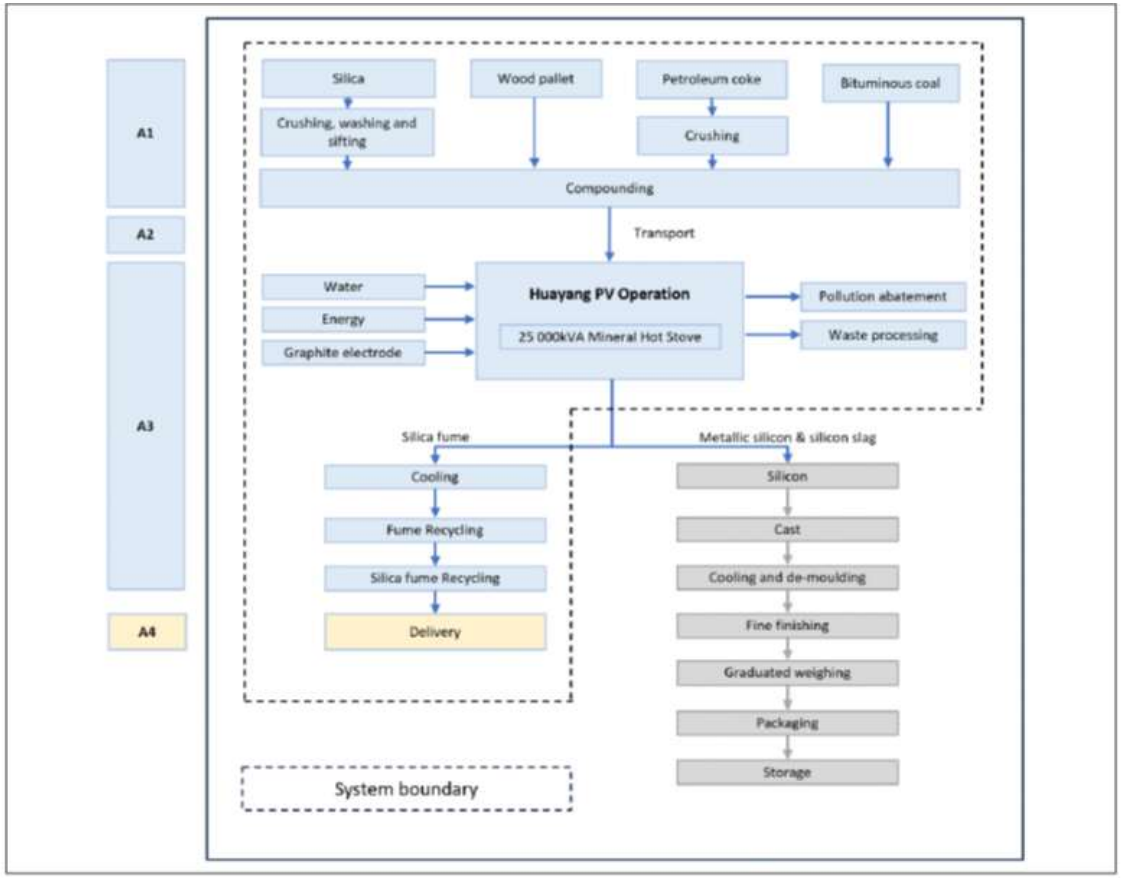
Allocation Method May Vary by Region

North American Allocation



Timm et al. 2019; Habert et al. 2011

Chinese Allocation



Ren 2024

Silica Fume EPDs Differences

Production stage EPD Results: Ferroglobe Production Weighted Average – per metric ton of silica fume

Impact category and inventory indicators	Unit	A1-A3 Total
Global warming potential, GWP 100, AR5	kg CO_2 eq	**52.0**
Ozone depletion potential, ODP	kg CFC-11 eq	**9.6E-6**
Smog formation potential, SFP	kg O_3 eq	**1.9**
Acidification potential, AP	kg SO_2 eq	**0.195**
Eutrophication potential, EP	kg N eq	**0.178**
Abiotic depletion potential for non-fossil mineral resources, ADP elements*	kg Sb eq	**5.6E-5**
Abiotic depletion potential for fossil resources, ADP fossil	MJ surplus LHV	**760.5**
Renewable primary resources used as an energy carrier (fuel), RPR_E*	MJ LHV	**698.7**
Renewable primary resources with energy content used as material, RPR_M*	MJ LHV	**0**
Non-renewable primary resources used as an energy carrier (fuel), $NRPR_E$*	MJ LHV	**1277.4**

North America, Garrahan et al., 2024

Mandatory impact category indicators according to EN 15804+A2:2019

Environmental Impact results per declared unit of 1 tonne of Micro Silica

Indicator	Unit	A1	A2	A3	A1-A3 (Total)	A4
GWP-total	kg CO_2 eq.	5.86E+02	5.55E+01	1.66E+00	6.43E+02	1.10E+01
GWP-fossil	kg CO_2 eq.	5.86E+02	5.52E+01	1.66E+00	6.43E+02	1.05E+01
GWP-biogenic	kg CO_2 eq.	-1.55E-01	2.50E-01	1.12E-03	9.57E-02	4.76E-01
GWP-luluc	kg CO_2 eq.	4.19E-01	3.27E-03	4.28E-05	4.22E-01	6.97E-04
ODP	kg CFC 11 eq.	1.87E-09	4.65E-13	3.68E-13	1.88E-09	1.25E-13
AP	mol H^+ eq.	1.50E+00	9.89E-01	2.26E-02	2.51E+00	1.22E-02
EP-freshwater	kg P eq.	2.13E-04	9.67E-06	1.72E-07	2.23E-04	2.32E-06
EP-marine	kg N eq.	3.41E-01	4.20E-01	3.29E-03	7.63E-01	4.80E-03
EP-terrestrial	mol N eq.	3.71E+00	4.59E+00	3.60E-02	8.34E+00	5.41E-02
POCP	kg NMVOC eq.	1.00E+00	1.15E+00	1.01E-02	2.16E+00	1.31E-02
ADP-minerals & metals*	kg Sb eq.	1.98E-05	1.17E-06	1.16E-08	2.10E-05	2.49E-07
ADP-fossil*	MJ	5.82E+03	6.70E+02	2.39E+01	6.51E+03	1.43E+02
WDP*	m^3	1.28E+02	3.62E-02	5.00E-02	1.28E+02	1.31E-02
Acronyms	GWP-fossil = Global Warming Potential fossil fuels; GWP-biogenic = Global Warming Potential biogenic; GWP-luluc = Global Warming Potential land use and land use change; ODP = Depletion potential of the stratospheric ozone layer; AP = Acidification potential, Accumulated Exceedance; EP-freshwater = Eutrophication potential, fraction of nutrients reaching freshwater end compartment; EP-marine = Eutrophication potential, fraction of nutrients reaching marine end compartment; EP-terrestrial = Eutrophication potential, Accumulated Exceedance; POCP = Formation potential of tropospheric ozone; ADP-minerals&metals = Abiotic depletion potential for non-fossil resources; ADP-fossil = Abiotic depletion for fossil resources potential; WDP = Water (user) deprivation potential, deprivation-weighted water consumption					

Middle East, Envirodec, 2025

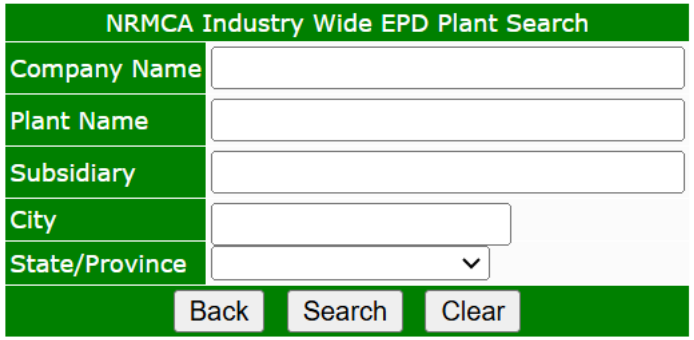
Available EPD Tools for Use – Concrete Specific

Multiple Methods

- NRMCA Industry Average and Regional Tools
  - Serves as the NA Industry Benchmark
  - Did the R/M producer participate in the industry average collection?
- Slag Cement Association - Life Cycle Assessment Tool
  - Free for everyone, just sign up!
    - https://www.slagcement.org/lca-calculator
  - LCA tool that compares to the NRMCA Regional Benchmarks
- Product Specific EPD – Type III
  - Software used by producers
    - Multiple sources of programs – Cost varies to producer $$ to $$$$
    - Time consuming for producers to initiate set up

Table 9b. Summary Results (A1-A3): 4001-5000 psi (27.6-34.5 MPa) RMC product mix design per cubic yard											
		Minimum	Maximum	4001-5000-00-FA/SL	4001-5000-20-FA	4001-5000-30-FA	4001-5000-40-FA	4001-5000-30-SL	4001-5000-40-SL	4001-5000-50-SL	4001-5000-50-FA/SL
Core Mandatory Impact Indicator											
GWP	kg CO2e	220.27	358.49	358.49	306.62	278.58	248.98	276.52	249.19	221.81	220.27
ODP	kg CFC11e	6.21E-06	9.26E-06	8.74E-06	7.54E-06	6.90E-06	6.21E-06	9.05E-06	9.15E-06	9.26E-06	7.87E-06
AP	kg SO2e	0.78	1.05	1.02	0.91	0.85	0.78	1.04	1.04	1.05	0.93
EP	kg Ne	0.29	0.43	0.43	0.37	0.34	0.30	0.35	0.33	0.30	0.29
SFP	kg O3e	17.09	22.32	21.86	19.60	18.38	17.09	22.14	22.23	22.32	19.89
ADPf	MJ, NCV	489.86	557.53	557.53	525.46	508.31	489.86	534.40	526.69	517.84	499.80
ADPe	kg Sbe	1.18E-04	1.45E-04	1.45E-04	1.33E-04	1.26E-04	1.18E-04	1.32E-04	1.28E-04	1.23E-04	1.19E-04
Use of Primary Resources											
RPRE	MJ, NCV	12.09	22.00	12.61	12.36	12.24	12.09	18.27	20.16	22.00	18.27
RPRM	MJ, NCV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NRPRE	MJ, NCV	1,472.42	1,978.06	1,978.06	1,738.53	1,609.25	1,472.42	1,770.60	1,701.45	1,631.09	1,518.77
NRPRM	MJ, NCV	0.00	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	0.00
RSF	MJ, NCV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NRSF	MJ, NCV	91.25	182.50	182.50	153.69	138.11	121.67	127.75	109.50	91.25	96.05
RE	MJ, NCV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mandatory Inventory Parameters											
FW	m3	0.49	0.64	0.64	0.58	0.55	0.51	0.55	0.52	0.50	0.49
CCE	kg CO2e	83.75	167.50	167.50	141.05	126.75	111.66	117.25	100.50	83.75	88.16
Indicators Describing Waste											
HWD	kg	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
NHWD	kg	7.37	7.37	7.37	7.37	7.37	7.37	7.37	7.37	7.37	7.37
HLRW	m3	1.58E-08	5.83E-08	1.65E-08	1.62E-08	1.60E-08	1.58E-08	4.16E-08	5.00E-08	5.83E-08	4.26E-08
LLRW	m3	2.09E-07	1.51E-06	2.22E-07	2.16E-07	2.12E-07	2.09E-07	9.96E-07	1.25E-06	1.51E-06	1.03E-06
CRU	kg	0.00	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	0.00
MER	kg	0.00	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	0.00

NRMCA

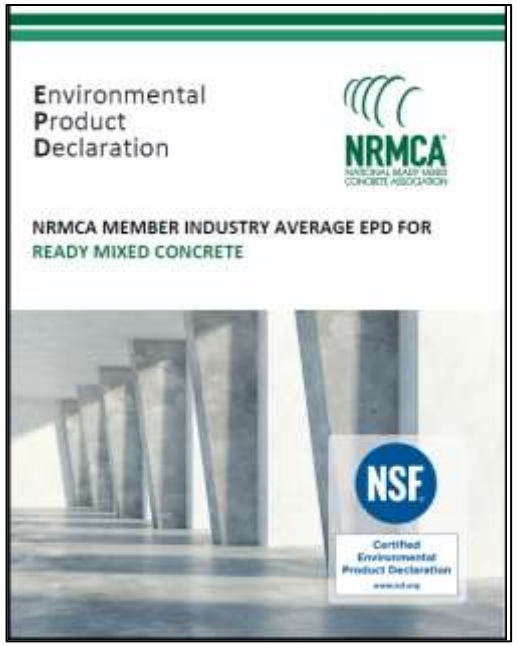


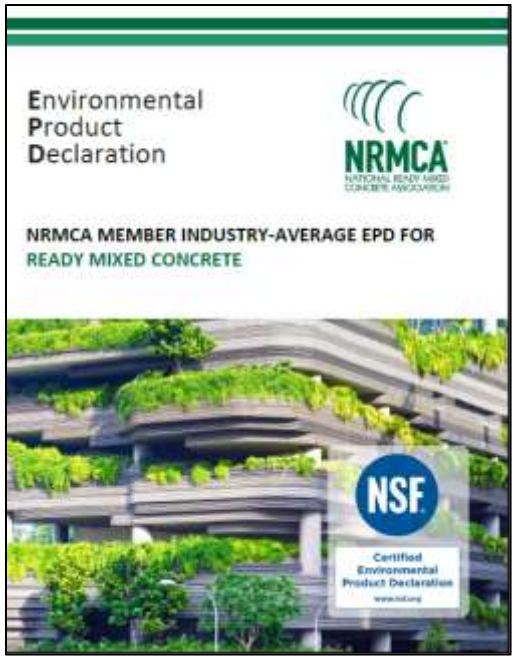
https://www.nrmca.org/association-resources/sustainability/environmental-product-declarations/edpd-program-search/

- **Limited SCMs**
- **Limited Admixtures**
- **Units are important !**
  - **1 yd^3 = 1.3 m^3**

GWP Baselines are Changing

- In practice, as baselines mature, the GWP values also become lower.
- Reductions from baseline will require a higher replacement rate of SCMs in concrete mixtures.
- Silica fume enables a greater replacement of slag cement and fly ash, as it enhances the reactivity of concretes.
  - Enables constructability schedules to be met.





NRMCA Regional Baseline 4000 PSI (27.6 MPa)			
	per yd^3		per m^3
2020	327.04		427.75
2021	293.28		383.60
2026 NA	200.26		260.34
2026 AEA	222.16		288.81



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SCA Tool

Adjust Slag Cement %

Select Mix to Adjust

Select Region

Slag Cement %
35%

Region
Great Lakes Midwest

Concrete Mix

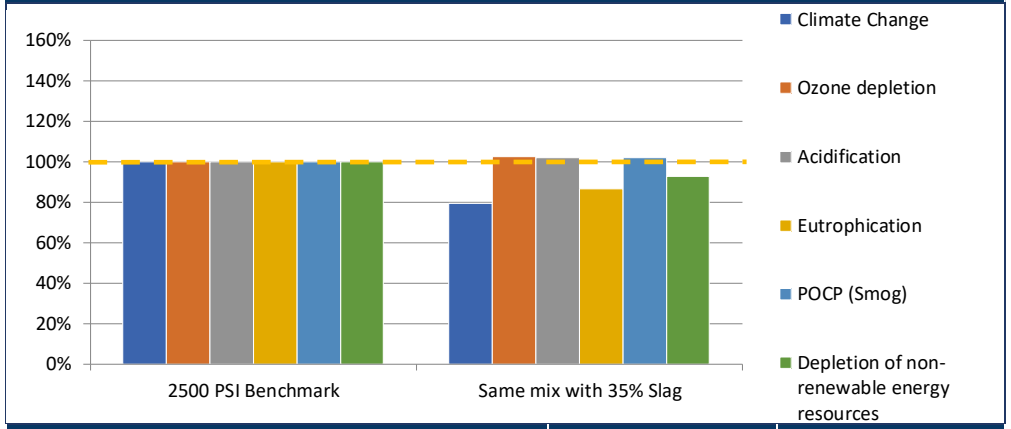
Mix ID	2500 PSI Benchmark	Same mix with 35% Slag
Slag Cement (%)	7%	35%
Strength (psi)	2500	2500
Portland Cement (lb)	341	237
Portland Limestone Cement (lb)	0	0
Masonry Cement (lb)	0	0
Slag Cement (lb)	24	128
Fly Ash (lb)	39	39
Crushed Coarse Aggregate (lb)	1517	1517
Natural Coarse Aggregate (lb)	245	245
Crushed Fine Aggregate (lb)	14	14
Natural Fine Aggregate (lb)	1460	1460
Manufactured Lightweight Aggregate (lb)	0	0
Accelerating Admixture-Chlorides (oz)	25	25
Air Entraining Admixture (oz)	1	1
Water Reducing Admixture - plasticizer (oz)	3	3
High Range Water Reducing Admixture - superplasticizer (oz)	0	0
Water (gal)	32	32

Additional Mix Options

Crushed Demolition Concrete (lb)	0	0
Crushed Returned Concrete (lb)	0	0
Fly Ash (processed) (lb)	0	0
Mineral Fillers (lb)	0	0
Road Dust Control Chemicals (lb)	0	0
Silica Fume (no processing) (lb)	0	0
Steel Fibers (lb)	0	0
Synthetic Fibers (lb)	0	0
Accelerating Admixture-Non Chlorides (oz)	0	0
Corrosion Inhibiting Admixture (oz)	0	0
Shrinkage Reducing Admixture (oz)	0	0
Water Retarding Admixture (oz)	0	0
Waterproofing Admixture (oz)	0	0

LCA is created

Comparison to Strength Class Benchmark



Mix ID	2500 PSI Benchmark	Same mix with 35% Slag
Strength (PSI) of Relevant Benchmark	2500	2500
Climate Change	100%	79%
Ozone depletion	100%	103%
Acidification	100%	102%
Eutrophication	100%	87%
POCP (Smog)	100%	102%
Depletion of non-renewable energy resources	100%	93%

Life Cycle Assessment Results

Mix ID	2500 PSI Benchmark	Same mix with 35% Slag
Climate Change (kg CO2-eq)	177.43	141.00
Ozone depletion (kg CFC-11-eq)	5.17E-06	5.31E-06
Acidification (kg SO2-eq)	0.58	0.59
Eutrophication (kg N-eq)	0.24	0.21
Photochemical Ozone Creation/Smog (kg O3-eq)	11.43	11.63
Abiotic Depletion Potential ADPf (MJ)	348.14	342.59
Abiotic Depletion Potential ADPe (kg Sb eq.)	0.00	0.00
Use of renewable primary energy (MJ)	8.19	10.69
Use of non-renewable primary energy (MJ)	1,176.45	1,088.57
Fresh water consumption (m3)	0.36	0.32

SCA Calculator

Ready Mixed Concrete LCA Calculator for Slag Cement - Version 3.0

Athena Sustainable Materials Institute

Enter Data for Custom Mixes on a per yd3 basis

Concrete Mix (per yd3)	
Mix ID	Girders
Strength for Benchmarking (psi)	5000
Portland Cement (lb)	
Portland Limestone Cement (lb)	355
Masonry Cement (lb)	
Slag Cement (lb)	266
Fly Ash (lb)	
Crushed Coarse Aggregate (lb)	1760
Natural Coarse Aggregate (lb)	
Crushed Fine Aggregate (lb)	1090
Natural Fine Aggregate (lb)	
Manufactured Lightweight Aggregate (lb)	
Accelerating Admixture-Chlorides (oz)	
Air Entraining Admixture (oz)	14
Water Reducing Admixture - plasticizer (oz)	33
High Range Water Reducing Admixture - superplasticizer (oz)	
Water (gal)	34.00

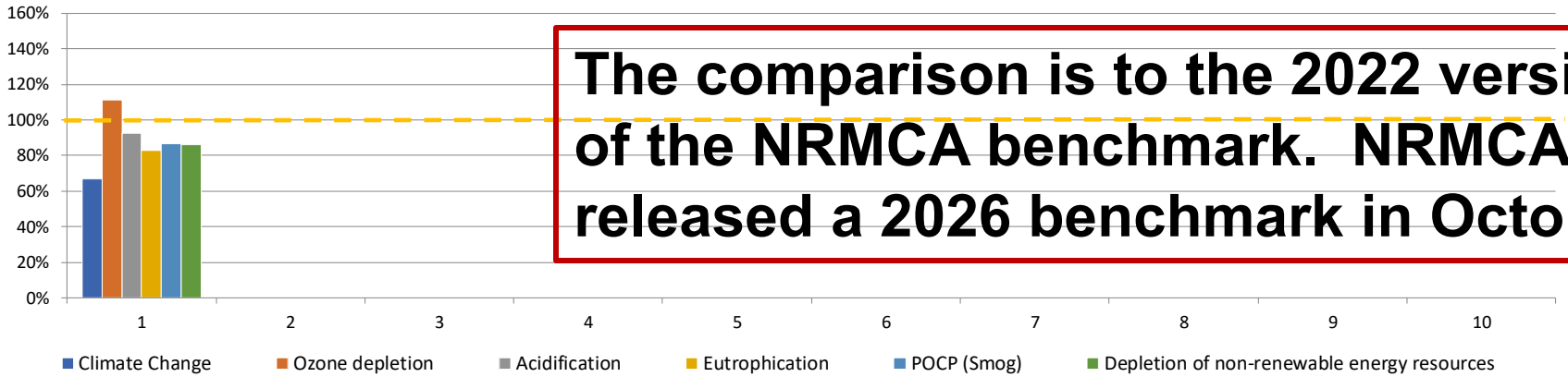
Better interface when accounting for bridge mixtures containing silica fume, corrosion inhibitors, accelerators, fibers, etc.

Additional Mix Options	
Crushed Demolition Concrete (lb)	
Crushed Returned Concrete (lb)	
Mineral Fillers (lb)	
Silica Fume (no processing) (lb)	39
Steel Fibers (lb)	
Synthetic Fibers (lb)	
Accelerating Admixture-Non Chlorides (oz)	
Corrosion Inhibiting Admixture (oz)	
Shrinkage Reducing Admixture (oz)	
Water Retarding Admixture (oz)	
Waterproofing Admixture (oz)	

Ready Mixed Concrete LCA Calculator for Slag Cement - Version 3.0

Athena Sustainable Materials Institute

Comparison of Entered Mixes to Strength Class Benchmarks



The comparison is to the 2022 version of the NRMCA benchmark. NRMCA released a 2026 benchmark in October

Mix in Graph	1	2	3	4	5	6	7	8	9	10
Mix ID	Girders									
Strength (PSI) of Relevant Benchmark	5000									
Climate Change	67%									
Ozone depletion	111%									
Acidification	93%									
Eutrophication	83%									
POCP (Smog)	87%									
Depletion of non-renewable energy resources	86%									

Life Cycle Assessment Results

Mix ID	Girders
Climate Change (kg CO2-eq)	186.10
Ozone depletion (kg CFC-11-eq)	8.32E-06
Acidification (kg SO2-eq)	0.74
Eutrophication (kg N-eq)	0.29
Photochemical Ozone Creation/Smog (kg O3-eq)	13.66
Abiotic Depletion Potential ADPf (MJ)	328.16
Abiotic Depletion Potential ADPe (kg Sb eq.)	1.74E-04
Use of renewable primary energy (MJ)	37.61
Use of non-renewable primary energy (MJ)	1,404.82
Fresh water consumption (m3)	0.41

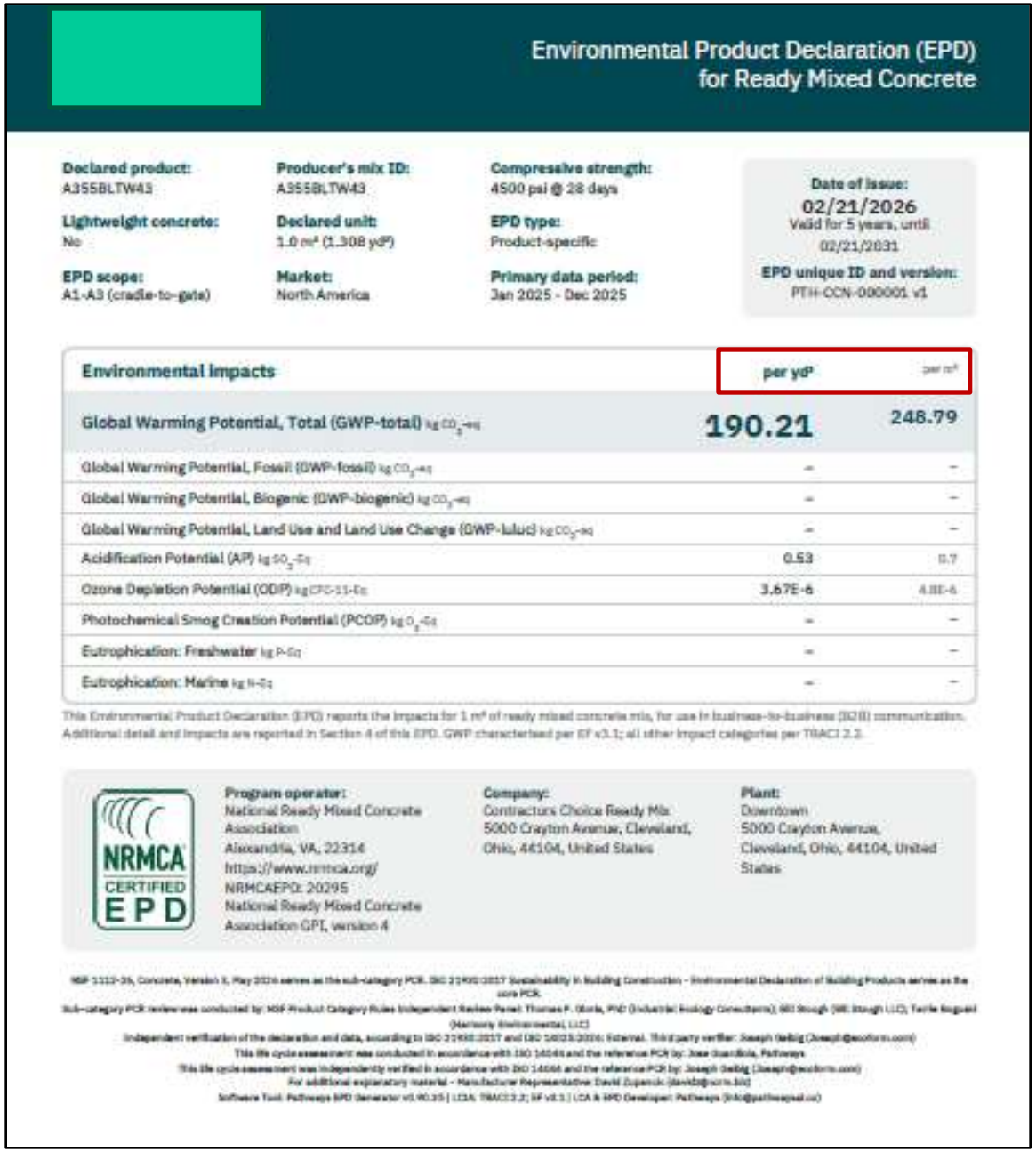
The numbers are still valid for use pertaining to the mixture.

EPD is Generated from Concrete Mixtures

- Very similar to the SCA - LCA calculations
- Producer Information may vary from region to region.

e.g., EPDs from North America vs. other world regions

1. A1 - A3 vs. A1 – A4
2. Allocation method



Environmental Product Declaration (EPD)
for Ready Mixed Concrete

Declared product: A355BLTW43
Producer's mix ID: A355BLTW43
Compressive strength: 4500 psi @ 28 days
Lightweight concrete: No
Declared unit: 1.0 m³ (1.308 yd³)
EPD type: Product-specific
EPD scope: A1-A3 (cradle-to-gate)
Market: North America
Primary data period: Jan 2025 - Dec 2025
Date of issue: 02/21/2026
Valid for 5 years, until 02/21/2031
EPD unique ID and version: PTH-CCN-000001 v1

Environmental impacts	per yd³	per m³
Global Warming Potential, Total (GWP-total) kg CO_2-eq	190.21	248.79
Global Warming Potential, Fossil (GWP-fossil) kg CO_2-eq	-	-
Global Warming Potential, Biogenic (GWP-biogenic) kg CO_2-eq	-	-
Global Warming Potential, Land Use and Land Use Change (GWP-luluc) kg CO_2-eq	-	-
Acidification Potential (AP) kg SO_2-Eq	0.53	0.7
Ozone Depletion Potential (ODP) kg CFC-11-Eq	3.67E-6	4.8E-6
Photochemical Smog Creation Potential (PCOP) kg O_3-Eq	-	-
Eutrophication: Freshwater kg P-Eq	-	-
Eutrophication: Marine kg N-Eq	-	-

This Environmental Product Declaration (EPD) reports the impacts for 1 m³ of ready mixed concrete mix, for use in business-to-business (B2B) communication. Additional detail and impacts are reported in Section 4 of this EPD. GWP characterised per EF v3.1; all other impact categories per TRACI 2.2.

NRMCA CERTIFIED EPD

Program operator:
National Ready Mixed Concrete Association
Alexandria, VA, 22314
https://www.nrmca.org/
NRMCAEPD: 20295
National Ready Mixed Concrete Association GPI, version 4

Company:
Contractors Choice Ready Mix
5000 Crayton Avenue, Cleveland, Ohio, 44104, United States

Plant:
Downtown
5000 Crayton Avenue, Cleveland, Ohio, 44104, United States

NSF 1113-24, Concrete, Version 1, May 2024 serves as the sub-category PCR. ISO 21930:2017 Sustainability in Building Construction – Environmental Declaration of Building Products serves as the core PCR.
Sub-category PCR review was conducted by: NSF Product Category Rules Independent Review Panel: Thomas P. Gloria, PhD (Industrial Ecology Consultants); Bill Stough (Bill Stough LLC); Tarik Bogard (Harmony Environmental, LLC)
Independent verification of the declaration and data, according to ISO 21930:2017 and ISO 14025:2006: External. Third party verifier: Joseph Gelbig (Joseph@ecoform.com)
This life cycle assessment was conducted in accordance with ISO 14044 and the reference PCR by: Jose Guardiola, Pathways
This life cycle assessment was independently verified in accordance with ISO 14044 and the reference PCR by: Joseph Gelbig (Joseph@ecoform.com)
For additional explanatory material – Manufacturer Representative: David Zupancic (david@ucrm.biz)
Software Tool: Pathways EPD Generator v0.90.25 | LCIA: TRACI 2.2; EF v3.1 | LCA & EPD Developer: Pathways (info@pathwaysal.co)

GWP Values and Benchmarks

What benchmark is used for comparison?

Concrete Vendor:	Dauch Concrete
Project Region:	Great Lakes
NRMCA Region	E3
Date:	11.9.26
Comments:	

= INPUTS NEEDED

LOW CARBON CONCRETE CALCULATOR

	strength	NRMCA 2020 Regional Baseline GWP	Proposed GWP	Proposed Cost	Quantities	Baseline GWP	Option #1 GWP	Option #1 Savings	Option #1 GWP Savings
units:	psi	kgCO2e/yd^3	kgCO2e/yd^3	$/yd3	yd^3	tCO2e	tCO2e	tCO2e	%
CONCRETE: FOUNDATIONS		-				0	0	0	-
CONCRETE: TILT-UP WALL PANELS		-				0	0	0	-
CONCRETE: SLAB ON GRADE		-				0	0	0	-
CONCRETE: SLAB ON METAL DECK		-				0	0	0	-
CONCRETE: EQUIPMENT PADS		-				0	0	0	-
CONCRETE: DUCT BANKS (BELOW GROUND)		-				0	0	0	-
CONCRETE: SIDEWALKS & PAVEMENTS	4,000	258	189	$ 150	**1,100**	283	208	76	27%
CONCRETE: OTHER CONCRETE ELEMENTS		-				0	0	0	-
CONCRETE: OTHER CONCRETE ELEMENTS		-				0	0	0	-
					1,100	**283**	**208**	**76**	**27%**

Target>35% ↑

Targets must be realistic for durability classification and constructability

Reduction of Overdesign in Concrete Mixtures

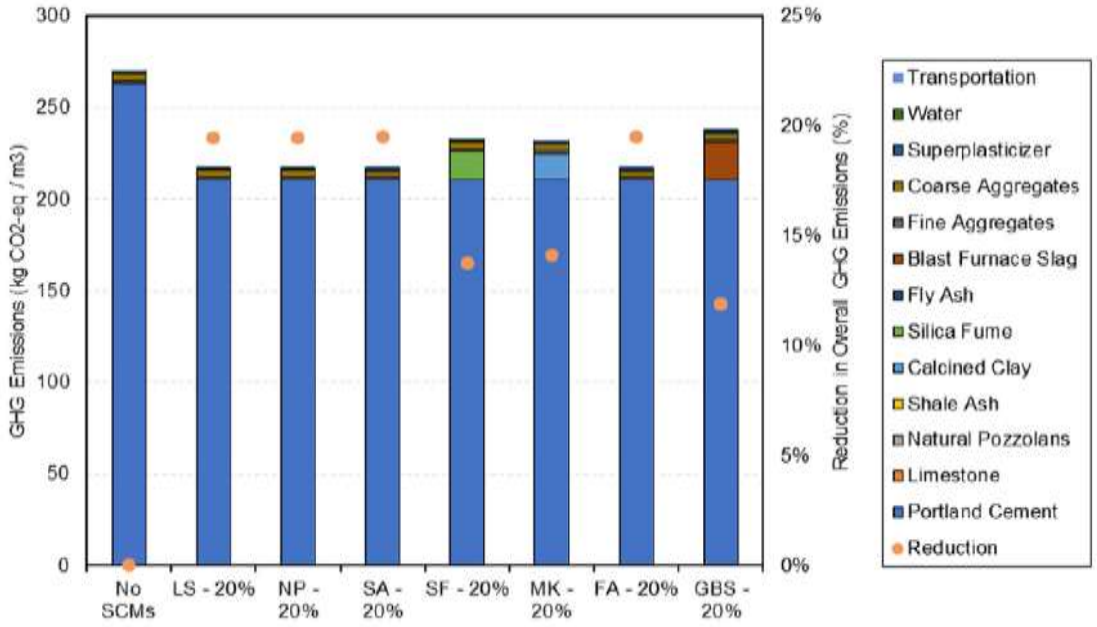
PRODUCTION: AT THE CEMENT PLANT	
Replace raw materials with decarbonated materials	Using decarbonated materials eliminates CO_2 emissions from processing traditional raw materials, like limestone.
Use alternative fuels	Replacing traditional fossil fuels with biomass and waste-derived fuels lowers GHG emissions and keeps materials out of landfills.
Continue efficiency improvements	Increasing energy efficiency reduces the amount of CO_2 emitted for each ton of product.
Implement carbon capture, utilization, and storage (CCUS) technology	CCUS directly avoids a significant portion of cement manufacturing emissions.
Promote new cement mixes	Creating new cements using existing and even alternative materials reduces emissions from mining for new materials, while optimizing the amount of clinker used ensures emissions correspond to necessary production.
Increase use of portland-limestone cement (PLC)	As an existing lower-carbon blend, universal acceptance of PLC will reduce clinker consumption and decrease emissions.
CONSTRUCTION: DESIGNING AND BUILDING	
Optimize concrete mixes	Considering the specific needs of the construction project and using only the materials necessary, avoiding excess emissions.
Use renewable fuels	Switching to solar, wind and other renewable sources of energy directly reduces emissions from other energy sources.
Increase the use of recycled materials	Diverting these materials from landfills.
Avoid overdesign and leverage construction technologies	Designing for the specific needs of the construction project reduces unnecessary overproduction and emissions; incorporating just-in-time deliveries.
Educate design and construction community	Improve design and specifications to be more performance oriented which will permit innovation in cement and concrete manufacturing. Encourage the use of advanced technologies to improve structural performance, energy efficiency, resiliency and carbon sequestration.
EVERYDAY: CONCRETE INFRASTRUCTURE IN USE	
Incentivize energy efficient buildings	Increasing buildings' energy efficiency can cut energy use and resulting emissions from heating and cooling.
Reduce vehicle emissions by improving fuel efficiency	Because of its rigidity, concrete pavements enhance the fuel efficiency of vehicles driving over them, reducing vehicle emissions.
Decreased maintenance	Due to their durability, concrete structures (buildings, pavements, bridges, dams, etc.) last longer and require less frequent maintenance.
Recycling	Concrete in place can be 100% recycled, limiting the use of raw materials and production emissions.
Carbonation	Every exposed concrete surface absorbs CO_2 and over the course of its service life, a building can reabsorb 10% of cement and concrete production emissions.

PCA Roadmap to Carbon Neutrality, 2021

- Conservatively 5% of the cement included in a concrete mixture design hedges against the stated prescriptive specifications, contractor practices, and testing agency issues.
- Industry averages approximate the overdesign of concrete between 30 to 36%, which is 20% greater than necessary to ensure compressive strength test results meet the required specified values (Obla, 2014.)
- For 2020 ready-mixed concrete production, an additional 7.0 million metric tons of portland cement consumed, equivalent to 6.7% of the total 103 million metric tons of cement consumed during the period (Buffenbarger et.al., 2023).
- Silica fume addition to concrete can mitigate strength loss while increasing durability, even with reduced cement content.

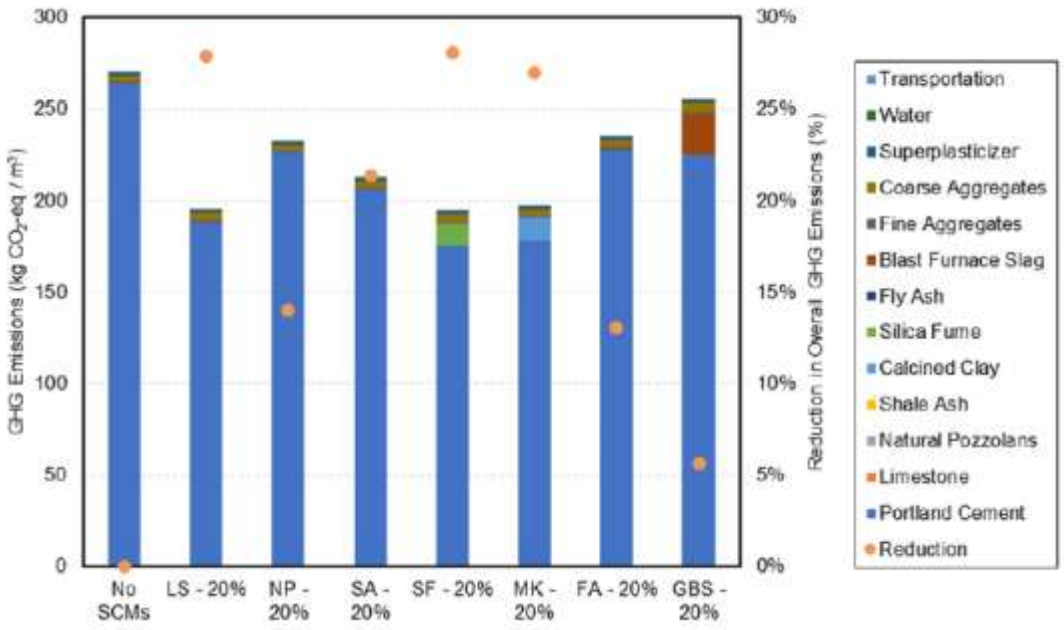
Comparison of GHG Emissions

Same cementitious content with 20% replacement



12-20% reduction with fly ash and shale ash showing the most significant reductions to OPC

20% replacement with constant strength, 4350 psi (30 MPa)



6-28% reduction with limestone and silica fume showing the most significant reductions to OPC

Knight et al. 2023

Silica Fume and Constructability



- Silica fume can facilitate the pumping and consolidation of plastic concrete without segregation.
- The reduction of plastic viscosity of HPC made with silica fume can enhance the flow rate or reduce pressure loss during pumping.
- Silica fume can reduce time of setting and enhance the construction process by allowing quicker form jumping, etc.



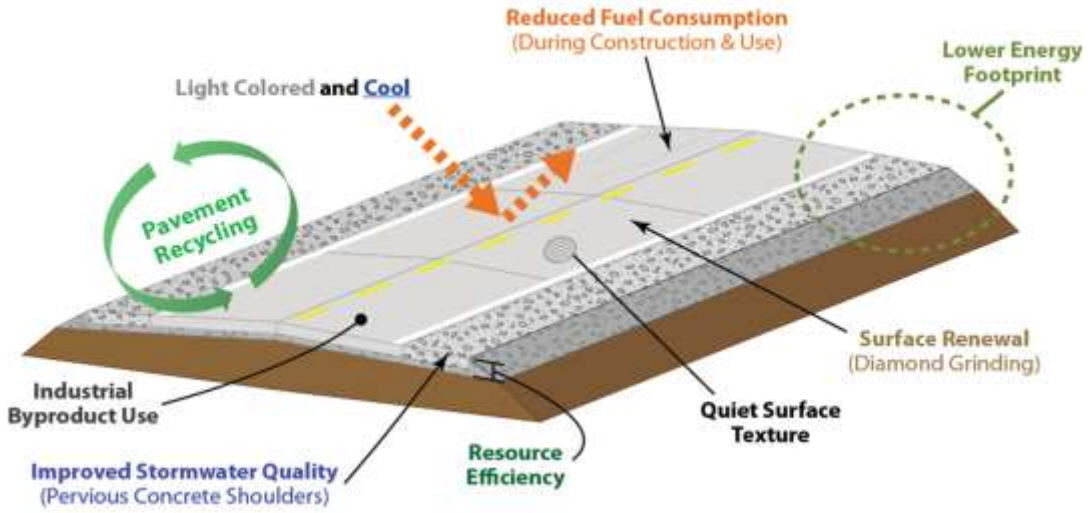


Sustainable & Resilient Applications with Silica Fume

- UHPC
- Precast Segments
- Pervious Pavements
- SCC







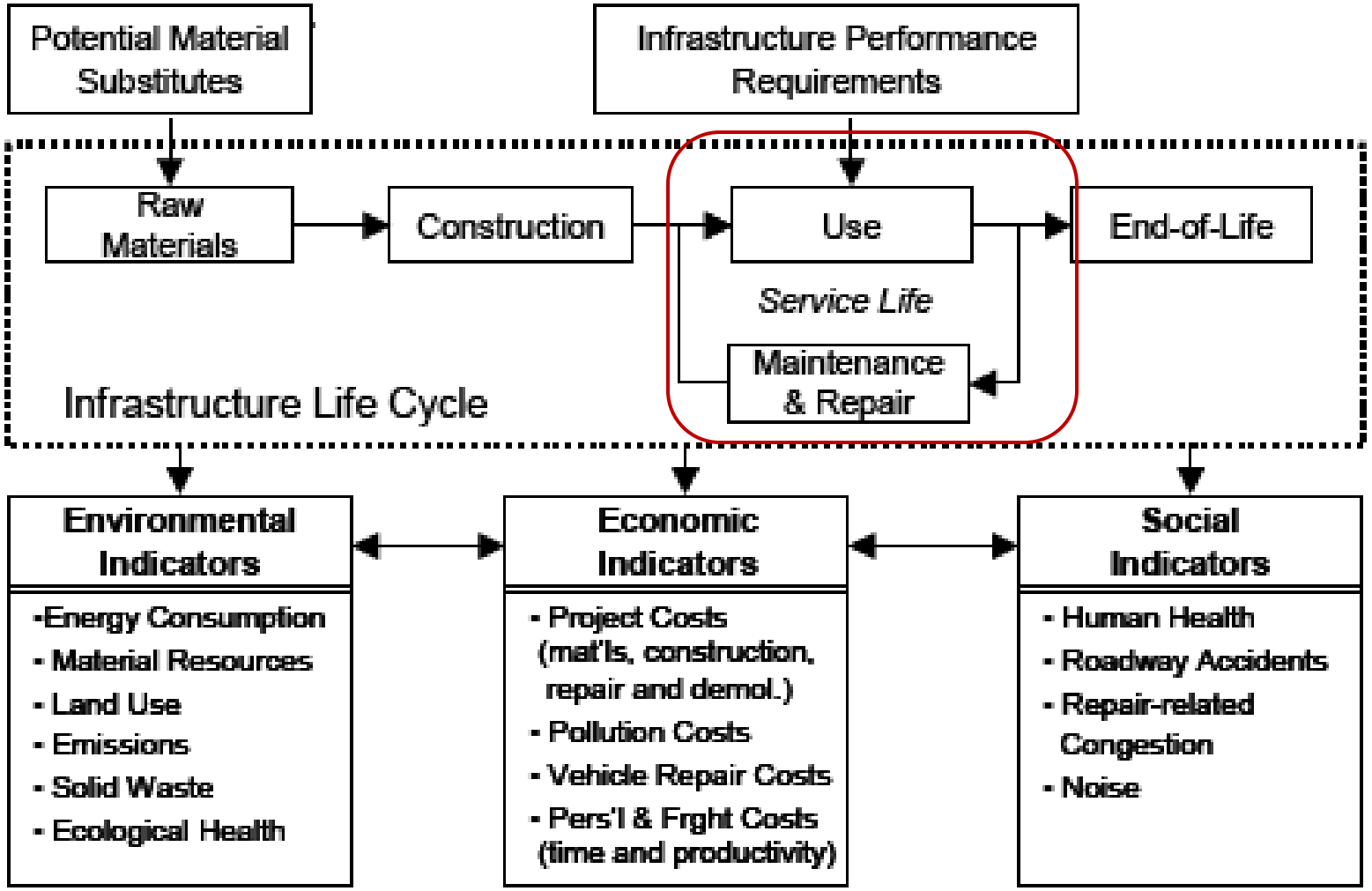
Silica Fume and the Use Stage



- **Significantly reduces the impact of GWP (non-renewable energy consumed to maintain, repair, restore, refurbish or replace materials, components or systems) during the structure's life span.**

- **GWP is heavily influenced by the durability and maintenance of construction materials, systems and components installed in the structure, and the life span of the structure.**

Infrastructure Life Cycle



* University of Michigan. 2006. Sustainable Concrete and Infrastructure Systems.

Durability

- Durability refers to the ability of concrete to maintain its integrity in service over a planned period without cost of maintenance.
- Durable materials remain useful for longer periods of time, reducing:
  - Environmental impacts of component/whole replacement (waste, manufacturing, deconstruction debris)
- The increase in service life of the infrastructure is a very efficient way to increase the eco-efficiency of the economy.

  (Division of the total environmental load cradle-to-grave basis by its service life.)



Confederation Bridge

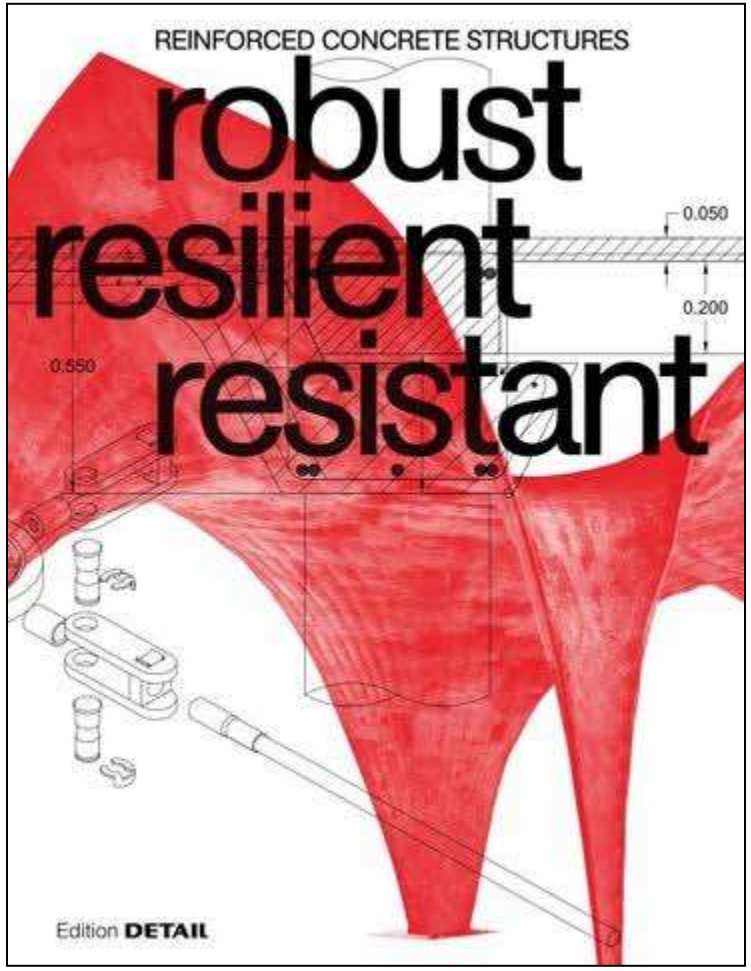
Service Life of Concrete

- The service life and utility of concrete is strongly dependent upon its transport properties (i.e., permeability, sorptivity and chloride permeability).

- The ingress of potentially deleterious materials such as chlorides, sulfates and water by diffusion and capillary transport can lead to the corrosion of steel reinforcement or a reduction of strength due to cracking by frost or sulfate attack.



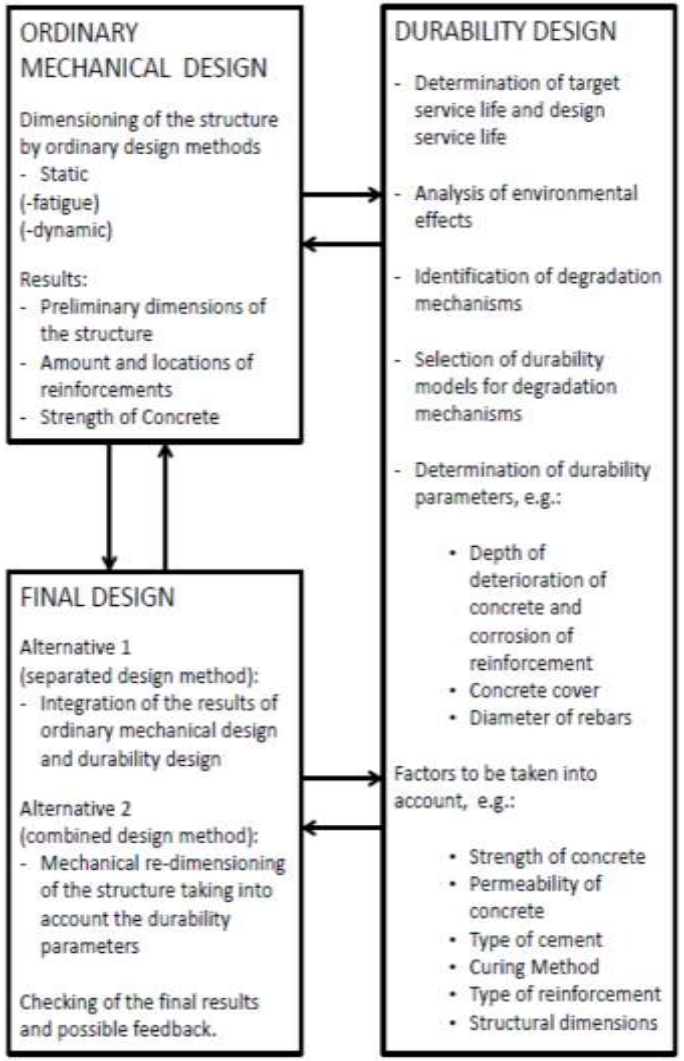
Robustness



The ability of a structure to withstand events such as fire, explosions, impact, or the consequences of human error without collapsing or being damaged or distressed to an extent disproportionate to the original cause/ local damage.

Design Strategies for Implementation

- **Maximized Service Life**
- **Durability and Robustness**
  - Mechanical and Environmental Loading
  - **Anticipated Deterioration Mechanisms**
  - Durability Risks
    - Present
    - Future
- **Hazard Risks**
  - Natural and Manmade



Sarja, 2000

Design for Extreme Loadings

HAZARD	ROUTINE	DESIGN	EXTREME
GROUND SNOW	50 YEAR MRI OR 64% IN 50 YEARS	300 TO 500 YEAR MRI[1] OR 15 TO 10% IN 50 YEARS	TBD[4]
RAIN	LOCALLY DETERMINED[2]	LOCALLY DETERMINED[2]	LOCALLY DETERMINED[2]
WIND- NON-HURRICANE	50 TO 100 YEAR MRI OR 64 TO 39% IN 50 YEARS	700 YEAR MRI OR 7% IN 50 YEAR	1,700 YEAR MRI[3] OR 3% IN 50 YEARS
WIND - HURRICANE	50 TO 100 YEAR MRI OR 64 TO 39% IN 50 YEARS	700 YEAR MRI OR 7% IN 50 YEAR	1,700 YEAR MRI[3] OR 3% IN 50 YEARS
WIND - TORNADO	LOCALLY DETERMINED[3]	LOCALLY DETERMINED[3]	LOCALLY DETERMINED[3]
EARTHQUAKE	50 YEAR MRI OR 64% IN 50 YEARS	50 YEAR MRI OR 10% IN 50 YEARS	2,500 YEAR MRI OR 2% IN 50 YEARS
TSUNAMI	LOCALLY DETERMINED[3]	LOCALLY DETERMINED[3]	LOCALLY DETERMINED[3]
FLOOD	LOCALLY DETERMINED	100 TO 500 YEARS MRI OR 39 TO 10% IN 50 YEARS	LOCALLY DETERMINED
FIRE- WILDFIRE	LOCALLY DETERMINED[4]	LOCALLY DETERMINED[4]	LOCALLY DETERMINED[4]
FIRE- URBAN/MANMADE	LOCALLY DETERMINED[4]	LOCALLY DETERMINED[4]	LOCALLY DETERMINED[4]
BLAST/ TERRORISM	LOCALLY DETERMINED[5]	LOCALLY DETERMINED[5]	LOCALLY DETERMINED[5]

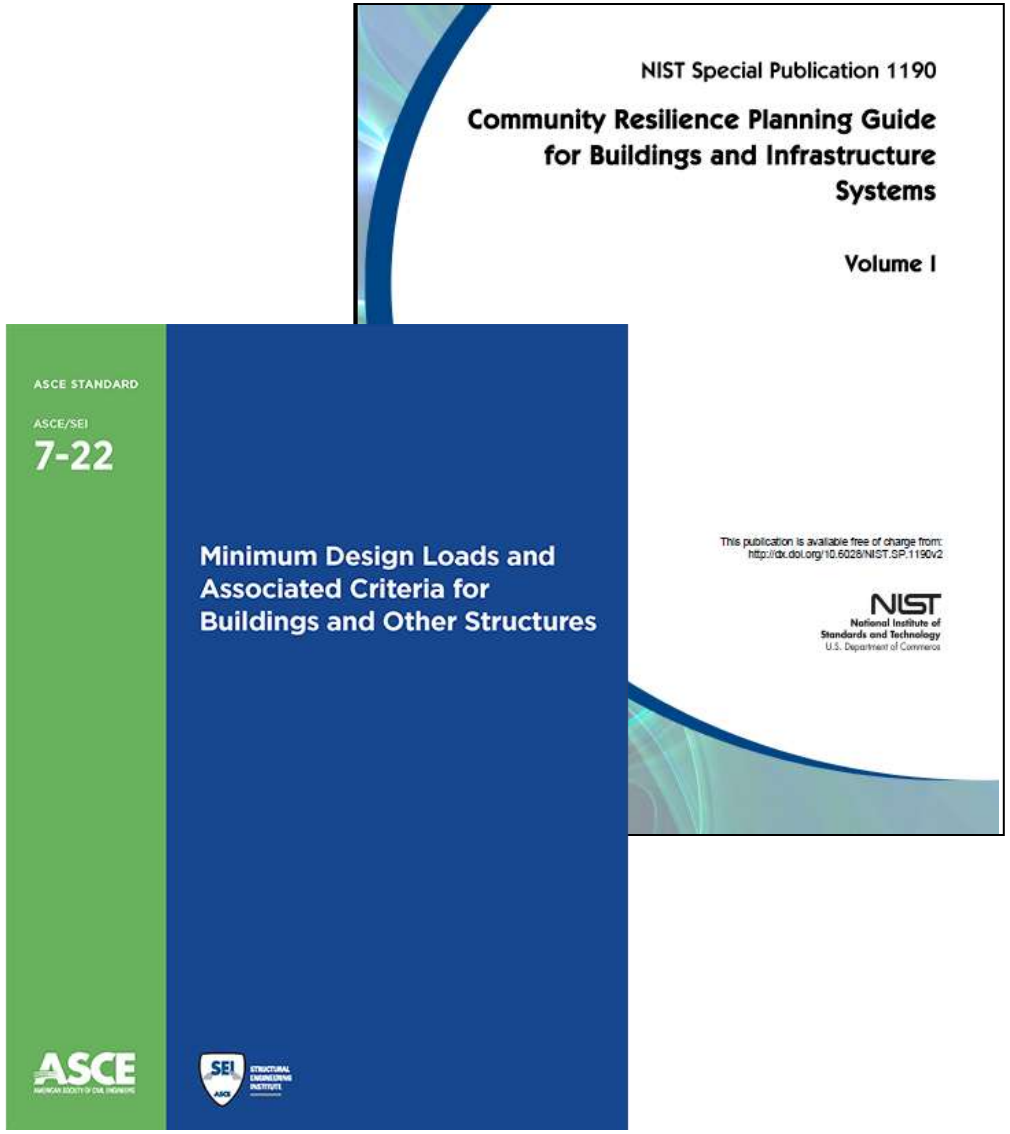
[1]For the Northeast, 1.6 (the Load and Resistance Factor Design (LRFD) factor on snow load) times the 50-year ground snow load is equivalent to the 300 to 500 year snow load.

[2] Rain is designed by rainfall intensity of inches per hour or mm/h, as specified by the local code.

[3]Tornado and tsunami loads are not addressed in ASCE 7-10. Tornadoes are presently classified by the EF scale. See FEMA 361 [2015] for tornado EF-scale wind speeds.

[4]Hazards to be determined in conjunction with design professionals based on deterministic scenarios.

[5]Hazards to be determined based on deterministic scenarios.



Minimum code criteria may not be sufficient
To ensure continued functionality.

FEMA, 2010; ASCE, 2022

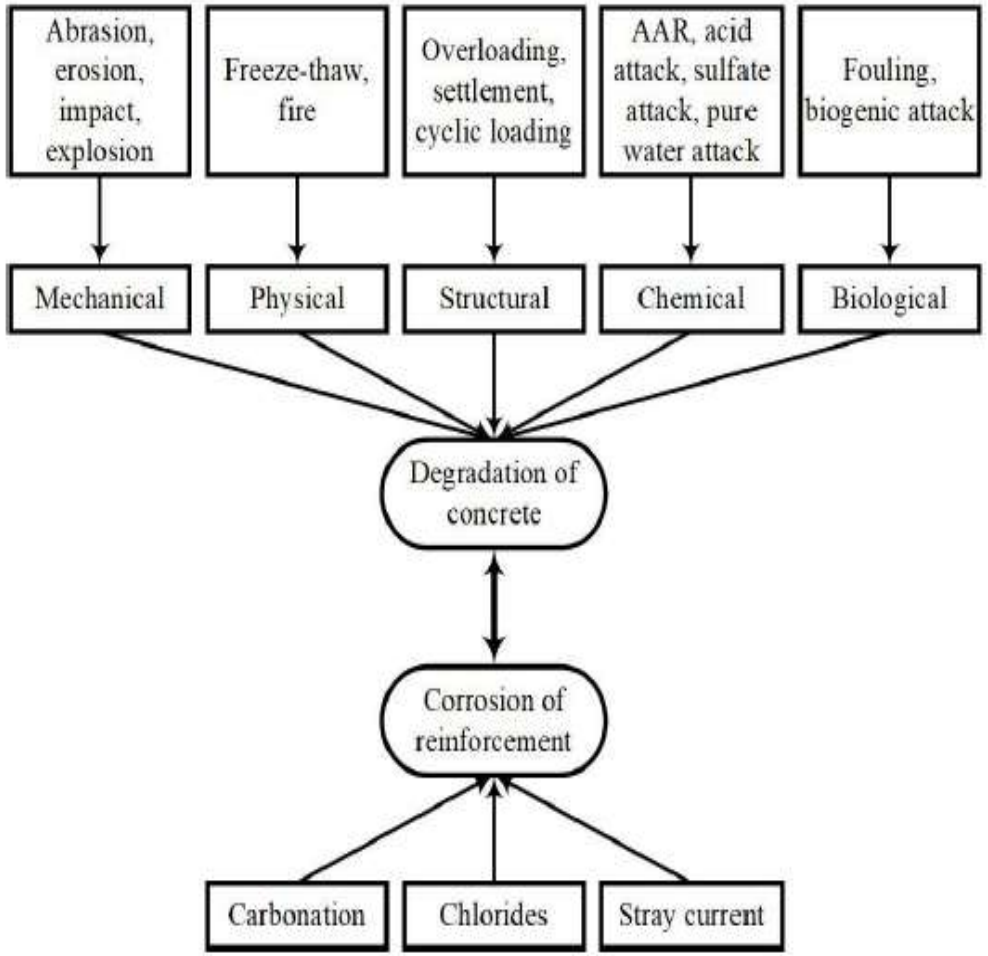
Assessment of Climatic Conditions

- **Regional vs. Global**
  - **Microclimates**
- **Atmospheric Cycles**
  - **Natural cycles – millennial, century, decadal, interannual,**
    - **e.g. El Niño, La Niña**
- **Slow Onset Events (SOEs) vs. Extreme Events**



Warsaw International Mechanism for Loss and Damage, 2013

Implications of Climate Change on Infrastructure



- Mechanical
- Physical
- Structural
- Chemical
- Biological



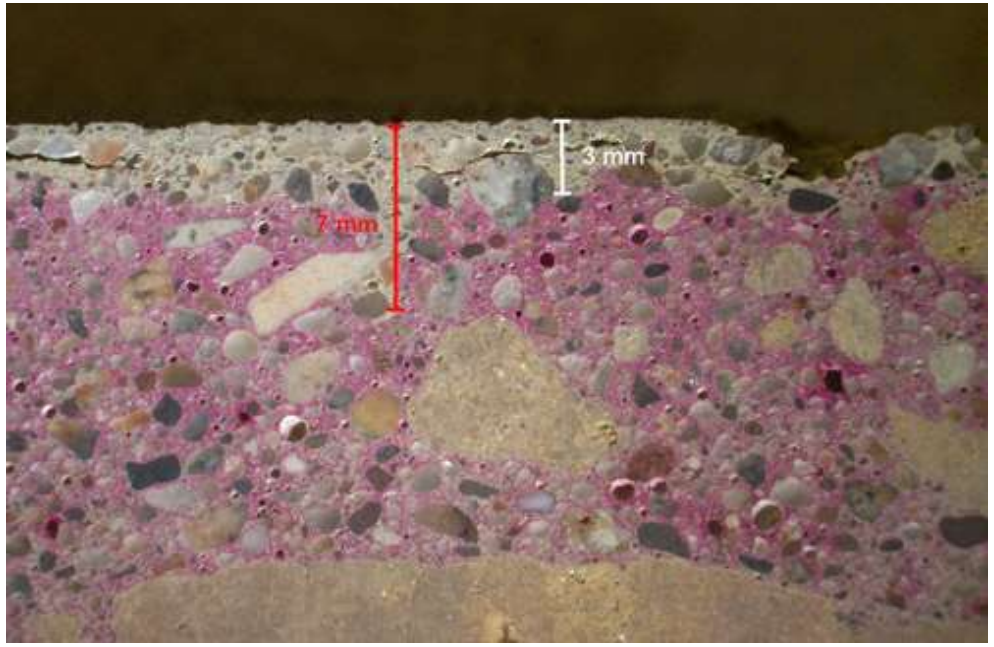


Corrosion Attach & Freeze – Thaw Damage

Implications of Climate Change on Concrete

Carbonation

- CO_2 levels
- Relative humidity



Corrosion

- CO_2 levels
- Temperature
- Relative humidity
- Sea water level
- Nutrient concentration
- Ocean acidification
- Time of saturation
- Airborne salinity
- Airborne pollutants



Other Climate Impacts

- **Atmospheric Pollutants**
  - Dry and Wet Deposition
    - NO_x and SO_2
- **Extreme Loads and Impacts from Extreme Hazards**
  - Tornadoes
  - Hurricanes, Cyclones, and Tsunamis
  - Snow and Wind Loads
  - Earthquake
  - Rain
  - Fire
  - Blast Resistance







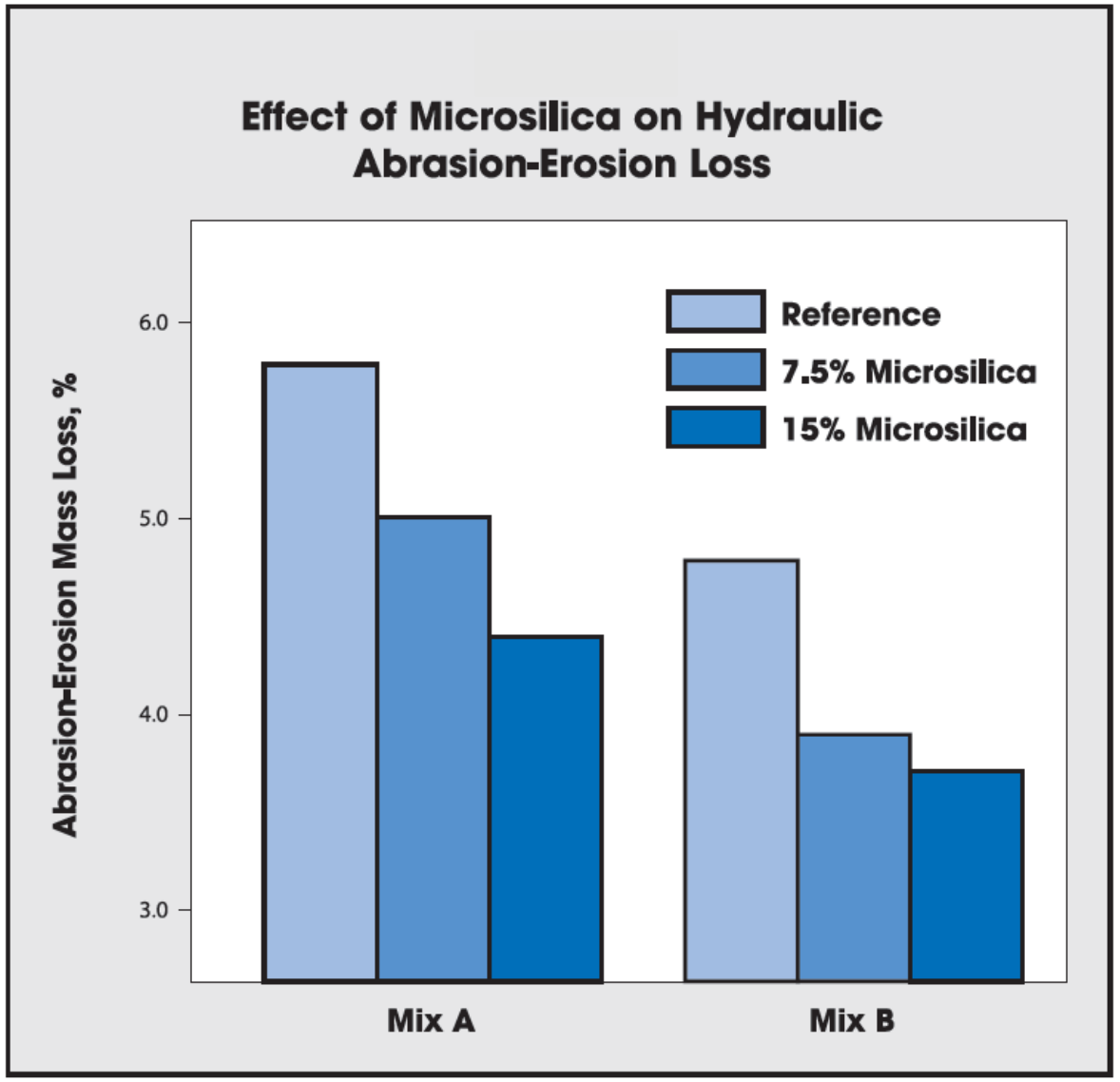




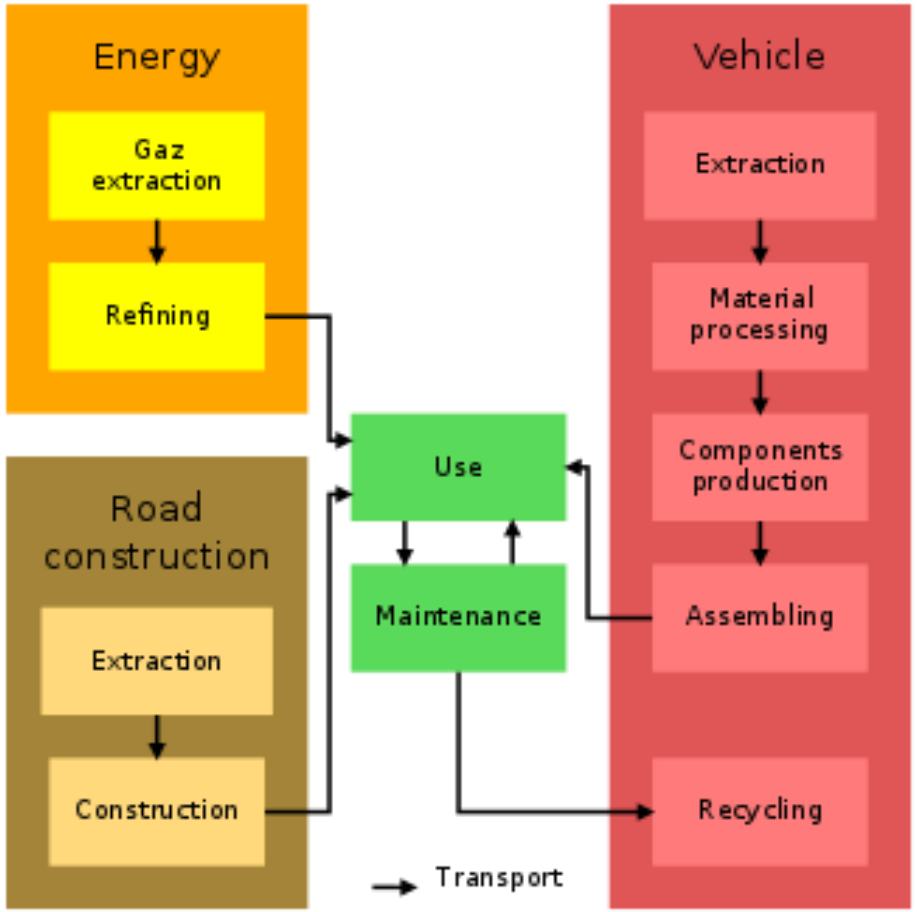
Abrasion Erosion

- Abrasion erosion from mechanical weathering from friction of impact of particles carried by debris, wind, water, or ice.

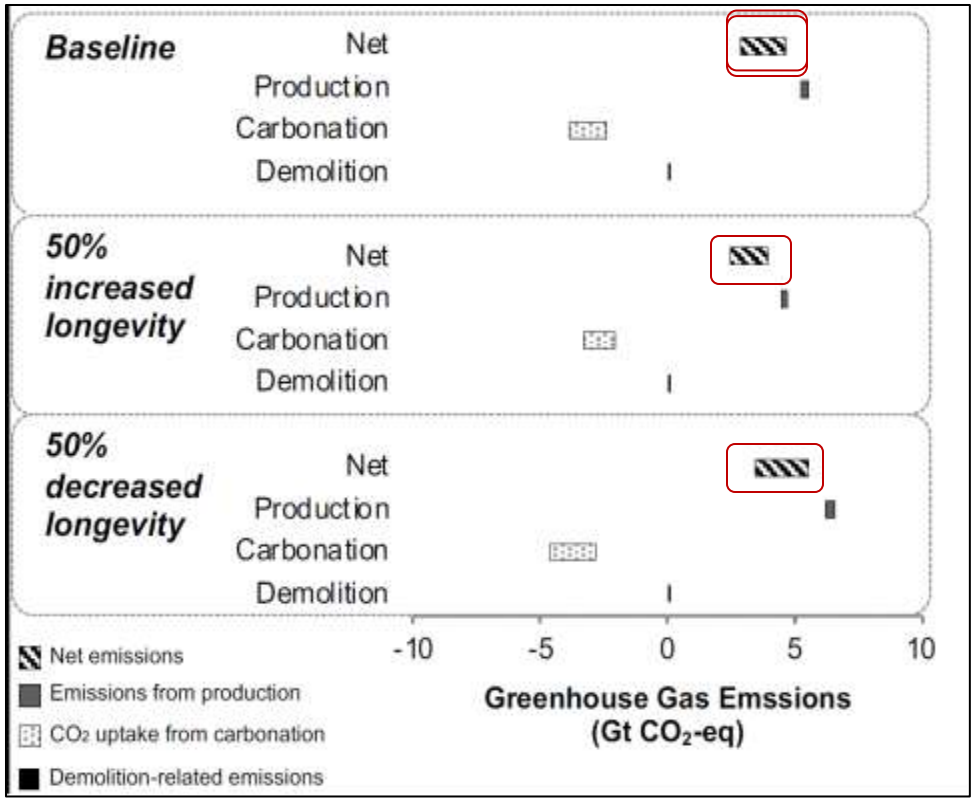
- The hardened cement paste assumes a greater role in resisting abrasion-erosion damage and the aggregate quality becomes correspondingly less important.
  - Assists when using sub-quality aggregates due to scarcity



Durability = Sustainability = Resilience



Enhancing long-term durability



Net Emissions

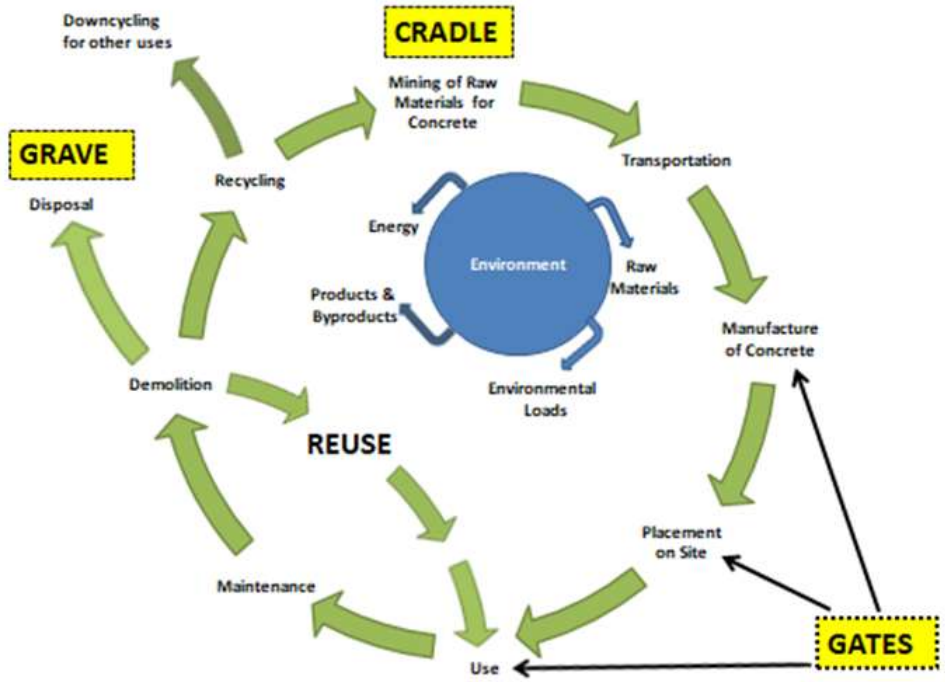
GHG (ranges represent anticipated low and high emissions based on typical US concrete mixtures) for concrete production from 1900-2015 and potential change in GHG emissions (carbonation uptake, net, and production) with 50% increased and 50% reduced service life

Miller 2020

Silica Fume Concretes: Deconstruction



- **Component recycling**
  - **Non-destructive reuse of components**
- **Lowering transport and energy consumption.**
- **Lowering waste and pollution**



Component Reuse

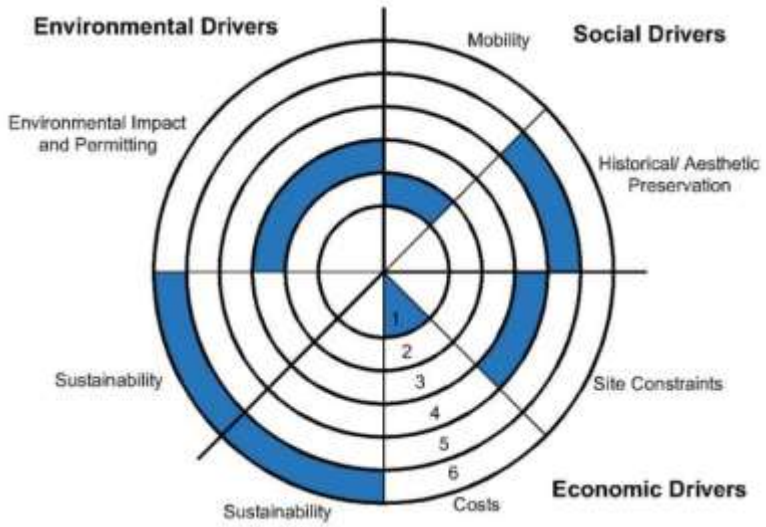
- In situ reuse of Concrete Components

“ Use of an existing foundation or substructure of a bridge, in whole or in part, when the existing foundation has been evaluated for new loads”

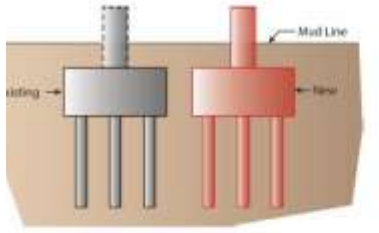


Foundation Reuse

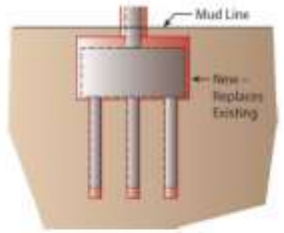
- **Constructability**
- **Risk Management**
- **LCCA**
- **Environmental Impact Assessment**



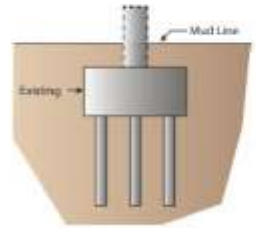
- Land use, zoning, and public policy
- Socioeconomic conditions
- Community facilities and services
- Open space
- Shadows
- Historic and cultural resources
- Urban design and visual resources
- Natural resources
- Hazardous materials
- Water and sewer infrastructure
- Solid waste and sanitation services
- Energy
- Transportation
- Air quality
- Greenhouse gas emissions
- Noise
- Public health
- Neighborhood character



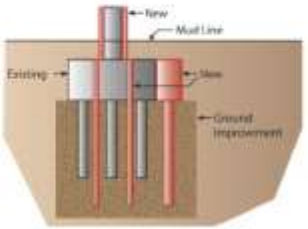
ption 1: Install new foundation on new alignment



B. Option 2: Install new foundation on the existing alignment



ption 3: Reevaluation and reuse existing foundation



D. Option 4: Reuse existing foundation by strengthening it

Component Reuse



Precast Element Salvage:

- Precast concrete bridge girders
- Precast beams,
- Deck panels,
- hollow-core slabs

Unbolted or uncoupled from a donor bridge and trucked to a new bridge.

Design for deconstruction approach.



ReCreate

Component Reuse

- Bridge components have been salvaged and reused in multiple projects worldwide, with both concrete and steel elements now being repurposed in new infrastructure.
- Massive reductions in GWP, raw material consumption, and energy use compared to casting new concrete.
- Substantial financial savings on material procurement and waste disposal costs



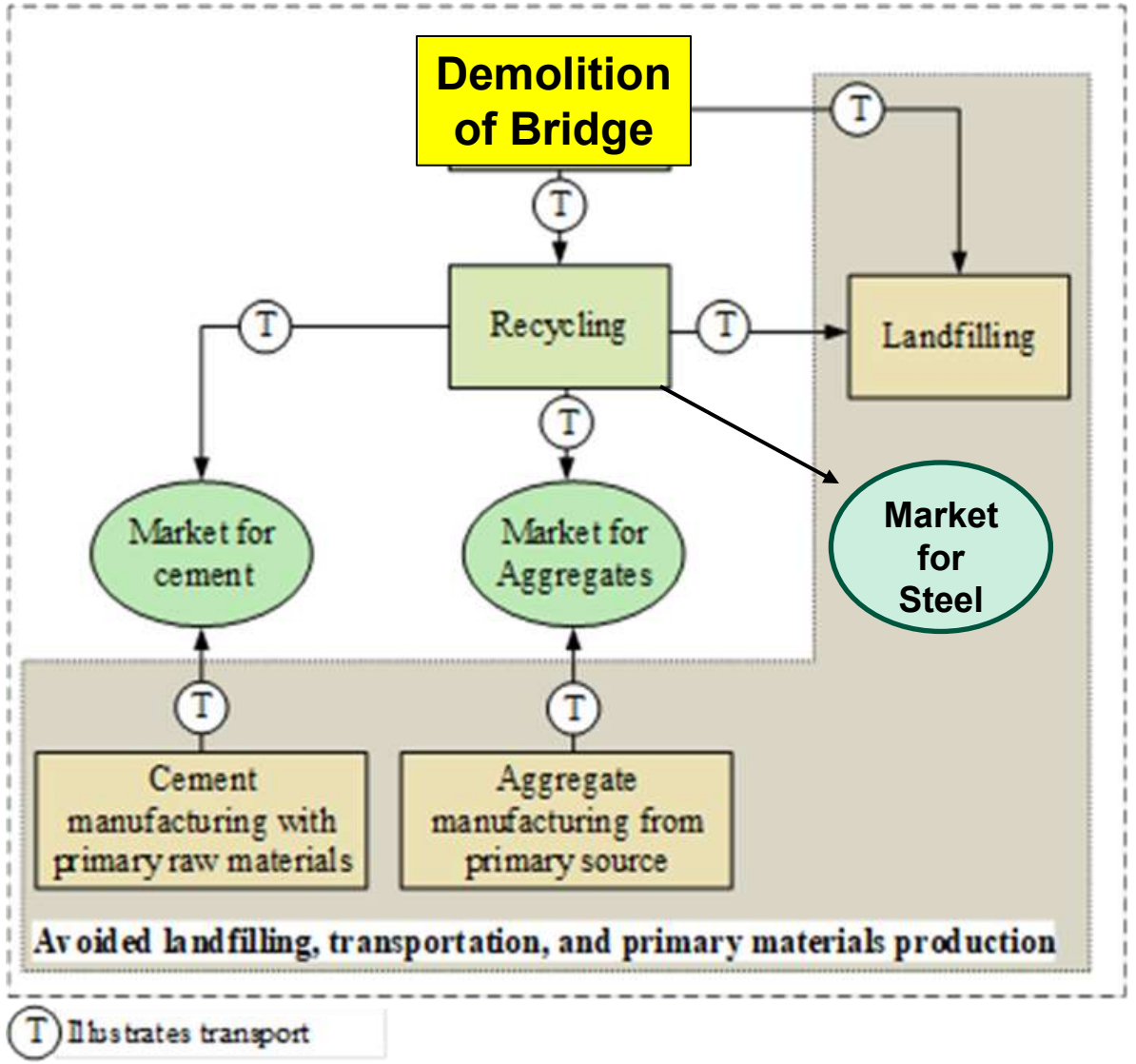
Reused Prestressed Concrete Bridge Girders

https://www.tudelft.nl/en/stories/articles/paving-the-way-for-reusing-concrete-girders

Demolition of Structures



Upcycling or Downcycling pathways for all components, e.g., aggregate used for concrete vs. aggregate used for roadbase.



Silica Fume
Bridge Projects

Binary and Ternary Mixtures – Bridge Decks

Mixture ID	Type I/II Cement, lb/yd^3 (kg/m^3)	Densified Silica Fume, lb/yd^3 (kg/m^3)	Slag Cement (Grade 120), lb/yd^3 (kg/m^3)	Water, lb/yd^3 (kg/m^3)
OPC	658 (390)	0	0	283 (168)
4% Silica Fume (96/4/0)	632 (375)	26 (16)	0	283 (168)
6% Silica Fume (94/6/0)	619 (367)	39 (23)	0	283 (168)
25% Slag Cement (75/0/25)	494 (293)	0	165 (98)	283 (168)
40% Slag Cement (60/0/40)	395 (234)	0	263 (156)	283 (168)
4/25 Ternary Blend (71/4/25)	467 (277)	26 (16)	165 (98)	283 (168)
4/40 Ternary Blend (56/4/40)	368 (219)	26 (16)	263 (156)	283 (168)
6/25 Ternary Blend (69/6/25)	454 (269)	39 (23)	165 (98)	283 (168)
6/40 Ternary Blend (54/6/40)	355 (211)	39 (23)	263 (156)	283 (168)

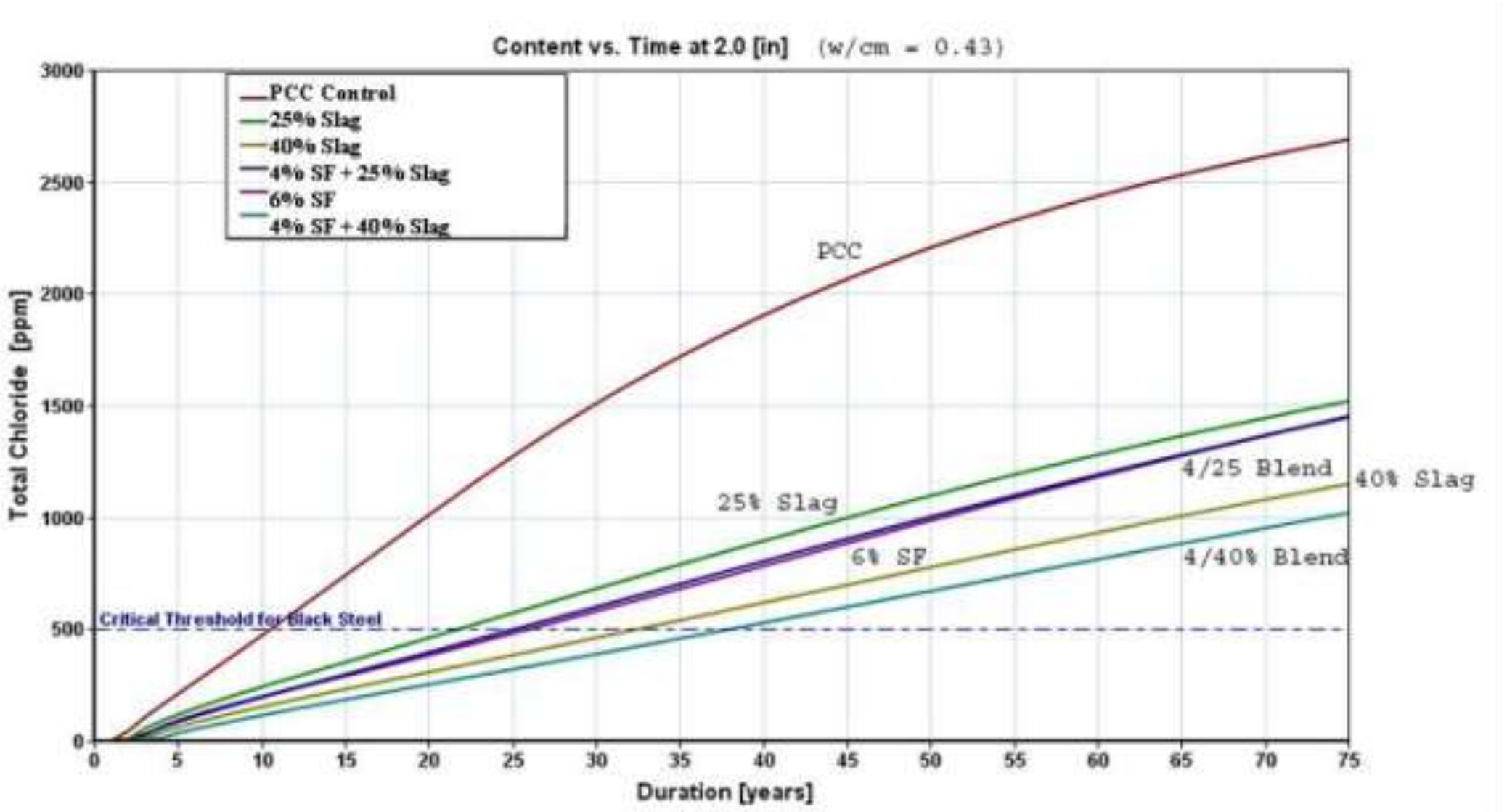
Enhanced Durability

Mixture ID	PCC	4% Silica Fume	6% Silica Fume	25% Slag Cement	40% Slag Cement	4/25 Ternary Blend	4/40 Ternary Blend	6/25 Ternary Blend	6/40 Ternary Blend
PC/SF/SL	100/0/0	96/4/0	94/6/0	75/0/25	60/0/40	71/4/25	56/4/40	69/6/25	54/6/40
Compressive Strength, ASTM C39, psi									
28 days, psi	5410	6210	6080	6420	7400	6550	7050	7090	7290
One year, psi	6800	6990	7110	7630	7860	7990	8480	7770	8210
Compressive Strength, ASTM C39, Mpa									
28 days, MPa	37.3	42.8	41.9	44.3	51.0	45.2	48.6	48.9	50.3
One year, MPa	46.9	48.2	49.0	52.6	54.2	55.1	58.5	53.6	56.6
Rapid Chloride Permeability Test, ASTM C1012, Coulombs									
28 days	3984	2687	1971	2442	1582	1277	845	928	727
One year	3290	2753	2210	1028	938	734	526	622	444
Two years	2250	2590	2372	1575	791	772	421	548	360
Boiled Absorption, ASTM C642 Test, % Mass									
28 days	6.0	5.8	6.0	5.9	5.7	5.8	6.0	5.9	5.8
One year	5.6	5.6	5.7	5.3	5.1	5.6	5.5	5.6	5.8
Two years	6.7	6.7	6.9	6.6	6.4	6.8	7.0	7.0	6.6
Porosity, ASTM C642 Test, % Volume									
28 days	13.1	12.7	13.0	12.9	12.5	12.7	13.2	12.8	12.8
One year	12.4	12.3	12.5	11.8	11.2	12.2	12.2	12.2	12.8
Two years	14.8	14.7	14.9	14.5	14.3	14.7	15.2	15.0	14.4
Bulk Diffusion Coefficient, ASTM C1556, x 10^{-12} m^2/s (1 x 10^{-12} m^2/s = 0.00124 x in^2/y)									
28 days	18.00	13.00	8.40	7.20	6.50	6.10	4.90	3.50	3.60
Two years	15.70	14.00	7.47	4.04	0.92	1.65	0.76	1.03	0.46
Hydroxide Ion Diffusion Coefficient, ASTM C1556, x 10^{-11} m^2/s (1 x 10^{-11} m^2/s = 0.0124 x in^2/y)									
28 days	12.20	11.00	10.30	10.60	7.80	6.80	4.80	6.60	6.50
Two years	12.10	9.60	5.00	5.00	3.20	4.10	2.30	2.80	2.60
Chloride Ion Diffusion Coefficient, ASTM C1556, x 10^{-11} m^2/s (1 x 10^{-11} m^2/s = 0.0124 x in^2/y)									
28 days	4.70	4.30	3.90	4.10	3.00	2.70	1.90	2.60	2.50
Two years	4.70	3.70	1.90	1.90	1.20	1.60	0.90	1.10	1.00

Hardened Properties

- Strength
- RCP
- Chloride Diffusion

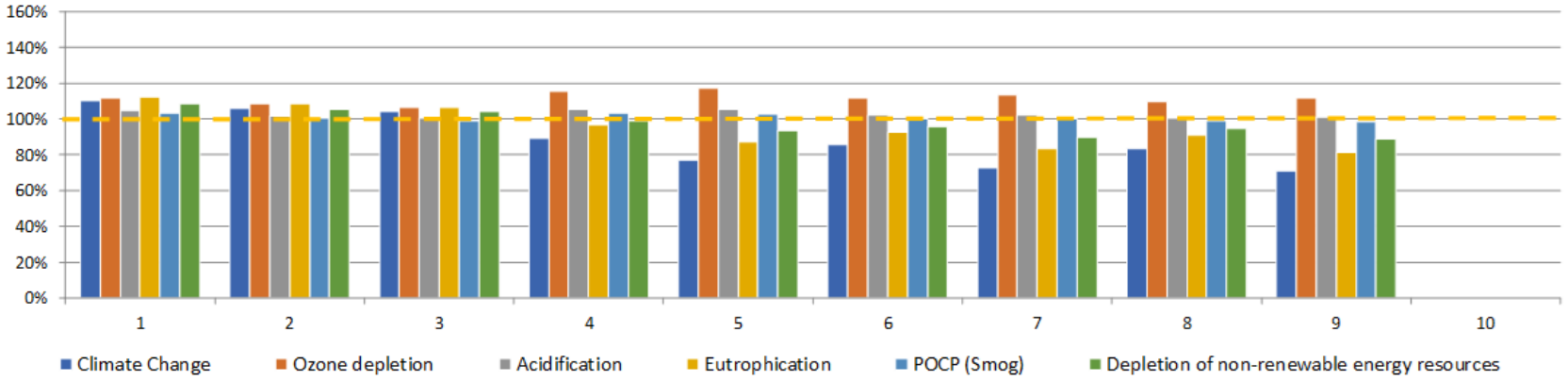
Durability of Binary and Ternary Concretes



Buffenbarger et al. 2012

Environmental Impact Compared to NRMCA Midwest Regional Baseline

Comparison of Entered Mixes to Strength Class Benchmarks



Mix in Graph	1	2	3	4	5	6	7	8	9	10
Mix ID	PCC	4% SF	6% SF	25% Slag	40% Slag	4/25 Blend	4/40 Blend	6/25 Blend	6/40 Blend	
Strength (PSI) of Relevant Benchmark	5000	5000	5000	5000	5000	5000	5000	5000	5000	
Climate Change	110%	106%	104%	89%	77%	85%	73%	83%	71%	
Ozone depletion	112%	108%	106%	115%	117%	112%	113%	110%	112%	
Acidification	105%	102%	100%	105%	105%	102%	102%	101%	101%	
Eutrophication	112%	108%	107%	97%	87%	93%	83%	91%	81%	
POCP (Smog)	103%	100%	99%	103%	103%	100%	100%	99%	99%	
Depletion of non-renewable energy resources	109%	106%	104%	99%	93%	96%	90%	94%	89%	

Life Cycle Assessment Results

Mix ID	PCC	4% SF	6% SF	25% Slag	40% Slag	4/25 Blend	4/40 Blend	6/25 Blend	6/40 Blend
Climate Change (kg CO2-eq)	318.18	306.84	301.24	258.65	222.60	246.89	210.85	241.28	205.24
Ozone depletion (kg CFC-11-eq)	7.72E-06	7.47E-06	7.34E-06	7.96E-06	8.08E-06	7.69E-06	7.82E-06	7.57E-06	7.69E-06
Acidification (kg SO2-eq)	0.95	0.92	0.91	0.95	0.95	0.92	0.93	0.91	0.91
Eutrophication (kg N-eq)	0.38	0.37	0.36	0.33	0.29	0.31	0.28	0.31	0.27
Photochemical Ozone Creation/Smog (kg O3-eq)	20.57	20.01	19.74	20.57	20.53	19.99	19.97	19.72	19.69
Abiotic Depletion Potential ADPf (MJ)	548.52	540.13	537.36	520.61	503.57	511.98	495.07	509.22	492.17
Abiotic Depletion Potential ADPe (kg Sb eq.)	1.60E-04	1.58E-04	1.56E-04	1.51E-04	1.45E-04	1.48E-04	1.42E-04	1.47E-04	1.41E-04
Use of renewable primary energy (MJ)	27.22	27.27	27.36	31.22	33.60	31.27	33.64	31.36	33.74
Use of non-renewable primary energy (MJ)	1,824.26	1,771.27	1,746.30	1,664.34	1,566.16	1,609.40	1,511.37	1,584.43	1,486.26
Fresh water consumption (m3)	0.94	0.96	0.92	0.47	0.84	0.81	0.42	0.45	0.41

The Longest Concrete-segmented, Cable-stayed Bridge – The New Harbor Bridge, Corpus Christi, TX





Largest Issues:

- Structural deficiencies
- Navigational restrictions of the current bridge,
- Improve safety conditions of motorists and create community connectivity and increased level of service to the community.

Performance-Based Concrete Mixtures for Durable, Long-Life Bridges – Buffenbarger, MacDonald and Vancura, 2018

Project Development

- There are 60 criteria within INVEST organized by module.
- The Project Development (PD) module includes twenty-nine criteria that are generally organized from planning to design to construction.

Project Development
Achievement Levels

Achievement level	Fraction of Total Points Possible	Points Required				
		Paving	Basic Rural	Extended Rural	Basic Urban	Extended Urban
Platinum	60%	34	57	69	63	76
Gold	50%	29	48	58	53	63
Silver	40%	23	38	46	42	50
Bronze	30%	17	29	35	32	38

- The Project Development module includes criteria that span the entire project development process from early planning, alternatives analysis, environmental documentation, preliminary and final design, and construction.
- Criteria includes economic analysis, LCCA, habitat restoration, bicycle and pedestrian access, reduce and reuse materials, long life pavement design, etc.

Neighborhood Connectivity



- **The selected route isolated two neighborhoods.**
  - **Residents of Hillcrest and Washington-Coles adversely affected received fair compensation to relocate;**
  - **Receive home and neighborhood improvements as mitigation**

New Harbor Cable-Stayed Bridge



- Main span of 1661 feet (505 meters); Main tower height 538 feet (164 meters)
- Clearance 205 feet (62 meters) above water
- Precast concrete segments for the main span and approaches
- Precast piles and girders for the structure maximizing the volume of bridge elements
- Fabricated using local materials and labor

Cable-Stayed Bridge

Design Requirements

- 75 and 170-year service life in panels and drilled shafts
- Thermal Requirements
  - Maximum peak curing temperature of all mass elements shall not exceed 71 °C (160 °F) during curing, nor exceed graduated differential temperature limits, the first that was of more than 2.0 °C (45 °F) within the first 48 hours.
- Specification Limitations
  - 50% maximum replacement with SCMs
- Strength Requirements
  - 28 day specified strength must be met at no later than 56 days
- Sustainability Requirements
  - INVEST Sustainable Rating System

Mixture Requirements

- Air, Slump, and Compressive strength ASTM C31 / ASTM C39
- Hardened Air Void Analysis ASTM C457
- Freeze/Thaw Resistance ASTM C666
- Surface Scaling ASTM C672
- 28-Dry Shrinkage ASTM C157
- Chloride Permeability ACI 1202
- Modulus of Elasticity at 3, 7, 28, 56, 90, 1 year, and 2 year.
- ASR at 14 and 28-Days ASTM C1260 / C1567
- Creep
- Chloride Ion Diffusion ASTM C1556

Stay-Cabled Bridge

- The precast panel mixtures utilized a ternary binder mixture with 35% slag cement and 15% fly ash/silica fume and 0.32 (*W/B*) ratio.
- The drilled shaft mixtures have utilized a 45% replacement of portland cement with fly ash and a 0.43 *W/B*.

	Mixture ID	Cement Type I/II kg/m3 [lb/yd3]	Grade 100 Slag kg/m3 [lb/yd3]	Fly Ash kg/m3 [lb/yd3]	Silica Fume kg/m3 [lb/yd3]	Mix Water kg/m3 [lb/yd3]
Precast Panels	BCE100	205 [350]	185 [315]	0	20 [35]	132 [224]
	BCE101	205 [350]	115 [189]	75 [126]	20 [35]	132 [224]
	BCE102	205 [350]	145 [350]	65 [105]	0	132 [224]
	BCE103	235 [350]	225 [350]	0	24 [40]	145 [246]
Drilled Shafts	DS1	210 [350]	0	175 [293]	0	165 [280]
	DS2	226 [385]	0	186 [315]	0	132 [238]



Testing Results

2 sets of specimens cast for each concrete mixture.

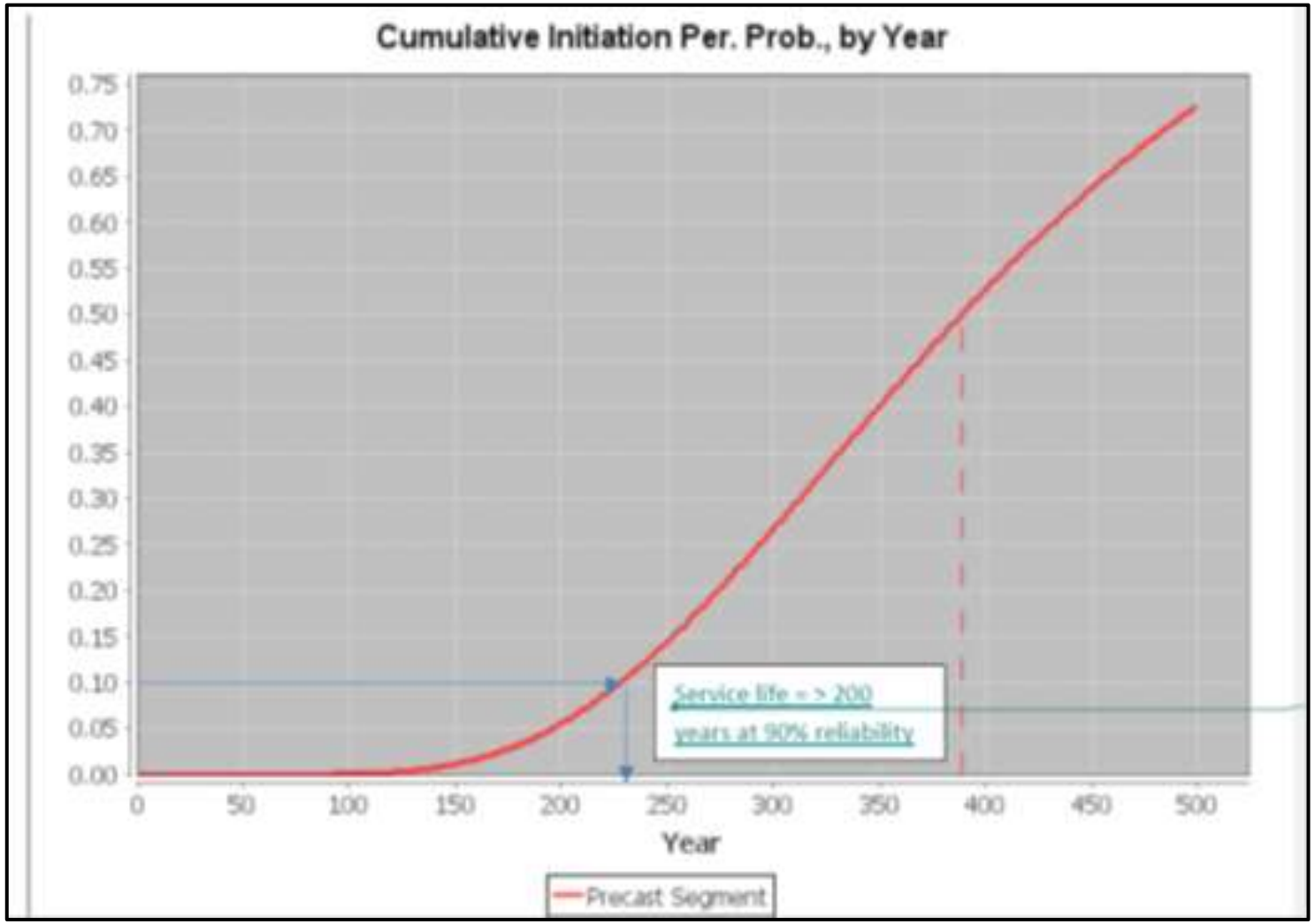
- **Standard laboratory conditions**
- **Accelerated curing conditions**

- **120 °F (49 °C) air and the length change and transport property specimens in a 100 °F (38 °C) water bath**

Mixture ID	BCE100	BCE101	BCE102	BCE103	DS1	DS2
Compressive Strength, ASTM C 1012, MPa (psi)						
12 Hr	4.4 (635)	7.1 (1025)	3.1 (450)	8.6 (1250)	2.4 (535)	3.0 (440)
1 Day	16.8 (2440)	15.9 (2300)	16.9 (2455)	20.8 (3025)	12.3 (1790)	10.6 (1540)
28 Days	83.0 (12030)	83.0 (12040)	82.5 (11960)	87.1 (12630)	51.8 (7510)	46.8 (6780)
56 Days	84.8 (12290)	81.2 (11780)	87.6 (12700)	90.8 (13170)	58.8 (8520)	57.4 (8320)
Accelerated Cure Compressive Strength, ASTM C 1012, MPa (psi)						
12 Hr	26.7 (3870)	23.0 (3335)	21.4 (3110)	33.0 (4780)	13.4 (1875)	11.0 (1600)
1 Day	45.1 (6540)	43.0 (6240)	40.9 (5925)	48.4 (7020)	20.3 (2945)	17.9 (2590)
Standard Length Change of Hardened-Hydraulic Mortar and Concrete, ASTM C 157, %						
28 Days	-0.014	-0.011	-0.02	-0.014	-0.019	-0.023
Resistance To Chloride Penetration, ASTM C 1202, Coulombs						
28 Days	221	223	578	249	1520	881
56 Days	140	123	468	137	616	490
Accelerated Cure Resistance To Chloride Penetration, ASTM C 1202, Coulombs						
28 Days	141	101	271	111	307	N/A
56 Days	108	75	289	103	127	N/A
Boiled Absorption, ASTM C 642, % mass						
28 Days	1.7	1.6	1.9	1.5	3.2	4.0
Porosity, ASTM C 642, % Volume						
28 Days	13.1	12.9	12.5	12.8	12.8	12.8
Bulk Diffusion Coefficient*, ASTM C 1556, x 10^{-13} m^2/s (1 x 10^{-13} m^2/s = 0.000124 x in^2/y)						
28 Days	7.60	8.35	9.60	5.30	2.15	1.70
Accelerated Cure Bulk Diffusion Coefficient*, ASTM C 1556, x 10^{-13} m^2/s (1 x 10^{-13} m^2/s = 0.000124 x in^2/y)						
28 Days	5.85	6.90	5.55	5.20	7.40	N/A
Chloride Migration Coefficient from Non-Steady-State Migration NT BUILD 492, x10^{-13} D m^2/s (1 x 10^{-13} m^2/s = 0.000124 x in^2/y)						
28 Days	5.45	13.00	22.70	3.60	77.00	42.80
Accelerated Cure Chloride Migration Coefficient from Non-Steady-State Migration NT BUILD 492, x10^{-13} D m^2/s (1 x 10^{-13} m^2/s = 0.000124 x in^2/y)						
28 Days	4.85	3.50	7.50	2.50	1.49	N/A
56 Days	3.50	3.80	7.20	1.50	6.90	N/A
Bulk Electrical Conductivity of Hardened Concrete, ASTM 1760, Ω^{-1}						
28 Days	921.0	368.0	226.0	363.0	69.0	148.0
56 Days	N/A	578.0	429.0	632.0	162.0	398.0
Accelerated Cure Bulk Electrical Conductivity of Hardened Concrete, ASTM 1760, Ω^{-1}						
28 Days	1725.0	1830.0	579.0	1500.0	563.0	N/A
56 Days	1760.0	2240.0	850.0	1515.0	1100.0	N/A

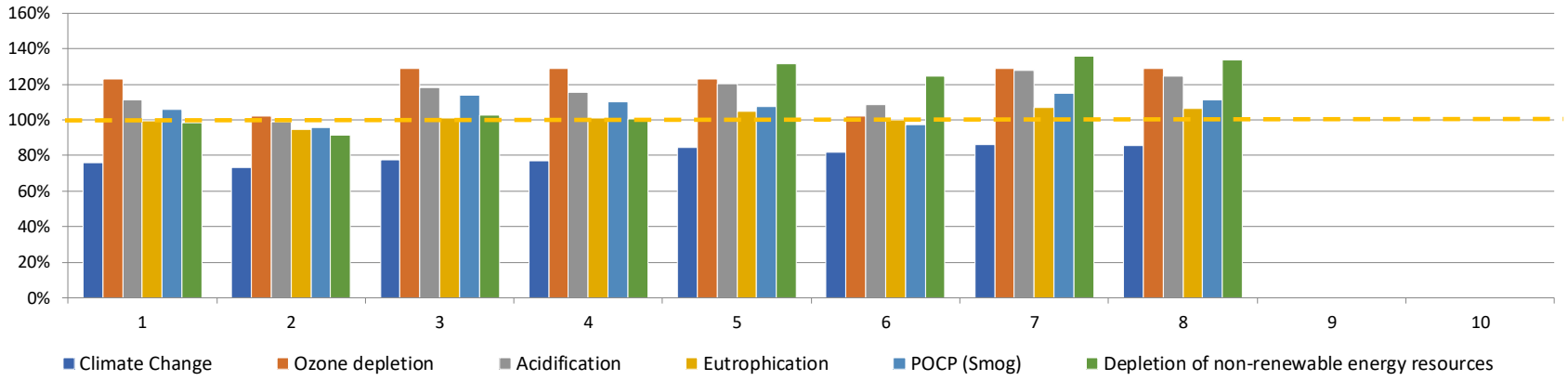
Service Life

A corrosion-inhibiting admixture was required at dosages between 1-2 gal/yd^3 (5.0-10.0 L/m^3) to meet the service life requirements in the specification.



GWP with and without Corrosion Inhibitor

Comparison of Entered Mixes to Strength Class Benchmarks



Mix in Graph	1	2	3	4	5	6	7	8	9	10
Mix ID	BCE100	BCE101	BCE102	BC103	BCA100 w/CI	BCE101 w/CI	BCE 102 w/CI	BCE103 w/CI		
Strength (PSI) of Relevant Benchmark	5000	5000	5000	5000	5000	5000	5000	5000		
Climate Change	76%	73%	77%	77%	84%	82%	86%	85%		
Ozone depletion	123%	102%	129%	129%	123%	102%	129%	129%		
Acidification	111%	99%	118%	115%	120%	108%	128%	125%		
Eutrophication	99%	95%	101%	101%	105%	100%	107%	106%		
POCP (Smog)	106%	96%	114%	110%	107%	97%	115%	111%		
Depletion of non-renewable energy resources	98%	91%	103%	101%	131%	124%	136%	134%		

Life Cycle Assessment Results

Mix ID	BCE100	BCE101	BCE102	BC103	BCA100 w/CI	BCE101 w/CI	BCE 102 w/CI	BCE103 w/CI		
Climate Change (kg CO2-eq)	215.55	207.73	220.35	218.38	240.34	232.53	245.15	243.17		
Ozone depletion (kg CFC-11-eq)	8.10E-06	6.73E-06	8.49E-06	8.49E-06	8.11E-06	6.73E-06	8.49E-06	8.49E-06		
Acidification (kg SO2-eq)	0.97	0.86	1.03	1.00	1.05	0.94	1.11	1.09		
Eutrophication (kg N-eq)	0.38	0.36	0.39	0.39	0.40	0.38	0.41	0.41		
Photochemical Ozone Creation/Smog (kg O3-eq)	19.38	17.52	20.80	20.13	19.63	17.76	21.04	20.37		
Abiotic Depletion Potential ADPf (MJ)	548.17	541.83	587.08	559.22	1,073.59	1,067.26	1,112.50	1,084.64		
Abiotic Depletion Potential ADPe (kg Sb eq.)	1.77E-04	1.72E-04	1.78E-04	1.78E-04	8.30E-04	8.26E-04	8.31E-04	8.31E-04		
Use of renewable primary energy (MJ)	33.68	30.55	34.54	34.54	99.30	96.18	100.17	100.17		
Use of non-renewable primary energy (MJ)	1,661.28	1,543.04	1,733.50	1,703.97	2,221.67	2,103.43	2,293.89	2,264.36		
Fresh water consumption (m3)	0.92	0.91	0.39	0.39	0.90	0.84	0.54	0.54		

Balance performance properties with GWP

St. Croix Crossing

- **Extradosed Bridge Design**
  - Cross between cable-stayed and precast box girder bridge
  - Lower main pillar than cable-stayed
- **5,075 ft (1523 m) bridge**
- **67 ft (20 m) tower height**
- **13 pier structures**
  - 5 piers in the waterway
- **Environmental Challenges**
  - Waterway, Bluffs, and Endangered Species





Additional Challenges

- **Construction in Bluffs**
  - **Hand construction** in some areas
  - **Turbidity curtains**, concrete barriers and silt fences were erected to control soils and construction traffic within the project to protect adjacent wetlands
- **Preservation of endangered species**
- **Water quality**
  - **Testing daily of water** to insure lack of contamination and neutral pH



Dotted Blazing Star



Higgins Eye Pearly Mussel



St. Croix Crossing Design Requirements

- 100-year service life
- Thermal Requirements
  - Maximum peak curing temperature of all mass elements shall not exceed 71 °C (160 °F) during curing, nor exceed graduated differential temperature limits, the first that was of more than 2.0 °C (45 °F) within the first 48 hours.
- Strength Requirements
  - 28 day specified strength must be met at no later than 56 days
- Concrete Placement
  - Due to extended haul times to the point of placement, all mixtures must remain plastic for 180 minutes.
  - All mixtures must be tested for standard delivery to 90 minutes and for extended delivery times up to 180 minutes

St. Croix Bridge Mixture Requirements

- Air, Slump, and Compressive strength ASTM C31 / ASTM C39
- Hardened Air Void Analysis ASTM C457
- Freeze/Thaw Resistance ASTM C666
- Surface Scaling ASTM C672
- 28-Dry Shrinkage ASTM C157
- Chloride Permeability ACI 1202
- Modulus of Elasticity at 3, 7, 28, 56, 90, 1 year, and 2 year.
- ASR at 14 and 28-Days ASTM C1260 / C1567
- Creep
- Chloride Ion Diffusion ASTM C1556

St. Croix Crossing

- Precast segments utilized air entrained concretes of 3500, 6000, 8000, and 9000 psi (24, 41, 55 and 62 MPa) depending on segment location.
- Piers utilized air-entrained 8000 psi (55 MPa) concrete with stripping strengths achieved between 24-48 hours after placement.



- Admixtures included an air entrainer, non-chloride accelerator, mid-range water-reducer, and viscosity modifier.
- The non-chloride accelerator and mid-range water reducer were used in precast segments and cast-in-place (CIP) box-girder mixtures to ensure adequate demolding strength and to achieve slump requirements.
- An air entrainer was utilized in all exposed structural elements to insure durability against freezing and thawing.

St. Croix Crossing





	Mixture ID	Cement Type I/II kg/m³ [lb/yd³]	Grade 100 Slag kg/m³ [lb/yd³]	Fly Ash kg/m³ [lb/yd³]	Silica Fume kg/m³ [lb/yd³]	Sand 190 mm [0.75 in] kg/m³ [lb/yd³]	Gravel 190 mm [0.75 in] kg/m³ [lb/yd³]	Granite 190 mm [0.75 in] kg/m³ [lb/yd³]	Mix Water kg/m³ [lb/yd³]	W/B
PIERS MASS CONCRETE	SCB46-1 SHAFTS PIERS 1-7	45 [80]	200 [360]	50 [90]	0	820 [1475]	1000 [1800]	0	138 [239]	0.45
	SCB46-3 SHAFTS PIER 13	50 [90]	200 [360]	50 [90]	0	822 [1475]	1002 [1800]	0	128 [232]	0.43
	SCB46-7 PIER 1-7, 13	47 [84]	208 [375]	56 [101]	0	764 [1375]	933 [1680]	0	131 [235]	0.42
	SCB46-9, PIERS 5-6, 8-12	50 [90]	223 [402]	60 [108]	0	753 [1355]	917 [1650]	0	133 [240]	0.40
	SCB46-10 EXTRADOSED PIER	50 [90]	223 [402]	60 [108]	0	758 [1365]	0	925 [1665]	133 [240]	0.40
CROSS BEAM MASS CONCRETE	SCB83-12 SCB83-12A SCB83-12B CROSS BEAMS 8-12	67 [120]	178 [320]	106 [190]	17 [30]	749 [1348]	0	911 [1640]	128 [231]	0.35
	SCB83-18 CROSS BEAMS 8-12	94 [170]	194 [350]	67 [120]	11 [20]	743 [1338]	0	743 [1338]	128 [231]	0.35
FOOTINGS ABUTMENTS/ RETAINING WALLS	SCB46-2	180 [324]	0	120 [216]	0	814 [1465]	994 [1790]	0	138 [248]	0.46
ABUTMENTS/ STEM & BACK WALLS	SCB46-8	129 [232]	64 [116]	129 [232]	0	754 [1358]	922 [1660]	0	136 [244]	0.42
PILE FILL	SCB56-4	207 [372]	0	138 [248]	0	811 [1460]	964 [1735]	0	145 [260]	0.42
CIP UNITS 1-2 & SKIRT	SCB63-11 SCB63-11B SCB63-12E SCB63-11F	141 [254]	82 [147]	163 [294]	0	722 [1300]	0	880 [1584]	139 [250]	0.34
CLOSURE POUR & EXTERNAL STRUTS & CIP UNIT 3	SCB83-13	184 [332]	92 [166]	184 [332]	0	699 [1258]	0	856 [1540]	138 [249]	0.30
PRECAST SEGMENTS 41 & 55 MPA [6000 & 8000 Psi]	SCB83-14 SCB83-15 SCB83-16 SCB83-16C SCB83-16D	311 [560]	89 [160]	44 [80]	0	710 [1278]	0	868 [1562]	142 [256]	0.32

Strength and Thermal Testing

- Stressing and stripping strength of mass concrete was performed with Flir Match Cure Boxes.
- All segment concrete was 8,000 psi or 9,000 psi with a 4,000 psi requirement in 18-hours for stripping strength.



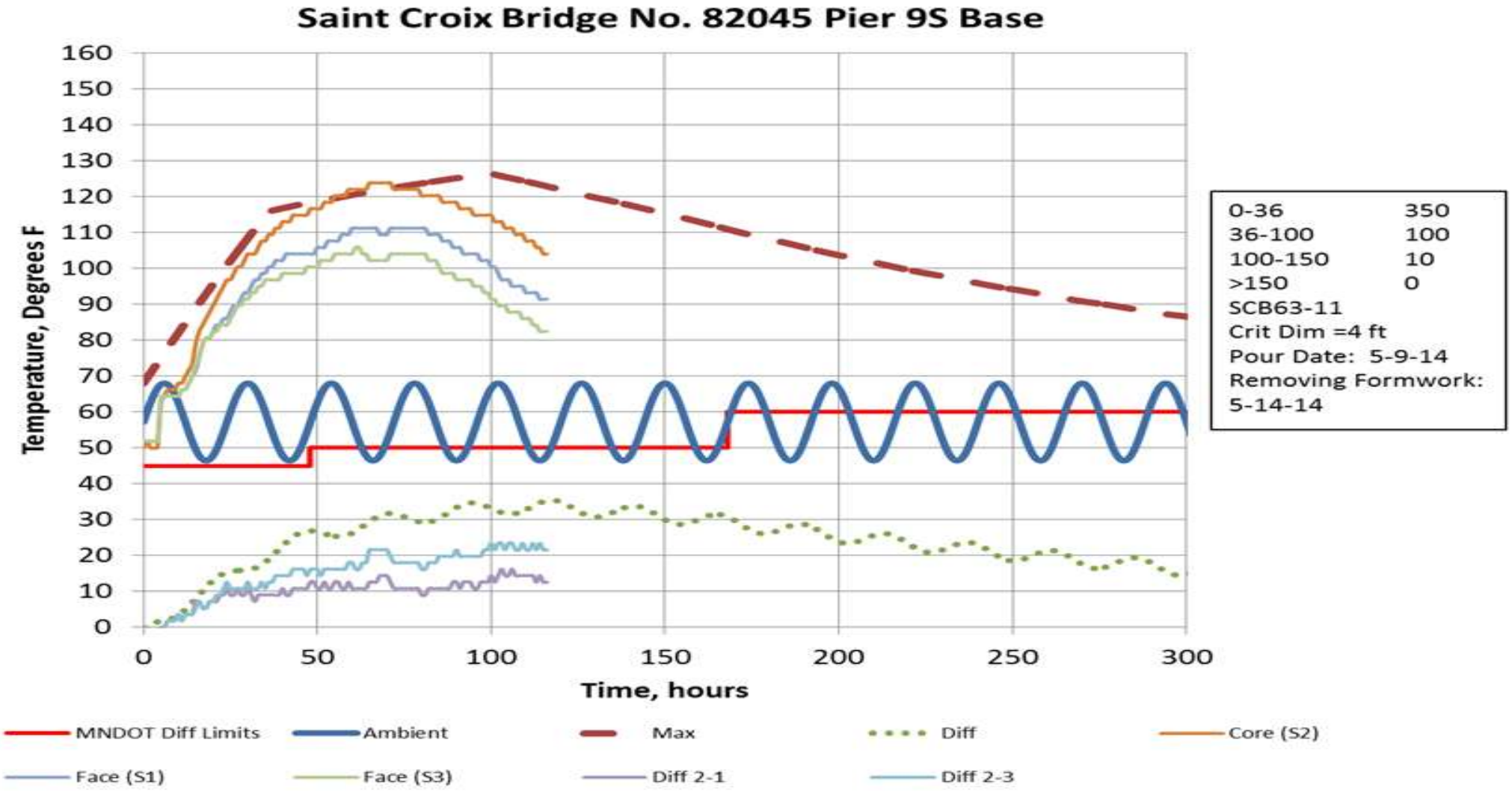




The heat of hydration of each mass concrete mixture was modeled for internal temperature and the temperature differential

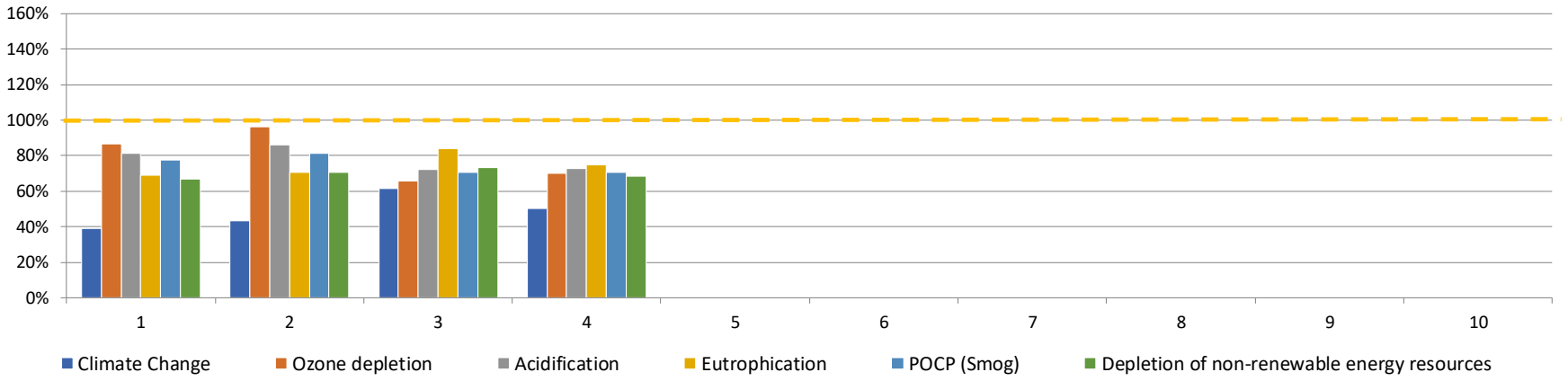
- 4 ft x 4 ft x 4 ft 1.2 m x 1.2 m x 1.2 m) unreinforced concrete block was constructed and instrumented with sensors to determine the semi-adiabatic internal temperature rise

Representative Thermal Modeling Result



Athena Sustainable Materials Institute

Comparison of Entered Mixes to Strength Class Benchmarks



Mix in Graph	1	2	3	4	5	6	7	8	9	10
Mix ID	SCB8312B	SCB83-18	SCB46-2	SCB46-8						
Strength (PSI) of Relevant Benchmark	6000	6000	6000	6000						
Climate Change	39%	43%	61%	50%						
Ozone depletion	86%	96%	66%	70%						
Acidification	81%	86%	72%	73%						
Eutrophication	69%	71%	84%	75%						
POCP (Smog)	77%	81%	71%	71%						
Depletion of non-renewable energy resources	67%	71%	73%	68%						

Very Low GWP

Life Cycle Assessment Results

Mix ID	SCB8312B	SCB83-18	SCB46-2	SCB46-8						
Climate Change (kg CO2-eq)	116.98	129.75	185.09	151.60						
Ozone depletion (kg CFC-11-eq)	6.02E-06	6.73E-06	4.59E-06	4.88E-06						
Acidification (kg SO2-eq)	0.75	0.79	0.66	0.67						
Eutrophication (kg N-eq)	0.28	0.29	0.34	0.30						
Photochemical Ozone Creation/Smog (kg O3-eq)	14.97	15.73	13.67	13.69						
Abiotic Depletion Potential ADPf (MJ)	465.14	449.79	503.79	477.37						
Abiotic Depletion Potential ADPe (kg Sb eq.)	1.62E-04	1.52E-04	1.83E-04	1.67E-04						
Use of renewable primary energy (MJ)	34.60	33.73	28.62	29.82						
Use of non-renewable primary energy (MJ)	1,199.02	1,261.29	1,312.63	1,220.82						
Fresh water consumption (m3)	0.29	0.30	0.37	0.32						

Wacker Bridge Viaduct

Reconstruction with

Quaternary Blend

- Type I portland cement, Class C fly ash, silica fume, slag cement, and 3/4 in. (19 mm) aggregate (natural siliceous sand)

- Air-entraining admixture and HRWRA.





Kaderbek et al. 2002; Issa and Khalil 2010

Wacker Bridge

Specimen Type*	Type I Cement, lbs/yd^3 (kg/m^3)	Slag Cement lbs/yd^3 (kg/m^3)	Class C Fly Ash lbs/yd^3 (kg/m^3)	Silica Fume lbs/yd^3 (kg/m^3)	Fine Aggregate lbs/yd^3 (kg/m^3)	Coarse Aggregate lbs/yd^3 (kg/m^3)	Water lbs./yd^3 (kg/m^3)	Air Entrainment$^{\lozenge}$ oz/yd^3 (L/m^3)	HRWR† oz/yd^3 (L/m^3)	WR oz/yd^3 (L/m^3)	Corrosion Inhibitor oz/yd^3 (L/m^3)	Retarder oz/yd^3 (L/m^3)	*w/cm* §
P1M1	534 (316)	79 (47)	52 (31)	27 (16)	1100 (651)	1898 (1124)	263 (156)	14 (0.41)	147.5 (4.35)	0	0	0	0.38
P1M2	584 (346)	0	117 (69)	29 (17)	1047 (620)	1888 (1118)	277 (164)	7 (0.21)	147 (4.34)	0	0	0	0.38
P1M3	584 (316)	0	0	0	1294 (766)	1888 (1118)	216 (128)	6 (0.18)	154.4 (5.24)	0	263.0 (10.13)	11.8 (0.46)	0.37
P2M1	534 (346)	79 (47)	54 (32)	27 (16)	1149 (680)	1772 (1049)	258 153)	14 (0.41)	200 (6.78)	0	0	0	0.37
P2M2	620 (367)	0	123 (73)	30 (18)	1116 (661)	1645 (974)	289 (171)	15 (0.44)	222.7 (7.55)	0	0	0	0.37
P2M3	584 (346)	0	0	0	1292 (765)	1878 (1112)	201 (119)	6 (0.18)	100.9 (3.42)	67.3 (2.28)	263.0 (10.13)	11.8 (0.46)	0.37
R1M1	534 (316)	79 (47)	52 (32)	27 (16)	1177 (697)	1746 (1034)	255 (151)	13 (0.38)	132.8 (4.54)	0	0	0	0.37
R1M2	584 (346)	0	117 (69)	29 (17)	1147 (679)	1705 (1010)	269 (153)	15 (0.44)	132.8 (4.54)	0	0	0	0.39
R2M1	534 (316)	79 (47)	54 (32)	27 (16)	1157 (685)	1828 (1082)	258 (153)	13 (0.38)	94.4 (3.26)	327.7 (11.11)	0	0	0.37
R2M2	584 (346)	0	117 (69)	29 (17)	1137 (673)	1829 (1082)	272 (161)	15 (0.44)	135.7 (3.42)	361.4 (12.25)	0	0	0.37
R2M3	534 (316)	79 (47)	54 (32)	27 (16)	1157 (685)	1830 (1082)	258 (153)	13 (0.38)	94.4 (3.26)	327.7 (11.11)	0	0	0.37
R3M3	572 (339)	86 (51)	51 (30)	25 (15)	1243 736)	1675 (992)	272 (161)	15 (0.44)	100.3 (3.44)	254.4 (8.32)	0	0	0.37
RM Mixture Selected	525 (311)	79 (31)	53 (16)	27 (16)	1140 (676)	1800 (1068)	254 (151)	14 (0.41)	82.5 (3.20)	41.0 (1.59)	0	0	0.37

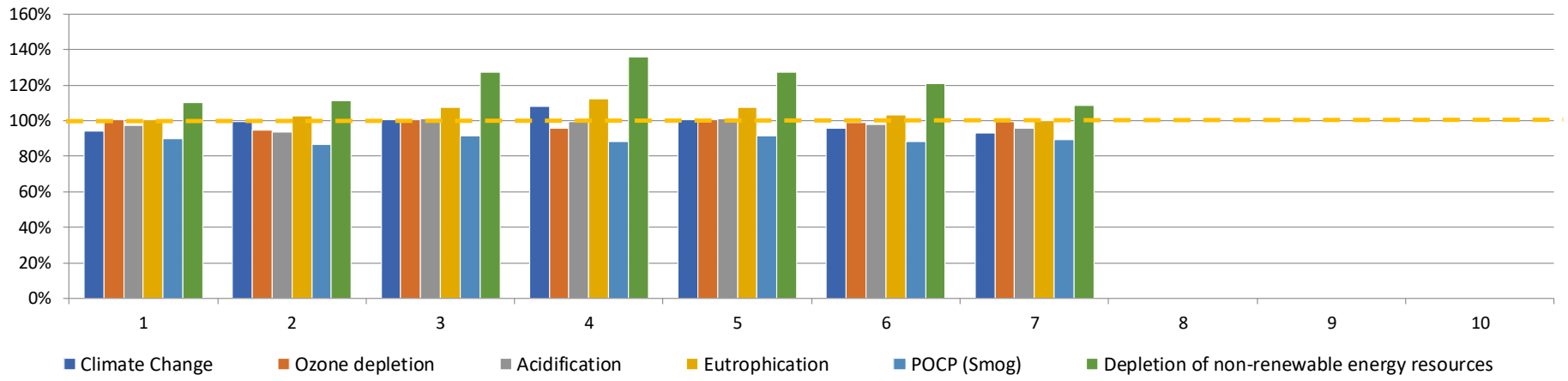
* P designates precast concrete, while R designates ready-mixed concrete.

$^{\lozenge}$ Air entrainment dosage was assumed was assumed that the air entrainment dosage was 2 oz/cwt when using silica fume and 1 oz/cwt when silica fume was not present in the concrete mixture.

† HRWR dosage was averaged when a range was given.

§ Water from the corrosion-inhibiting admixture was accounted for in the *w/cm*.

Comparison of Entered Mixes to Strength Class Benchmarks



Mix in Graph	1	2	3	4	5	6	7	8	9	10
Mix ID	R1M1	R1M2	R2M1	R2M2	R2M3	R3M3	Chosen Mixture			
Strength (PSI) of Relevant Benchmark	6000	6000	6000	6000	6000	6000	6000			
Climate Change	94%	99%	100%	108%	100%	96%	93%			
Ozone depletion	100%	95%	101%	96%	101%	99%	99%			
Acidification	97%	93%	101%	99%	101%	98%	96%			
Eutrophication	100%	103%	108%	112%	108%	103%	100%			
POCP (Smog)	90%	86%	91%	88%	91%	88%	89%			
Depletion of non-renewable energy resources	110%	111%	128%	136%	128%	121%	109%			

Life Cycle Assessment Results

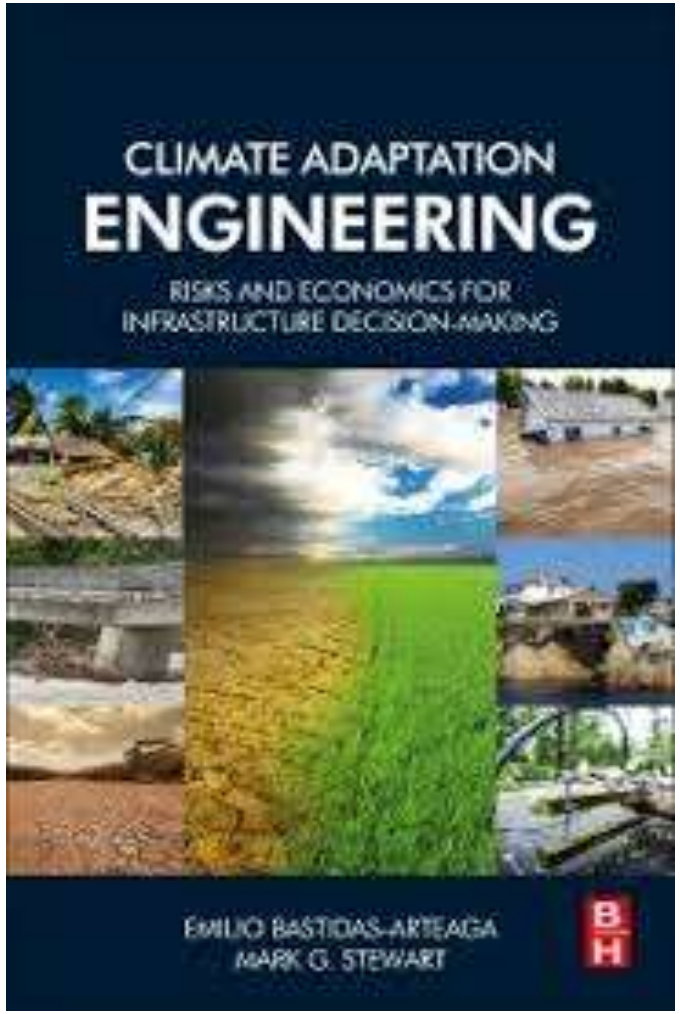
Mix ID	R1M1	R1M2	R2M1	R2M2	R2M3	R3M3	Chosen Mixture			
Climate Change (kg CO2-eq)	275.17	290.76	294.20	316.37	294.20	280.60	272.37			
Ozone depletion (kg CFC-11-eq)	7.89E-06	7.47E-06	7.93E-06	7.54E-06	7.93E-06	7.77E-06	7.82E-06			
Acidification (kg SO2-eq)	0.81	0.78	0.84	0.83	0.84	0.82	0.80			
Eutrophication (kg N-eq)	0.37	0.38	0.40	0.42	0.40	0.38	0.37			
Photochemical Ozone Creation/Smog (kg O3-eq)	14.90	14.31	15.11	14.61	15.11	14.64	14.80			
Abiotic Depletion Potential ADPf (MJ)	630.76	632.91	900.45	1,024.73	900.45	824.24	615.39			
Abiotic Depletion Potential ADPe (kg Sb eq.)	5.26E-04	5.24E-04	4.43E-04	5.51E-04	4.43E-04	4.51E-04	4.01E-04			
Use of renewable primary energy (MJ)	45.91	43.92	53.77	64.30	53.77	51.47	37.49			
Use of non-renewable primary energy (MJ)	1,891.61	1,904.47	2,186.35	2,332.31	2,186.35	2,072.01	1,861.97			
Fresh water consumption (m3)	0.80	0.42	0.45	0.50	0.81	0.75	0.39			

Closing Comments

Conclusions

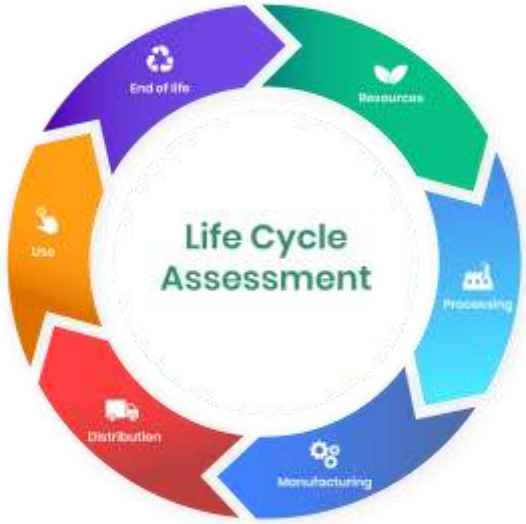
- Sustainability and Resiliency are now being recognized as a vital and central core to infrastructure development.

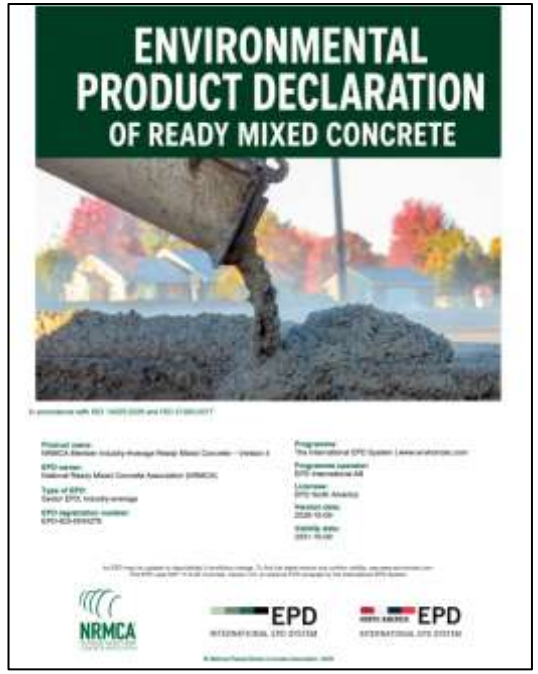
- High Performance and Silica Fume Concrete is a construction material that plays an important positive role in minimizing the impacts of our built civilization by providing resilient social, environmental and economic benefits.

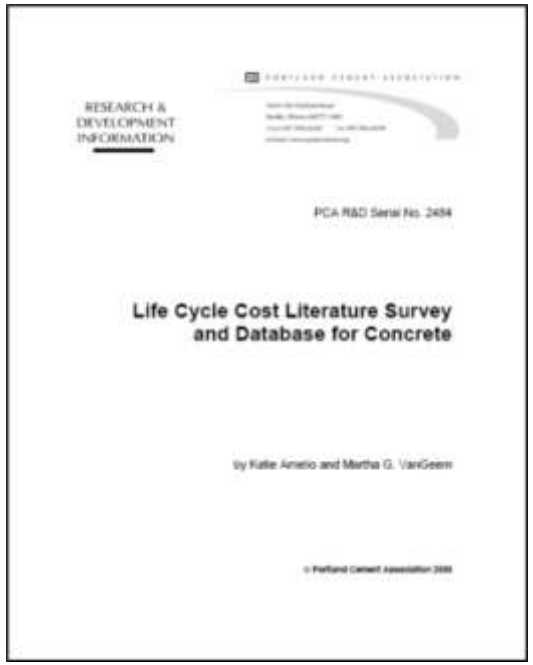


LCA, EPDs, and Performance

- **Life Cycle Assessment**
  - Environmental Product Declarations (EPDs)
  - Full Cradle-to-Grave LCA
- **Life Cycle Costing**
- **LCC over First Cost Criteria**
- **Performance Specifications**
  - Drying Shrinkage, ASR, Corrosion
- **Sustainability Framework for Infrastructure**
  - INVEST (FHWA)
  - Envision (ISI)







Resilience is a Subset of Sustainability



feature

Resilience is the new Sustainability

Disasters show the need to build for the future
Part 1

By: Tien Peng, Senior Director, Sustainability, Codes and Standards, NRMCA
Lionel Lemay, Senior Vice President, Development, NRMCA
Jon Hanson, Senior Director, National Resources, Mid/Northwest

Sustainability lessons from Katrina

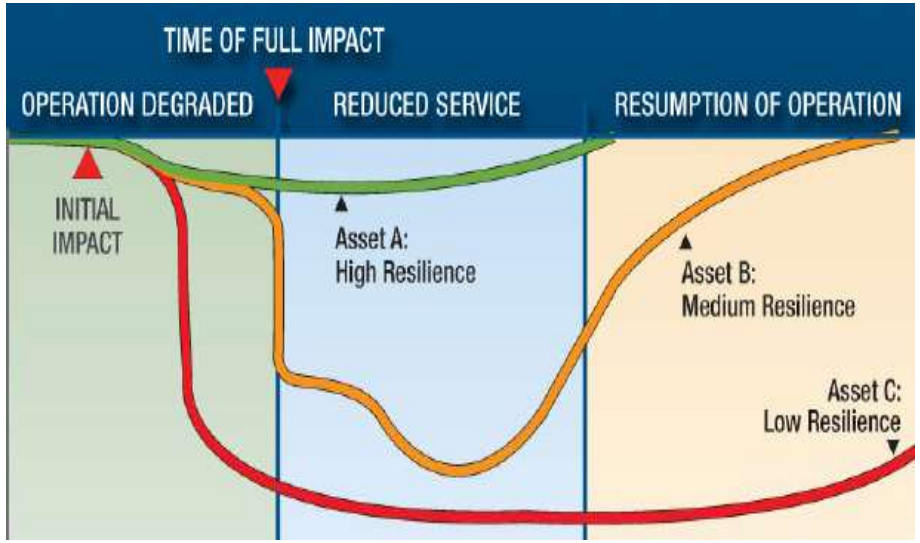
"Katrina was man-made," declared Brad Pitt, initiator of the Make It Right Foundation, the organization acting as the catalyst for the redevelopment of the Lower 9th Ward of New Orleans. Mr. Pitt was not addressing the Category 3 hurricane that made landfall on Aug. 29, 2005, killing more than 1,800 people, but the surge protection failures that happened as a result of decades of reckless handling of the levees, combined with the destruction of thousands of acres of buffering potential wetlands.

Katrina's storm surge submerged 80 percent of the city. A June 2007 report by the American Society of Civil Engineers indicated that two-thirds of the flooding was caused by the multiple failures of the city's floodwalls.' The storm surge also devastated the coasts of Mississippi and Alabama,

The Sundberg's concrete home survived the devastating effects of high winds and storm surge of Hurricane Katrina.

Implementation

- Higher-performance codes
- Materials
- Innovative practices



NRMCA, InFocus, Spring 2012; M. Kennett, Resilient Buildings Workshop, November 2012.

Durability, Robustness & Service Life

- It is imperative to include durability, robustness and adaptability into the original design of structures to accommodate resilience to natural and manmade disasters.
- Sustainable and Resilient considerations should be intertwined in design, materials, construction and maintenance of structures for the future.
- Designing functional resilience into structural design will support the resilience of the community.
- Design choices must consider present climatic conditions but also future climatic conditions while being practical and easily employed in the structures.

Silica Fume and Concrete

- Silica fume enables a greater replacement of slag cement and fly ash, as it enhances the reactivity of concretes in conventional and performance-based mixtures. Even at LOW dosages of 4-5%.

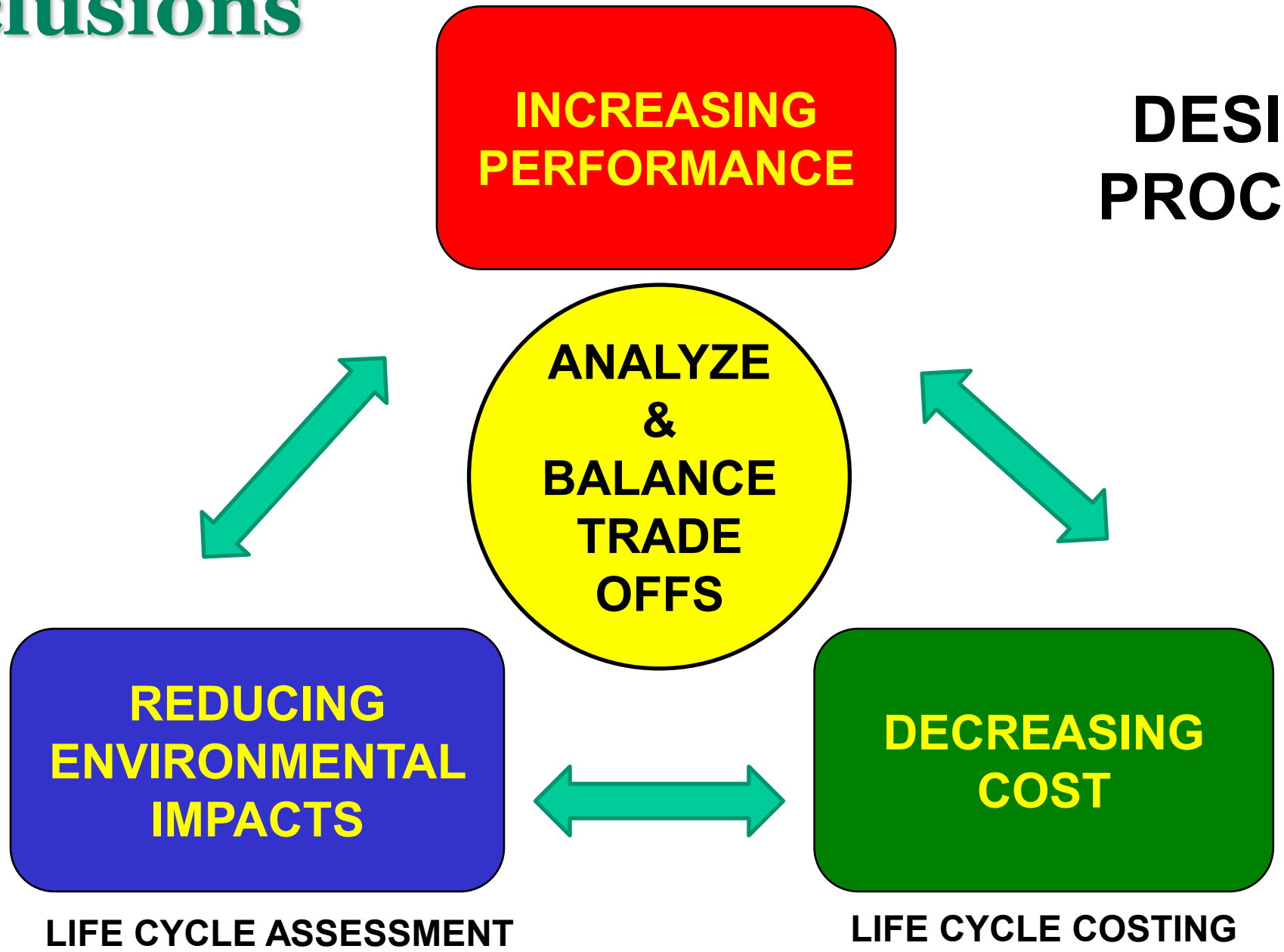


- High-performance concrete (HPC) is intrinsically sustainable. Silica fume is a key component in designing HPC.



- HPC and UHPC mixtures may contain SCMs, water-reducing admixtures (WRAs), and high-range WRAs (HRWRAs), and, in some cases, fibers that lead to lower cradle-to-grave GWP through extended service lives.

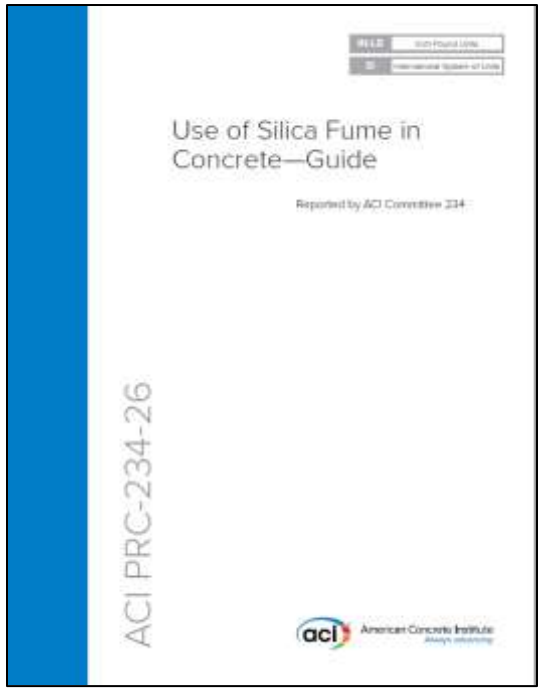
Conclusions



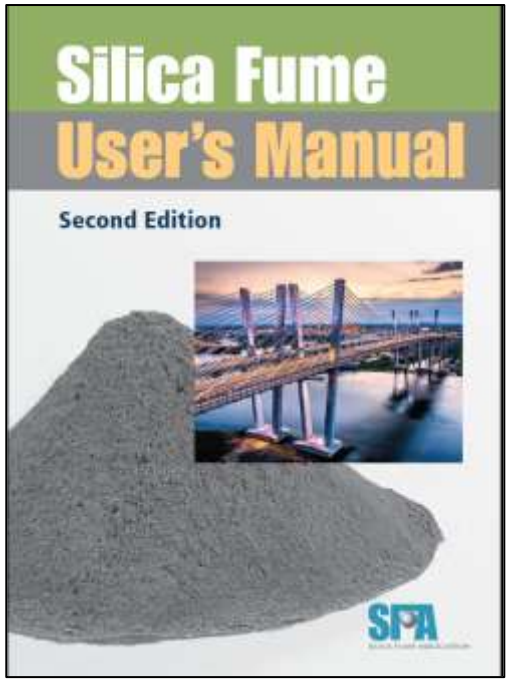
DESIGN PROCESS

Resources

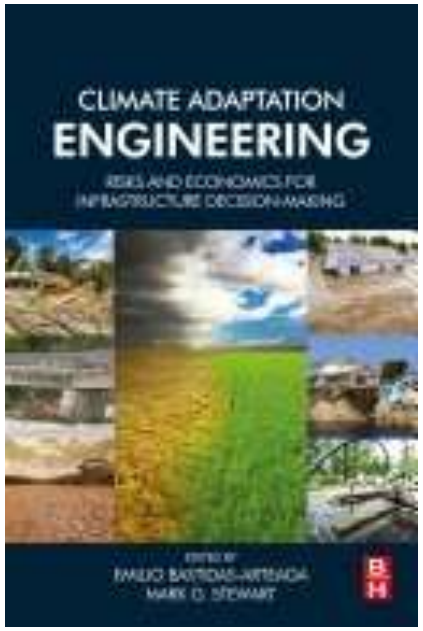
Resources



www.concrete.org



www.silicafume.org



www.google.com/books

neu
An ACI Center of Excellence for Carbon Neutral Concrete

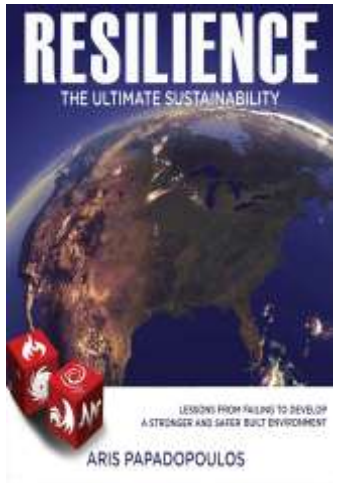
www.neuconcrete.org

Resilience Action Fund

buildingresilient.com

INVEST
ECONOMIC • SOCIAL • ENVIRONMENTAL

https://www.transportation.gov/grants/dot-navigator/infrastructure-voluntary-evaluation-sustainability-tool-invest





Questions ?



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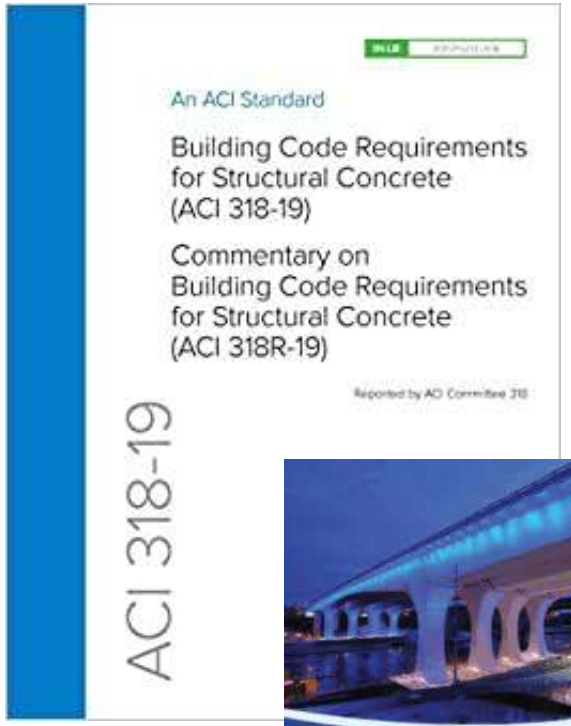
Thank you!

Please sign up for future NCBC webinars

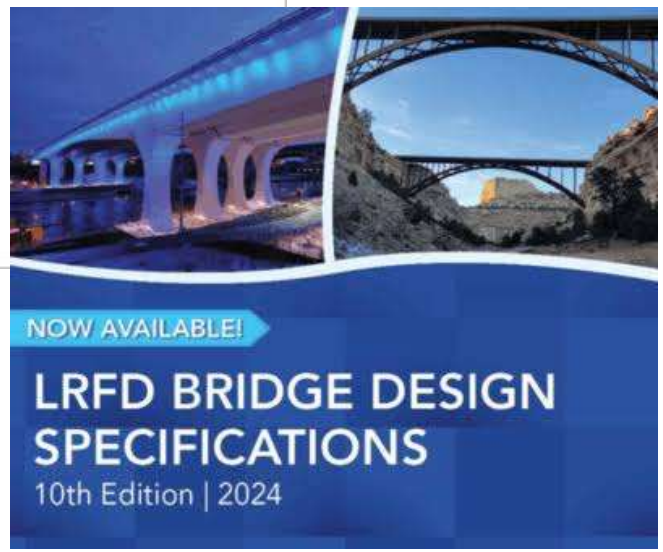
www.nationalconcretebridge.org

Photo: HNTB, © Core-Visual as seen in *ASPIRE* Summer 2023.

US Building & Bridge Codes



Appendix C: Sustainability Resilience



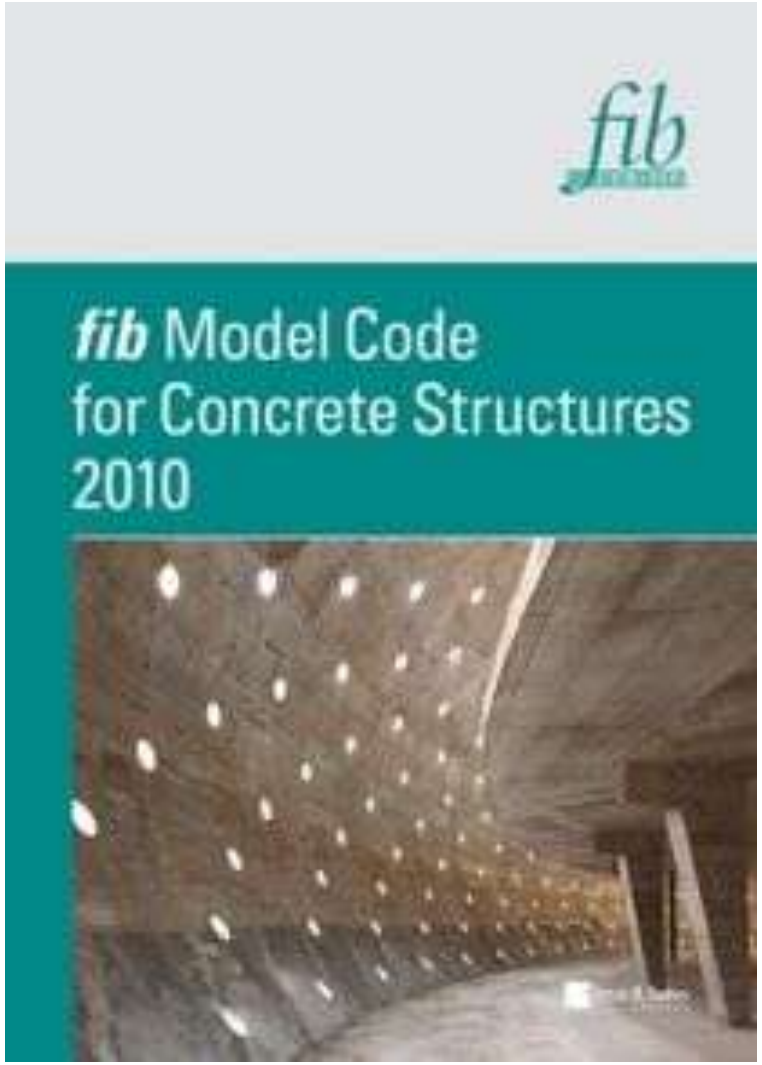
Integrating Environmental Sustainability and Disaster Resilience in Building Codes*

- **Codes**
  - The principal mechanism regulating the design and construction of structures.
- **Life Safety and Collapse Prevention Based**
  - Minimum level of threat that a structure must be able to tolerate
  - Probability-based ultimate strength design.

There are NO regulations for ensuring that a structure will be usable after a disaster.

*UN Top Priority

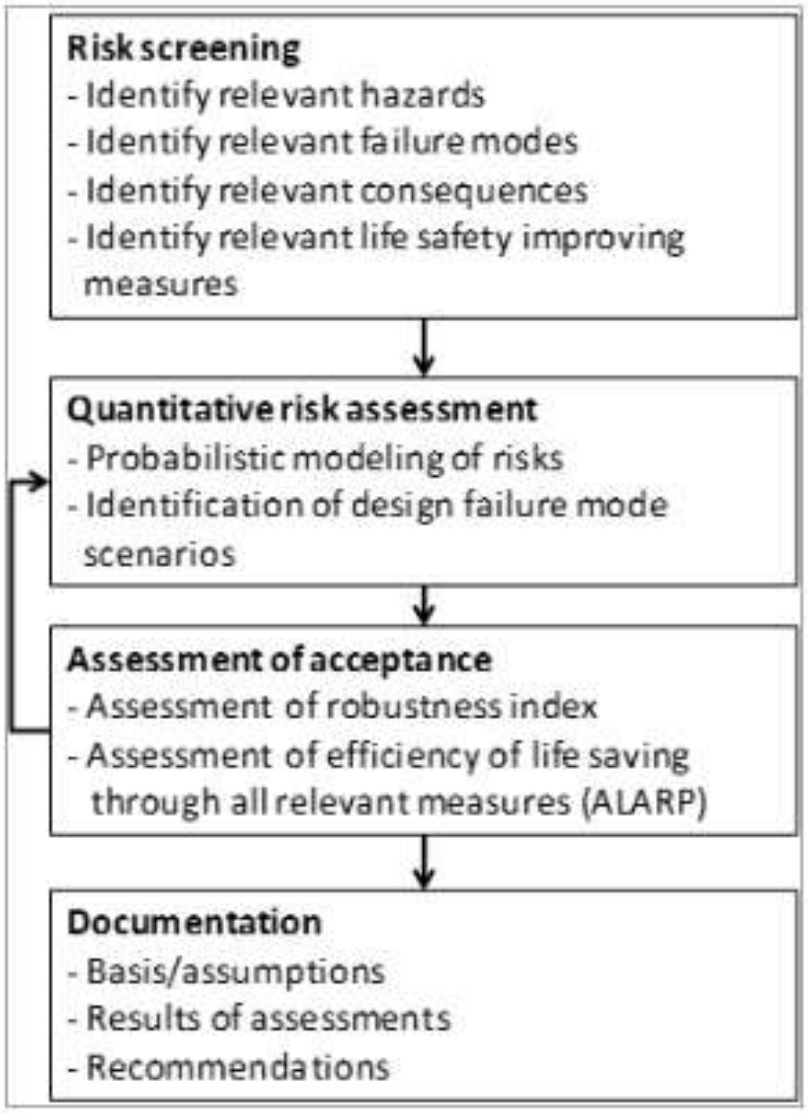
Model Code 2020



- Sustainability approach is a key conceptual principle to be considered through the life cycle of concrete structures in all activities, including design, production, construction, operation, maintenance, repair and dismantlement or circular use of any building or civil engineering work forming the built environment.

- Structural resilience, defined as ability of a structure to respond, absorb, and adapt to, as well as recover from a disruptive event, whereby a structure is expected to be able to resist an extreme event with minimal damages and functionality disruptions during the event and whereby after the event, the structure should be able to rapidly recovery its functionality similar to the pre-event level.

Model Code 2020



Consequence Type	Consequence
Health	Fatalities
	Injuries
	By damaging vital facilities (e.g. hospitals), spread of diseases
	Delayed long term health effects
	Psychological
Economic/Property	Damage to the building/structure
	Damage to surrounding properties
	Damage to contents
Business Continuity	Loss of income
	Loss of customers
	Inability provide vital services and/or activities
	Costs of detours and delays
	Costs to the economy of a region
Environmental	Reversible environmental damage.
	Irreversible environment damage
Social and Political	Loss of reputation
	Increase of public fears
	Loss of political support/enforcement of stringent new measures.
	"Blight"/long-term evacuation