Low Embodied Carbon Concrete Workshop Series: Near Zero & Zero Emissions Concrete for DOTs

May 29, 2024

State DOT Low Carbon Concrete Workshops

Workshop 1: Case studies from Buy Clean / EPD program implementation	JUNE 2023
Workshop 2: DOT Application of Limestone Calcined Clay Cement (LC3)	AUGUST 2023
Workshop 3: A Deep Dive on Specifications	JANUARY 2024
Workshop 4: Near Zero and Zero Emissions Concrete	TODAY

Speakers

Anish Tilak
Manager – Carbon Free Buildings at RMI

Audrey Rempher
Associate – Carbon Free Buildings at RMI

Sabbie Miller
Professor – UC Davis
Department of Civil & Environmental Engineering

Ben Skinner
Manager – Carbon Free Buildings at RMI

Agenda

Near Zero & Zero Emissions Concrete for DOTs

Welcome and speaker introduction	**10 mins**
Speaker presentations	**30 mins**
Q&A	**10 mins**
Live polling session	**10 mins**

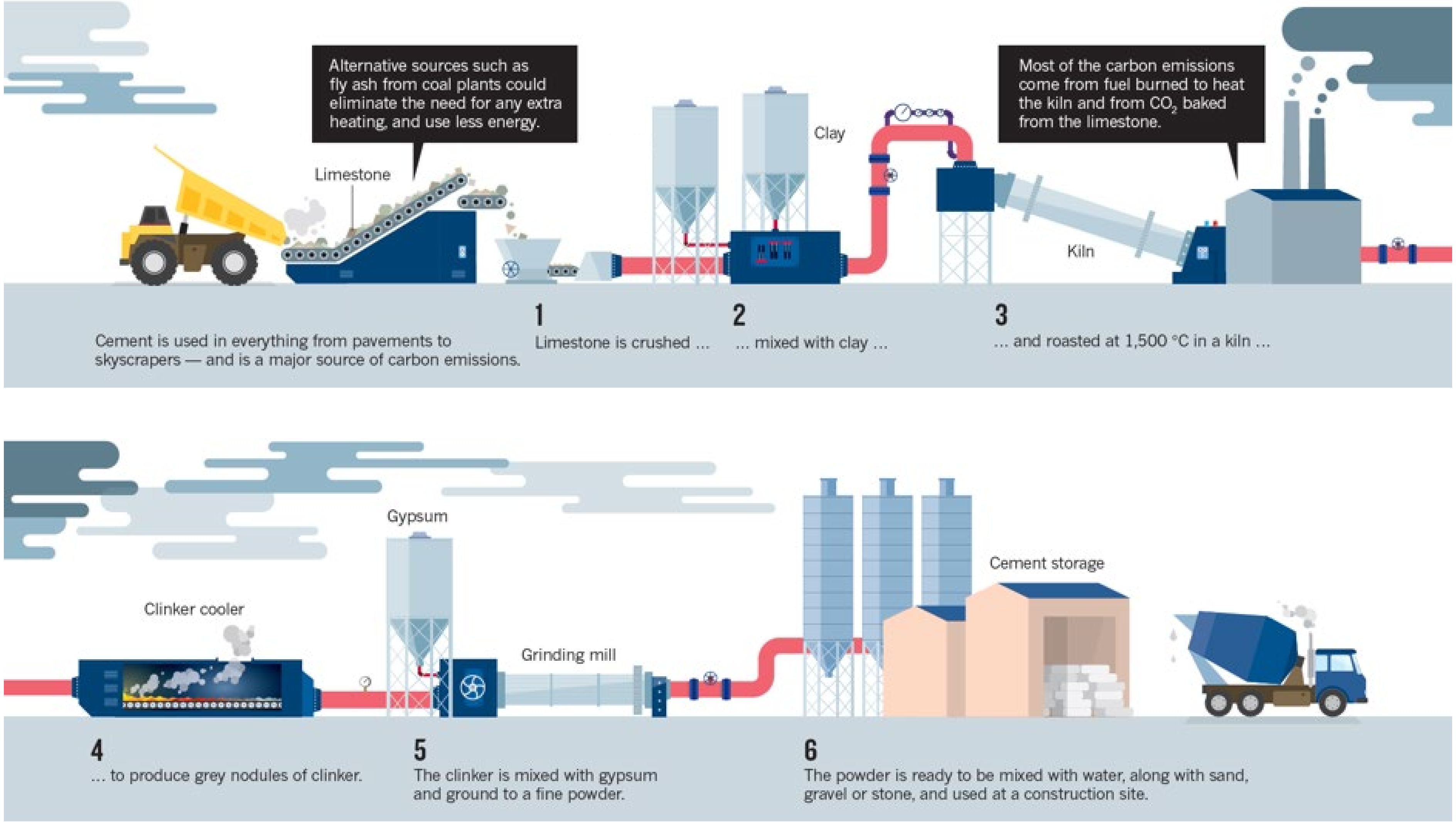
Near zero cement and integration pathways

Sabbie Miller
Associate Professor, University of California Davis
Faculty Scientist, Lawrence Berkeley National Laboratory

Agenda

- **Context**
- **Alternative materials**
- **Steps to integrate new strategies**
  - **Life cycle assessment**
  - **Performance and piloting**
  - **Specifications**
- **Fast wins**

Cradle-to-gate emissions



(Amato, 2013)

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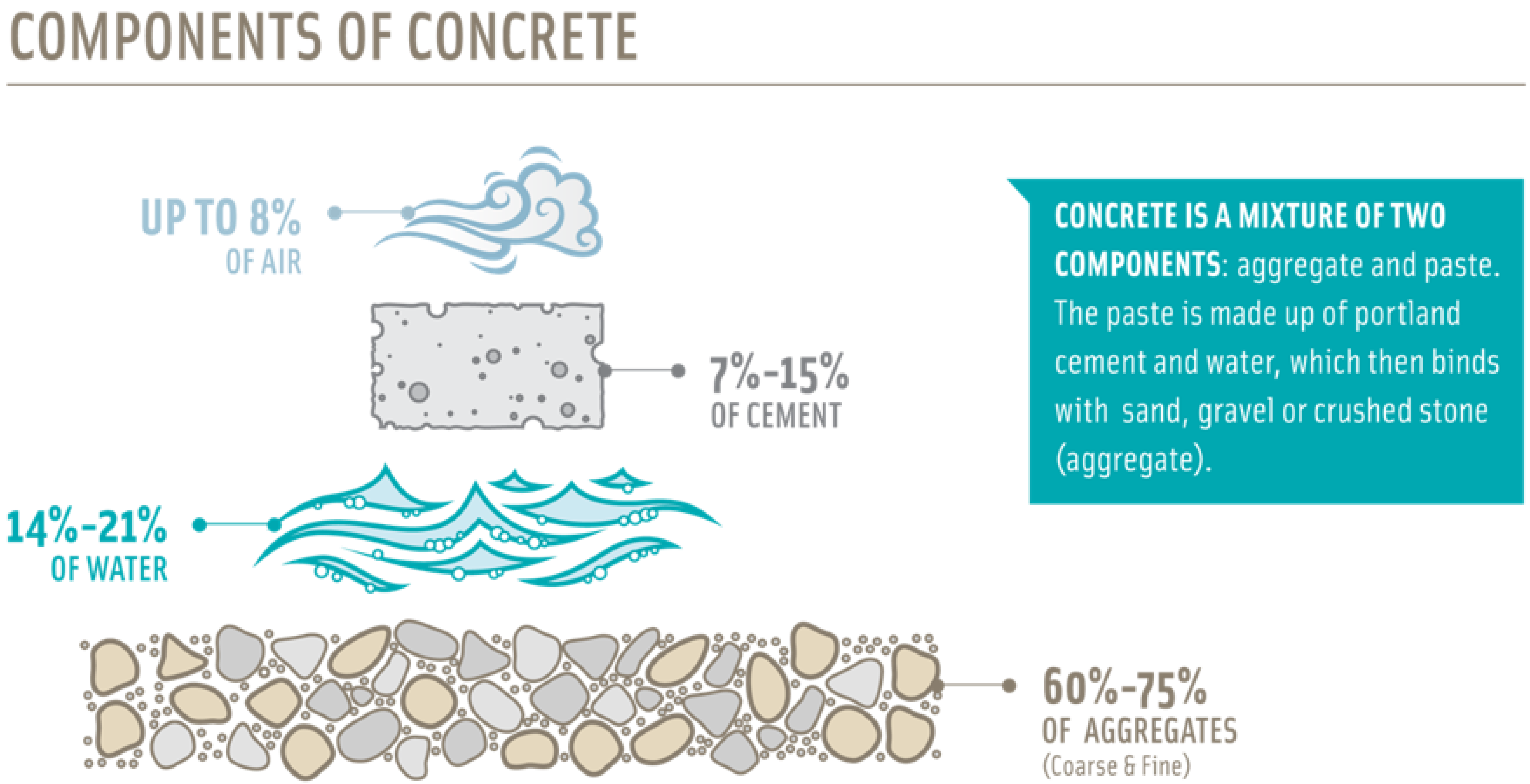

(PCA 2017)

Alternatives

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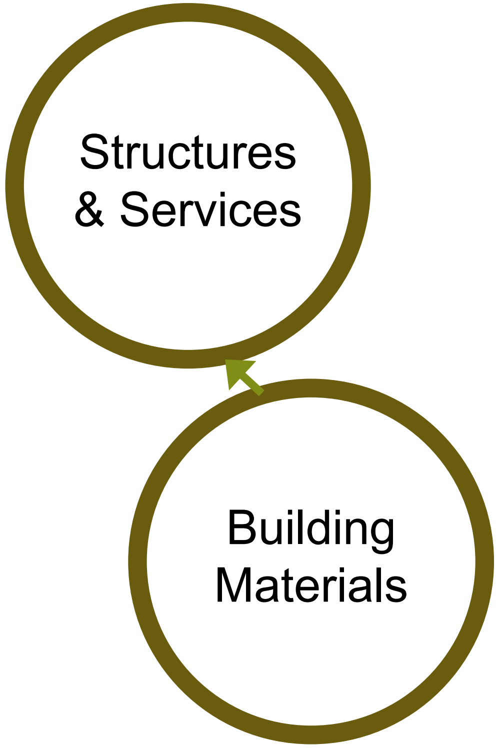
- Alkali activated materials
- Electrochemical production, biocements, or chemical dissolution of minerals

Building materials

Building Materials

Building materials



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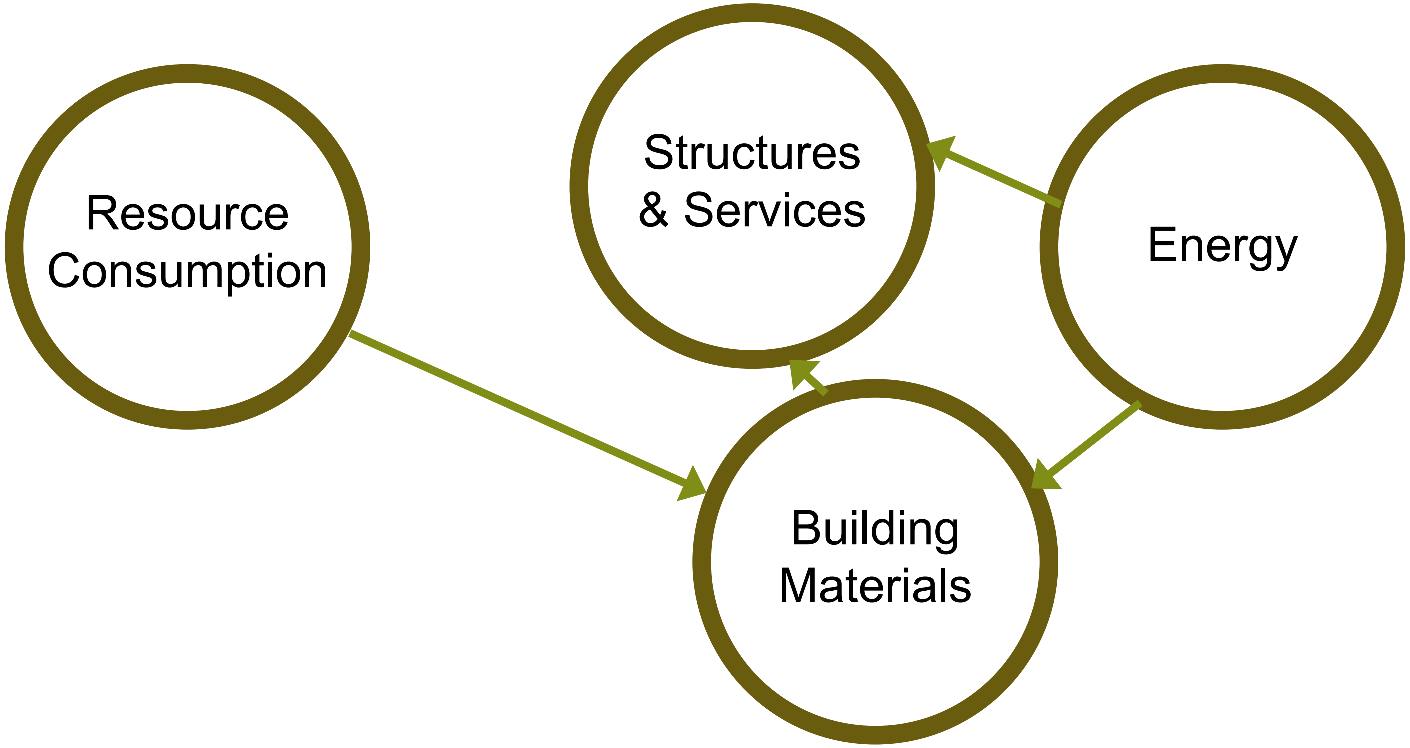

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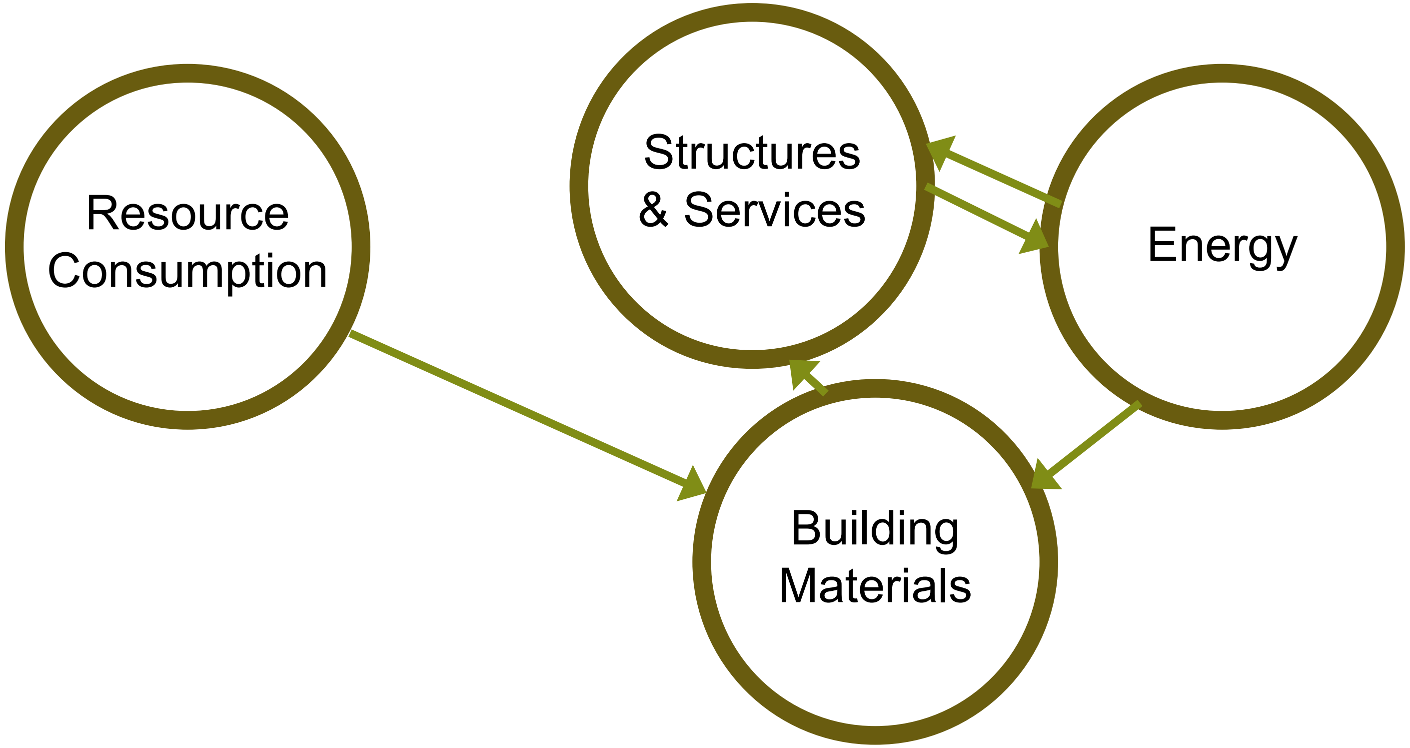

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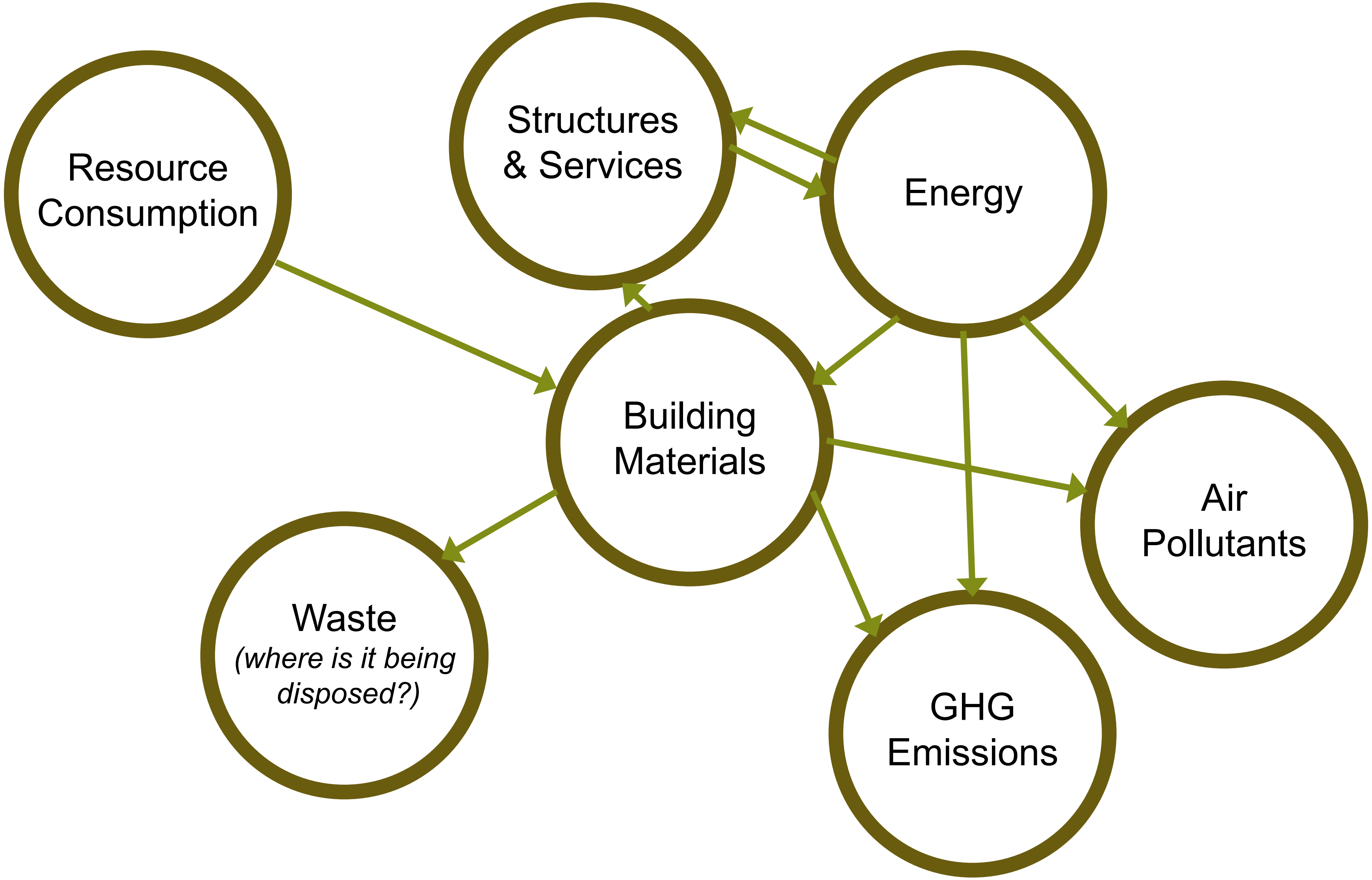

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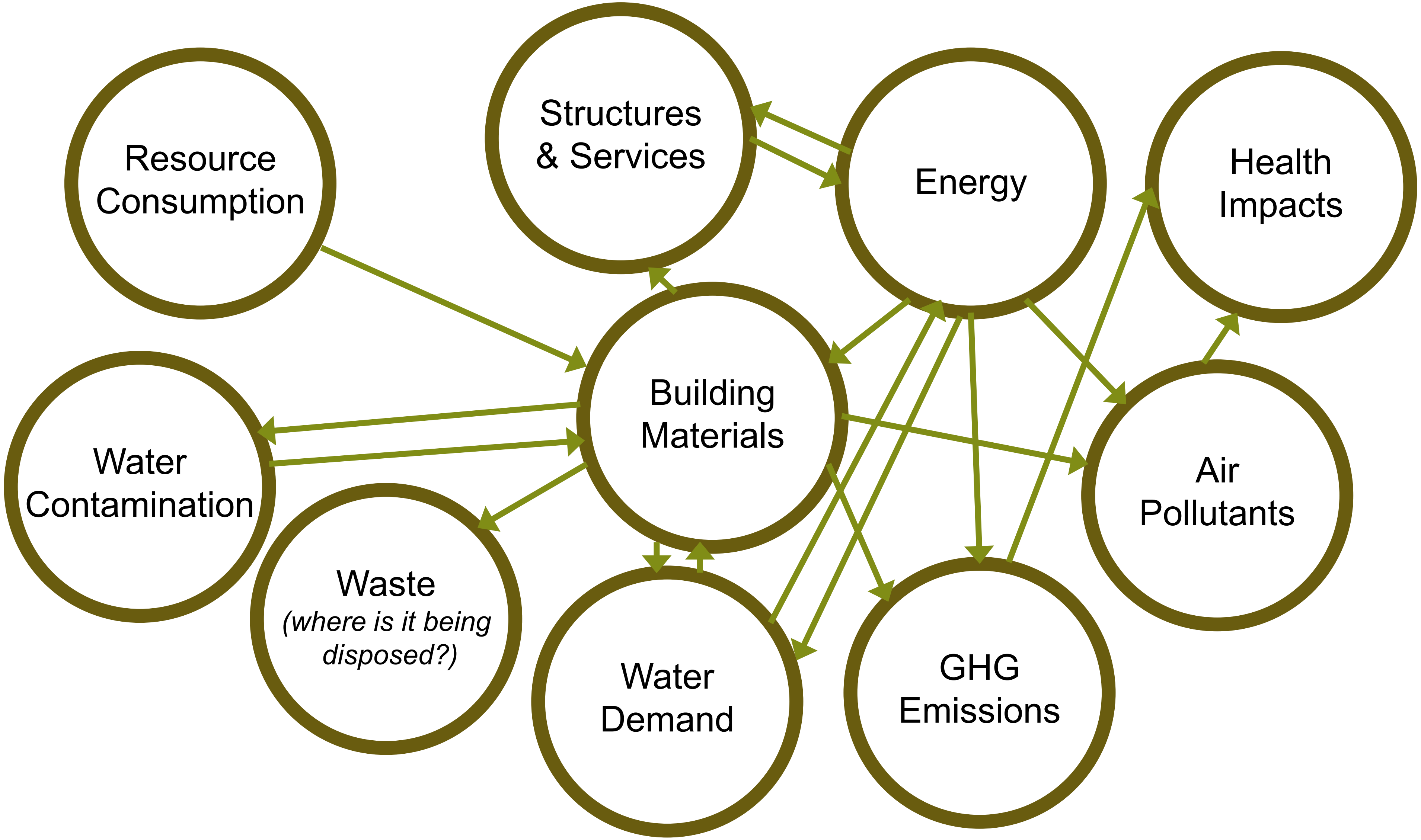
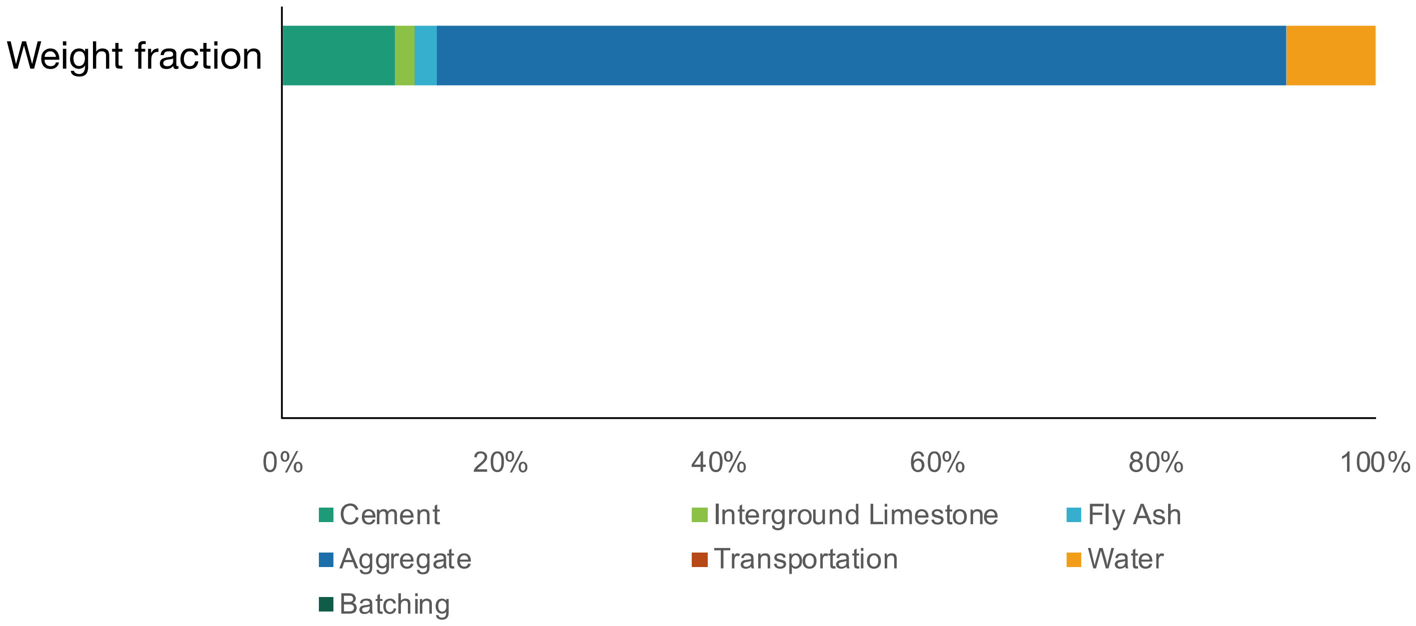


Concepts as applied to concrete



(Kim *et al.* 2022)

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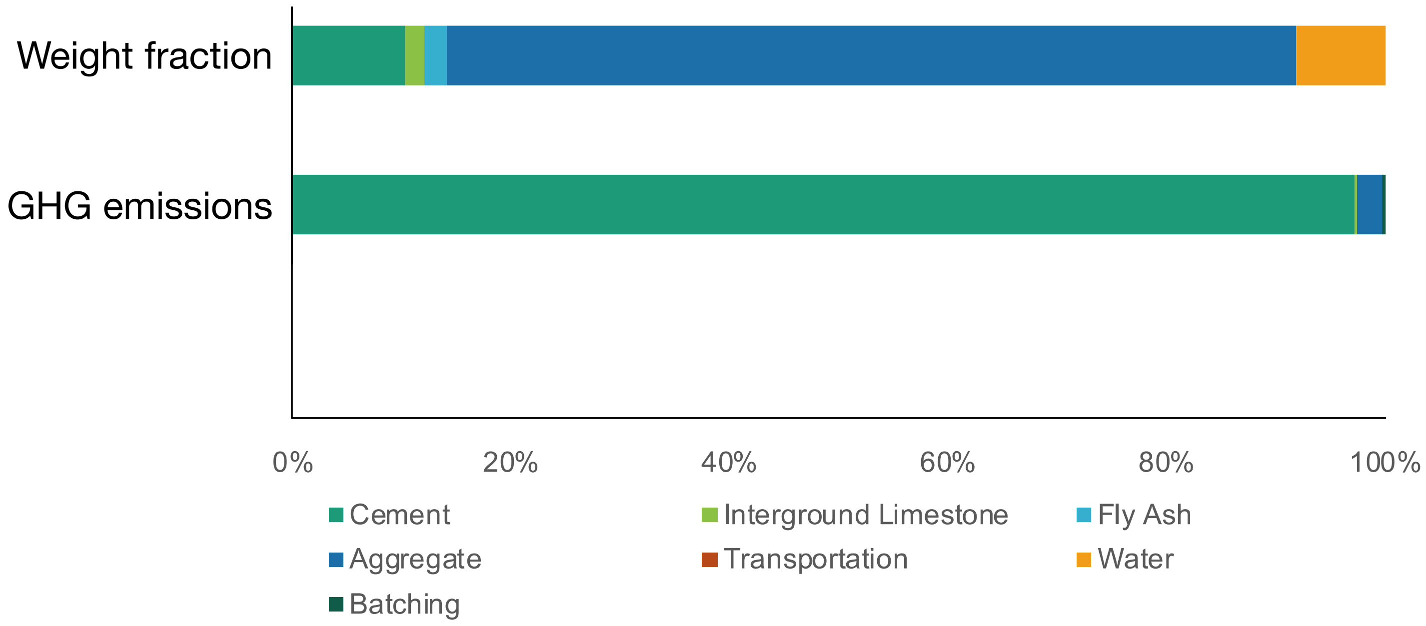

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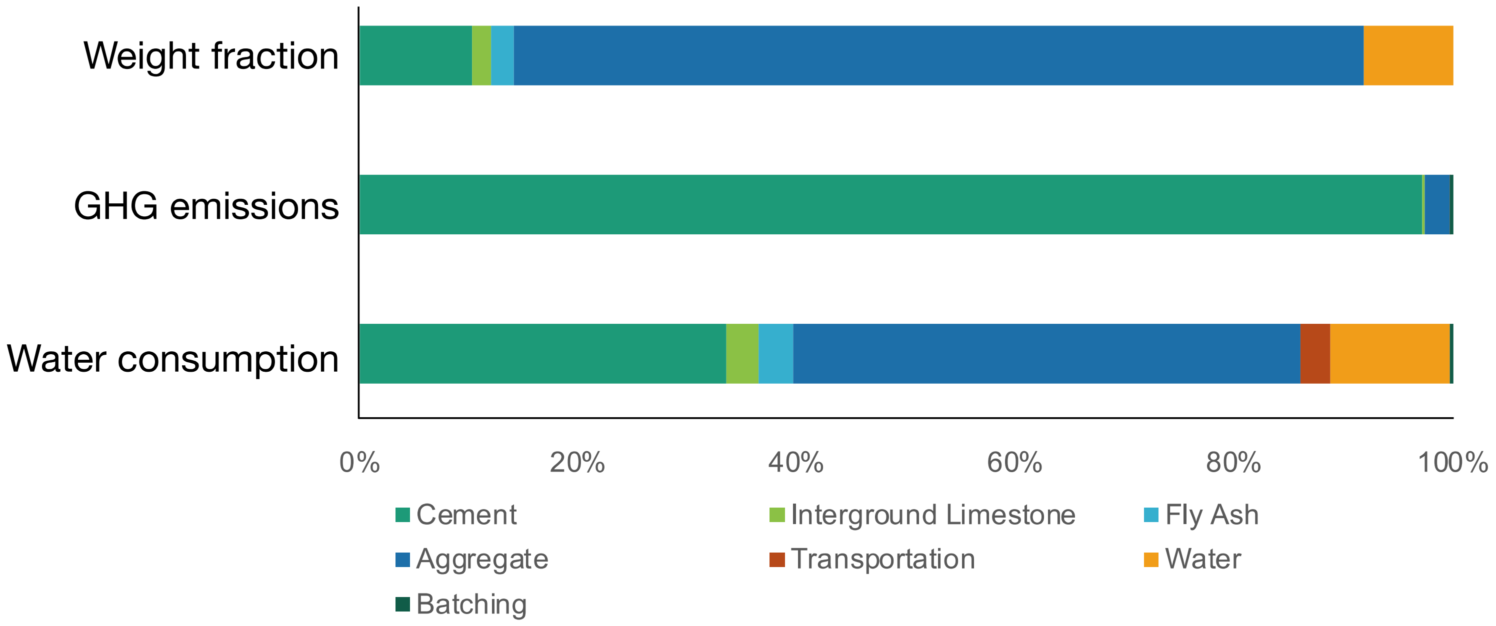
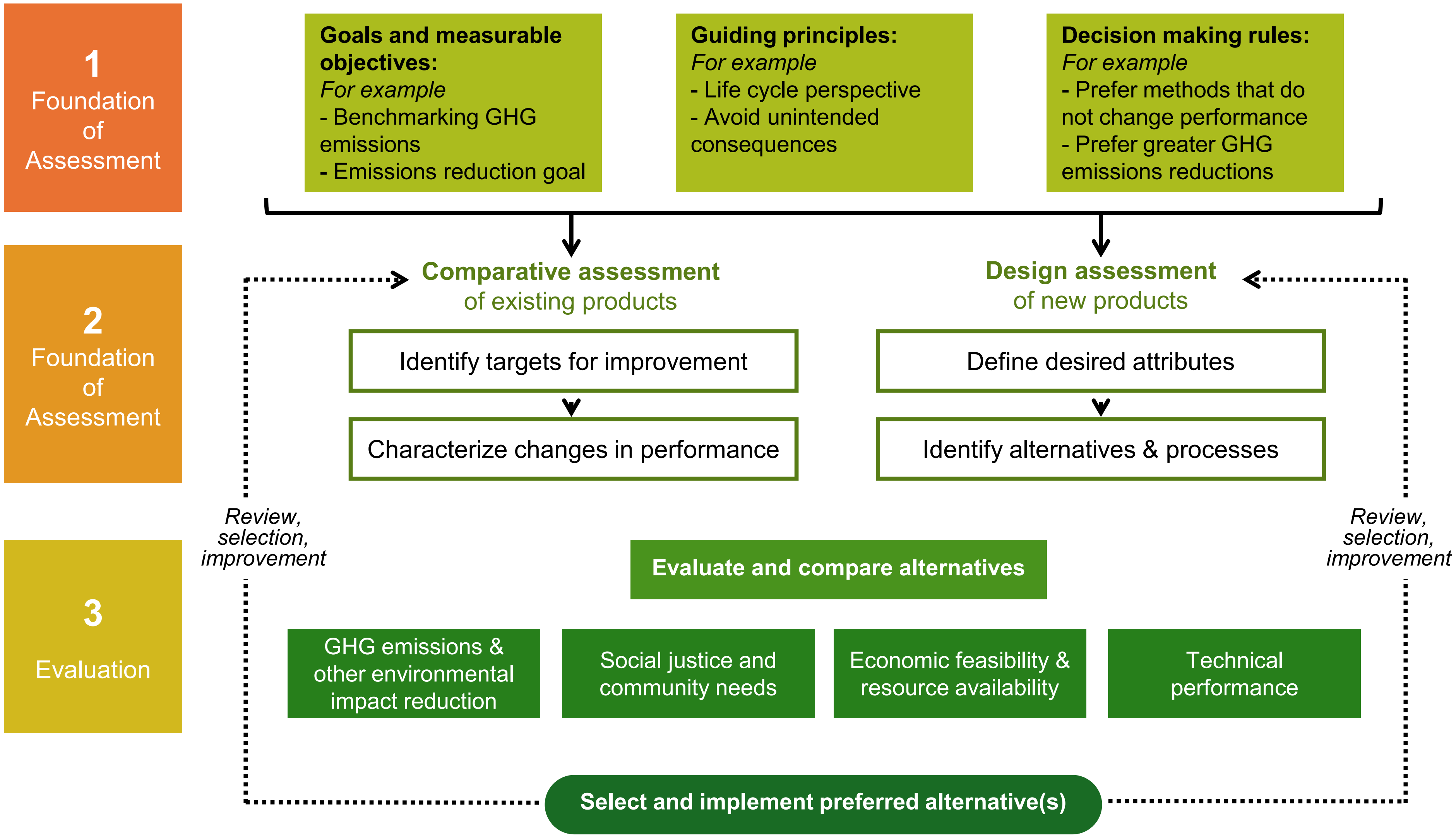


(Kim *et al.* 2022)

Framework for implementation



(Adapted from Rossi, 2006)

Framework for implementation

- Remain technology agnostic, and establish physical, thermodynamic, and environmental potential

- Next:

1. Conduct robust Life Cycle Assessments – avoid unintended consequences
2. Conduct supply assessments – capacity & availability
3. Determine technology readiness, remaining barriers to scale
4. Laboratory scale validation (e.g., ASTM C150, C595, C618, C311, C1897, C1157, C1697, and others)
5. Concrete testing – ensure appropriate education of different characteristics, e.g., finishing, strength development, other differences
6. Field testing
7. Other steps required by your individual DOT
8. Consider integration of key steps to adoption in state DOT specifications so alternative material producers are aware of key steps needed for adoption.

Launching Lab-to-Slab Initiative at UCPRC

FHWA Sustainable Pavement Program Cooperative Center (SPPCC) at UC Davis

- Lab-to-Slab evaluation includes:
  - Prequalification laboratory testing: working at lab scale?
  - Construction of test slabs at UCPRC:
    - QA/QC testing as part of construction
    - Constructability evaluation
  - Several years of monitoring for volumetric stability under environmental loading
- We will send regular updates from lab-to-slab@ucdavis.edu to all suppliers who have provided materials for testing
  - Send an email lab-to-slab@ucdavis.edu to keep informed
- Join the initiative by providing your materials for construction
  - Each test section to be about 9 cu yd of concrete (this is flexible)

Potential fast wins

- Performance-based specifications (instead of prescriptive)
- Consider material longevity, where can repurposing, diamond grinding, or other mechanisms allow for elongation of life without substantial material or vehicle emissions
- In cases where you have multiple materials (e.g., steel), design for low emissions while remaining within the code
- Provide mechanisms that can offer insurance against risk of failure

Efficient utilization of materials and resources

Examples

Less construction; efficient cross-sections; substitution of high emissions materials; material efficiency

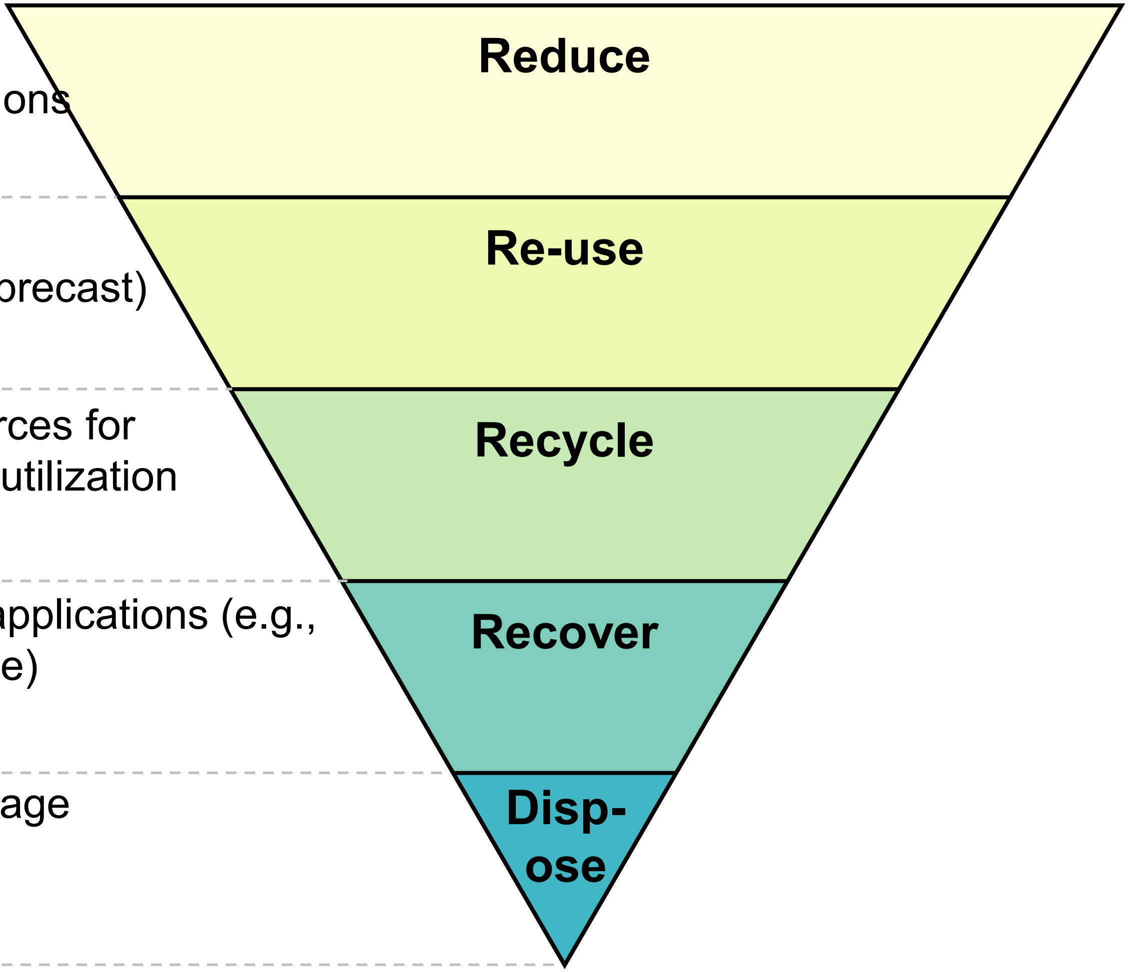
Standard component connections; prefabricated panels; off-site (e.g., precast) manufacturing

End-of-life materials used as resources for new materials; carbon capture and utilization

End-of-life materials used in other applications (e.g., crushed concrete used as road base)

Landfilling; carbon capture and storage

Materials use hierarchy



(based on Miller 2021a)

RMI
ENERGY. TRANSFORMED.

Concrete Innovation Landscape

Ben Skinner
Manager, Climate-Aligned Industries, Concrete/Cement

Global Initiatives are pushing to hit decarbonization targets in 2030 and Net Zero 2050

iea

CLIMATE GROUP
CONCRETE ZERO

gcca

Global Alliance for Buildings and Construction

wbcsd

eit Climate-KIC

C40 CITIES

CONCRETE SUSTAINABILITY COUNCIL

GSA

neu
An ACI Center of Excellence for Carbon Neutral Concrete

Net Zero Teesside

INNOVANDI
Open Challenge

Energy Transitions Commission

First Movers Coalition

INDUSTRIAL DEEP DECARBONISATION
AN INITIATIVE OF THE CLEAN ENERGY MINISTERIAL

Current Global Cement/Concrete Decarbonization Efforts

INITIATIVE	TYPE	DEFINITIONS & BENCHMARKS	TARGET
FMC	Public-private	Near zero emissions cement: 184kgCO_2/t. Near zero emissions concrete: 70-144 kgCO_2/m^3.	10% by 2030
IDDI	Public	Near zero emission cement: 40-125 kgCO_2e/t. Low emission cement: 250-750 kgCO_2e/t.	Signatories to decide
ConcreteZero	Private	Low embodied carbon concrete: 100-270 kgCO_2/m^3. Net zero concrete: As close to zero as possible with at least 90% mitigation.	30% low carbon by 2025 50% low carbon by 2030 100% net zero by 2050

Innovation Landscape

Alternative SCMs

What's the problem?

- Traditional SCMs have seen a reduction in availability and quality, resulting in the need for new SCMs.

What are alternative SCMs?

- SCMs are used as substitutes to lower the amount of carbon-intensive clinker used and to improve performance.

Why do we care?

- Leveraging alternative SCMs in mix design increases cement replacement, lowering the emissions associated with the mix.

Innovation Landscape

Alternative Cements

What's the problem?

- Decarbonizing OPC requires CCUS, which is expensive and logistically challenging.

What is alternative Cement?

- Alternative cements leverage material and production process changes that can result in different physical and chemical properties and lower carbon emissions.

Why do we care?

- Alternative cements offer zero or near zero emissions alternatives to OPC.

Innovation Landscape

Alternative SCMS

- Calcined clay
- Concrete fines
- Reactive silica from mine tailings
- New or synthetic fly ash, slag, or limestone
- Carbonated SCMs
- Bio ash

Alternative Cements

- Belite-rich cement
- Calcium sulfoaluminate
- Alkali-activated materials
- Bio-based cement
- Calcium silicate-based
- Carbonation based cements

Startup Landscape

	Make Less (use more SCMs)		Make Better (Optimize)		Make New (ACMs)	
	Existing:	**Startups:**	**Existing:**	**Startups:**	**Existing:**	**Startups:**
Known	• Slag • Fly ash • Ground limestone • Natural pozzolans	cocoon	• LCA and EPDs • alternative materials in appropriate applications		• Limestone-based (CSA, BCS, CAC) • Magnesium-based	
Growth	• ground glass pozzolan • calcined clay (LC3) • silica fume	THINK pozzotive	• Design efficiency, measurement and optimization		• Geopolymers • Alkali-activated materials	BETOLAR ecocem
New & Alternative	• bio ash (rice husk ash) • Reused activated concrete • Mine tailings • Beneficiated fly ash, slag, or quarry waste	ENVICORE fortera SonoAsh LLC COAL ASH 2.0: A STRATEGIC RESOURCE MAGSORT TERRA CO2	• AI for concrete mix design • Admixtures to improve SCM performance and increase volume. • Superplasticizers • Manufactured aggregates	MIXTERESTING AI FOR GREEN CONCRETE alcemy AICRETE concrete.ai Blue Planet SOLID CARBON ecoLocked NEOCRETE REDEFINING CONCRETE	**Bio-based:** BIOMASON PROMETHEUS MATERIALS MINUS MATERIALS	**Mineral-based:** BRIMSTONE Sublime Systems CarbiCrete fortera AMATEC

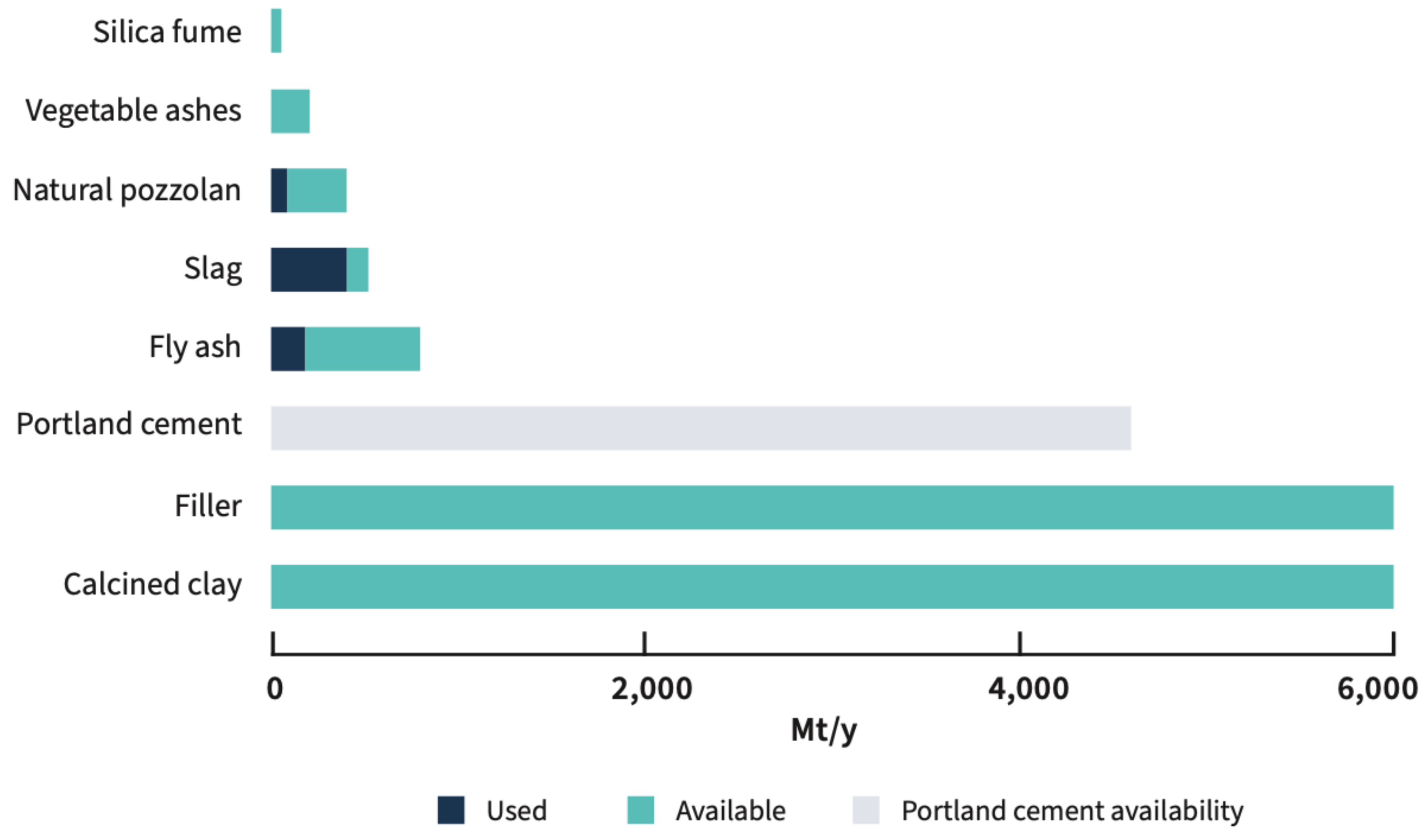
Source: MPP STS Cement and Concrete, RMI Research

DOE grant awards signal technology shift

Project Name	Location	Grant Size	Company	Technology
First Commercial Electrochemical Cement Manufacturing	Holyoke, MA	$86.9M	Sublime	Alternative cement
Lebec Net Zero Cement Plant Project	Lebec, CA	$500M	National Cement (Vicat)	SCM (LC3), Alt Fuels, CCS
Limestone Calcined Clay Cement Production	Troutville, VA	$61.7M	Roanoke Cement (Titan)	SCM (LC3)
Low-Carbon Calcined Clay Cement Demonstration	Port Deposit, MD; McIntyre, GA; Elmendorf, TX; Sulphur Springs, TX	$215.6M	Summit Materials	SCM (LC3)
Mitchell Cement Plant Decarbonization Project	Mitchell, IN	$500M	Heidelberg	CCS
Deeply Decarbonized Cement	TBD	$189M	Brimstone	Alternative cement

Source: DOE

Use and estimated availability of possible SCMs and fillers compared with portland cement



Note: Fillers are fine particulate materials, inert or weakly reactive, produced by grinding, that can partially replace clinker or other reactive SCMs.

Source: Eco-efficient Cements, MPP Cement and Concrete STS

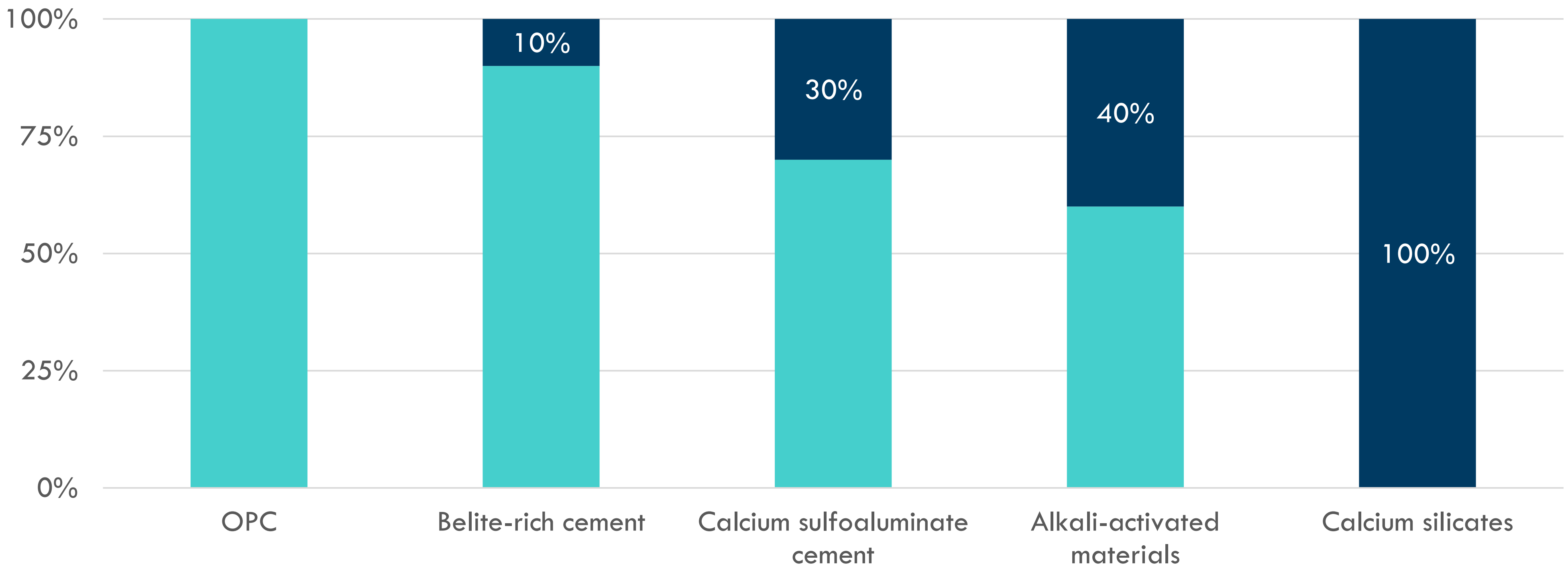
SCMs provide additional benefits on top of carbon reductions

Category	SCMs	Benefits
Conventional SCMs	Slag	• High substitution rates possible
	Fly ash	• Utilizes waste product from coal combustion • Greater availability than slag
	Ground limestone	• Widely available • Low cost
	Natural pozzolans	• Higher durability and increased resistance to chemically-aggressive environments
	Silica fume	• High (early) strength and resistance to chemically-aggressive environments
Alternative SCMs	Calcined clay	• Abundant reserves across the globe • Cost-efficient • Synergies with limestone and clinker (LC3 cement) lead to strength and durability benefits
	Vegetable ashes	• Improved long-term strength and durability
	New or synthetic SCMs	• Increases potential supply of raw materials (ie bottom ash) • Other co-benefits such as storing CO2
	Reactive silica from mine tailings	• Large quantities across the globe • Reduces solid waste from mining
	Concrete fines	• Help reduce landfilling of demolished structures

Early LC3 applications demonstrate performance

Source: LC3 in use

Emissions Savings Potential of Alternative Cements



Note: Bio-based cement is not included in the comparison because there is no publicly available data on its emissions saving potential.

Source: Third Derivative, Alliance for an Energy Efficient Economy, and Hanein et al.

SCMs and alternative cement challenges

Integration vs Disruption. While solutions that integrate with existing processes may face less challenges than disruptors, we feel there is room, and requirement, for both.

Sourcing raw materials at scale. To succeed, innovations need a raw material that is abundant enough to serve a significant market.

Costs of early-stage technology development, and high capex needed to get a foothold.

Standards and code acceptance. SCMs that fall under existing codes and procurement specifications face less challenges. However, alternatives are not currently specified in standards and may need new codes (ie ASTM) to be developed, which will take time.

Testing for standards and performance requirements: structural and EPDs. In general, testing to meet standards is slow and expensive, which can present fiscal and timing challenges for innovations. EPDs are critical for sourcing low-carbon concrete from major incumbents. However, EPD requirements are currently a major barrier for innovative startups, as EPDs require 18 months of data at commercial-scale manufacturing facilities, which early innovations don't have.

Consumer preference and risk aversion. Many consumers (purchasers – materials procurers, contractors, developers) are risk adverse and very hesitant to try new mix designs where they may be liable if failure occurs. Public (Government) purchasers can significantly de-risk new innovations for the rest of the construction industry through testing and pilots.

Source: MPP STS Cement and Concrete

Decarbonized Cement & Concrete Alliance

Blue Planet™

PROMETHEUS MATERIALS

fortera

CARBONBUILT

BIOMASON

SOLIDIA®

MINUS MATERIALS

BRIMSTONE

chement

QUEENS CARBON

Sublime Systems

TERRA CO2

Where to Start

First projects to…

Test the use of alternative cements & concretes in *nonstructural components* of construction projects.

- low-risk
- jumpstart market penetration
- allows for collection of real-world data

Performance-Based Mix Specifications and testing that…

- ✓ demonstrates reproducibility of results
- ✓ is practical and relatively quick to conduct
- ✓ allows for sampling and uniformity testing

For all durability exposures:

- A test that can measure or provide an index of the resistance to ingress of aggressive fluids (e.g. RCPT or Bulk Resistivity).
- ASR tests to qualify the aggregates, or to determine required mitigation, if aggregates are potentially reactive

For specific exposures (as applicable):

- Sulfate Resistance test for chemical resistance of cementitious materials.
- Freeze/Thaw test
- De-icer salt scaling test.

Demonstration of Innovative, Emerging Low-Carbon Materials

Recommended Project Opportunities:

1) Develop concrete mixture approval process that is performance-based and applicable to all concrete materials

2) Develop site demonstration placements to evaluate the constructability and performance of key emerging low-carbon concrete solutions

3) Set informed near-zero or zero GWP thresholds without prescriptive material specification with consideration of design and construction needs and local material availability

4) Leverage EPD procurement processes to ensure that low-carbon outcomes are validated

5) Coordinate with other DOTs and FHWA to develop a consistent data reporting framework across all states

Scan this QR code to view RMI's recommended low-carbon concrete initiatives for FHWA LCTM applications

Instructions

Go to

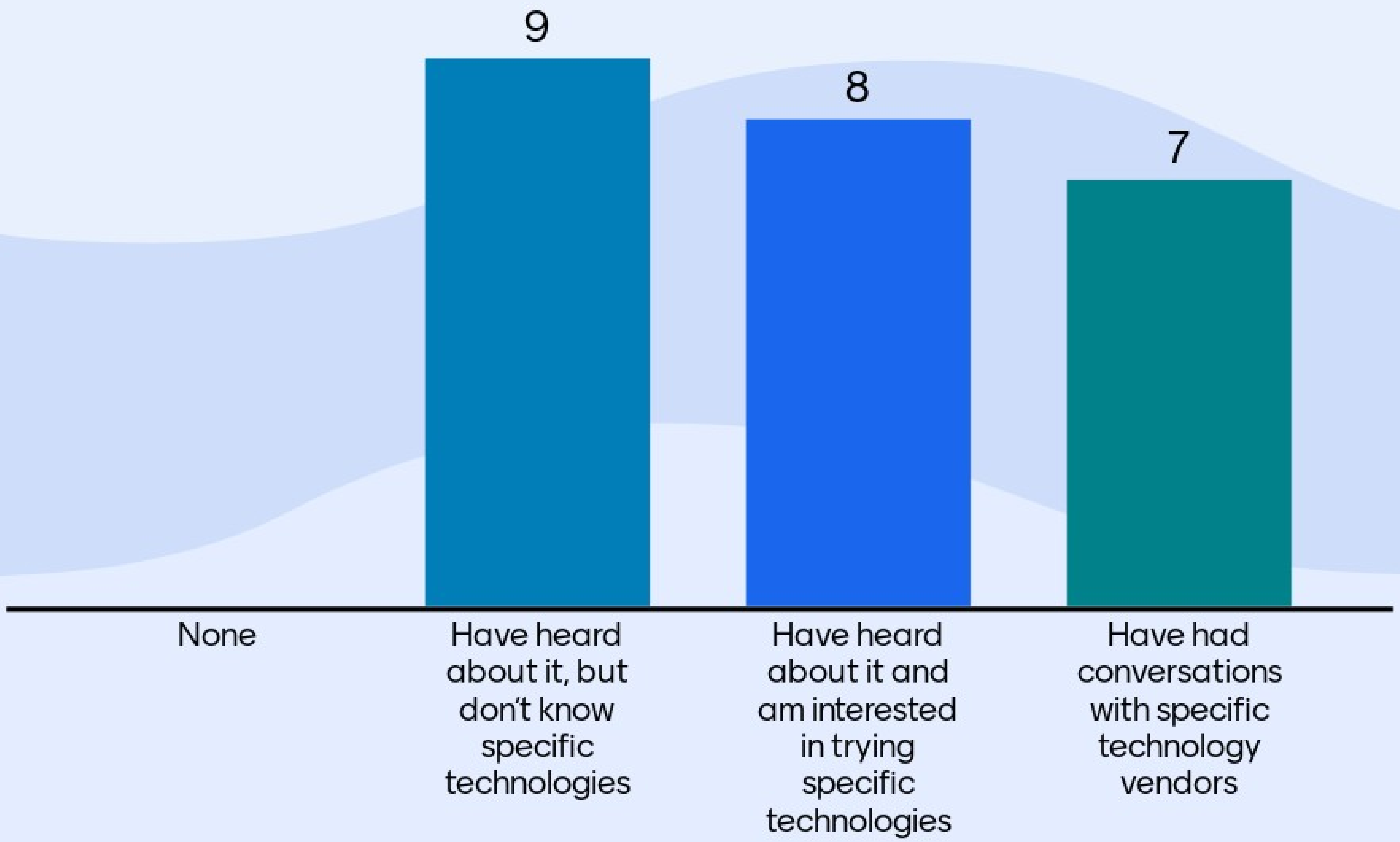
www.menti.com

Enter the code

2727 0308

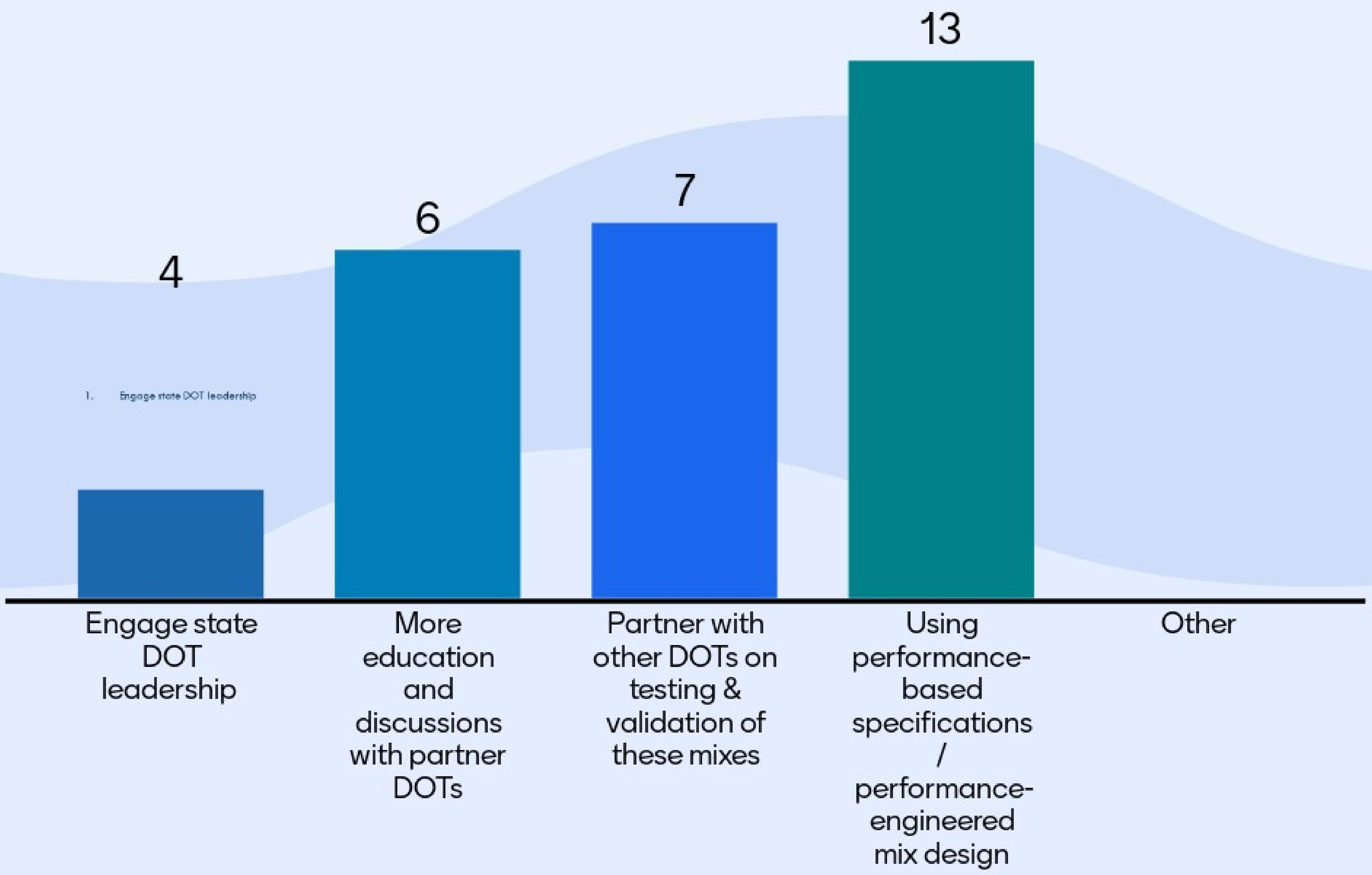
Or use QR code

What is your knowledge of near-zero emissions concrete products?



Mentimeter

What do you believe is your first step to demonstrating near-zero emissions concrete? (check all that apply)



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Mentimeter

If you chose other, what do you think should be the first step? (fill in the blank)

Incentives to use low carbon cements and SCM's

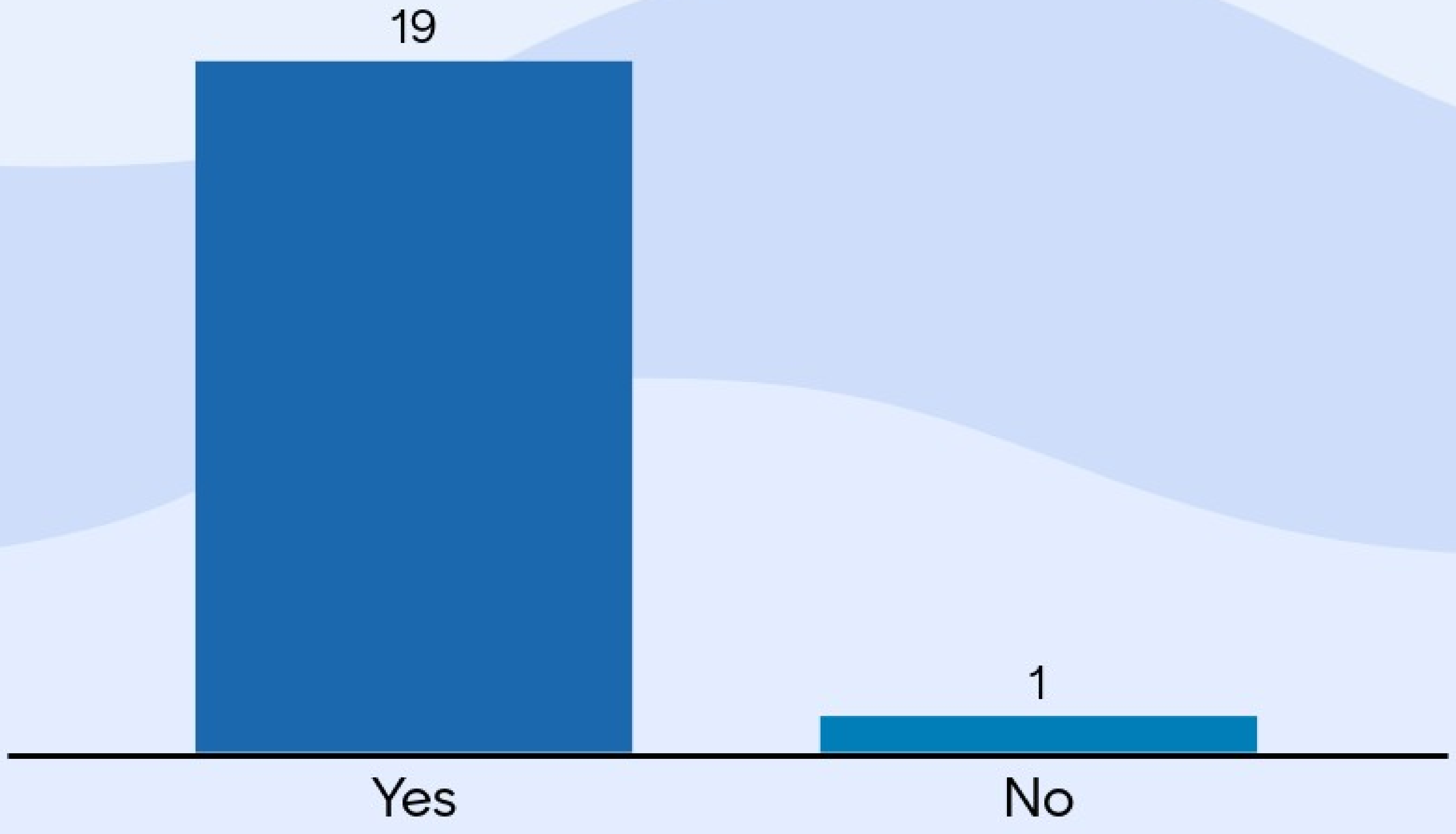
Not a first step, but contacting insurance companies to see how they would treat new concrete formulations is one idea.

Quantify carbon intensity contributions of zero emission concrete in the construction supply chain

Yes

4

Are you interested in or currently pursuing a demonstration project using performance-based specifications?



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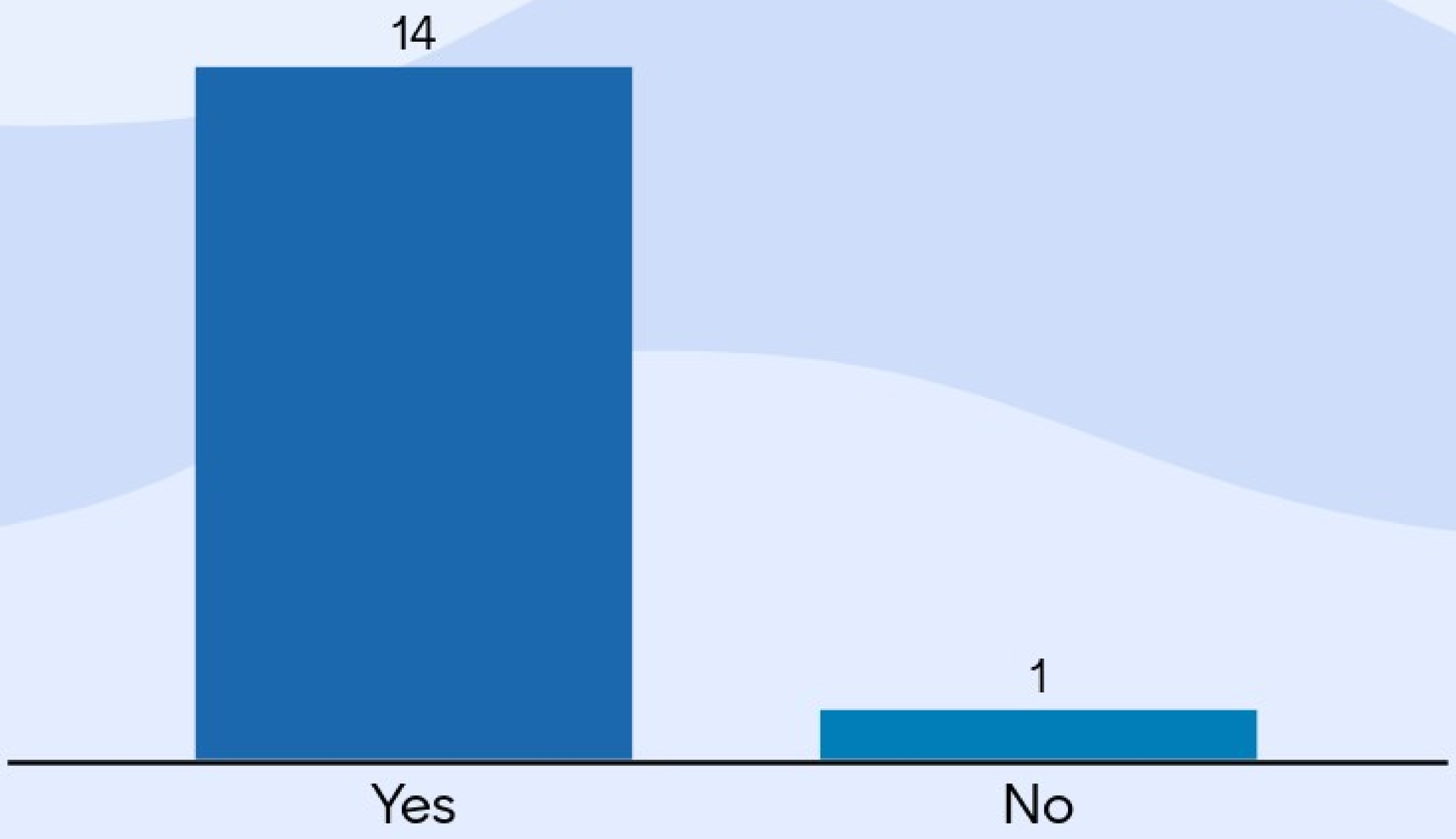
Are you interested in trying performance-based specifications for near-zero emissions concrete?



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Mentimeter

What type of support, education, or technical assistance do you need to begin using near-zero emissions concrete?

- Could use help dealing with insurance companies to see how they will treat our use of these new materials and get their support.
- Online trainings
- Understand impacts on design and construction practices
- More case studies of successful uses!
- Cost vs benefits report especially regarding carbon intensity
- Research, database/shared knowledge
- More information on scalability of these technologies, not interested in one-off projects
- Incentivize bidding processes so that lower carbon materials are promoted

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Mentimeter

What type of support, education, or technical assistance do you need to begin using near-zero emissions concrete?

Reduce red tape to do a demo

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Thank you for attending!