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Back to Basics

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DENVER, COLORADO | OCTOBER 22-25, 2024

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The Future of Cementitious Materials:
Portland-Limestone Cements and Other Blended Cements

Presented by: Michelle L. Wilson
Portland Cement Association

2024 FALL CONVENTION
OCTOBER 22-25, 2024

Copyright Materials

Learning Objectives

Upon completing this program, the participant should be able to:

1. List the different cement specifications and types of cement available for construction
2. Discuss the influence each cement type has on fresh and hardened properties of concrete.
3. Define several emerging trends and innovations in cement.
4. Explain the influence each cement type has on concrete sustainability.

Discussion

- Cementitious Materials
- History of Modern Portland Cement
- Manufacturing Portland Cement
- Roadmap to Carbon Neutrality
- Evolving Cement Specifications
- Cement Types
- Barriers and Challenges to Adoption
- Future Prospects for Blended Cements
- Emerging Trends and Innovations
- Call to Action

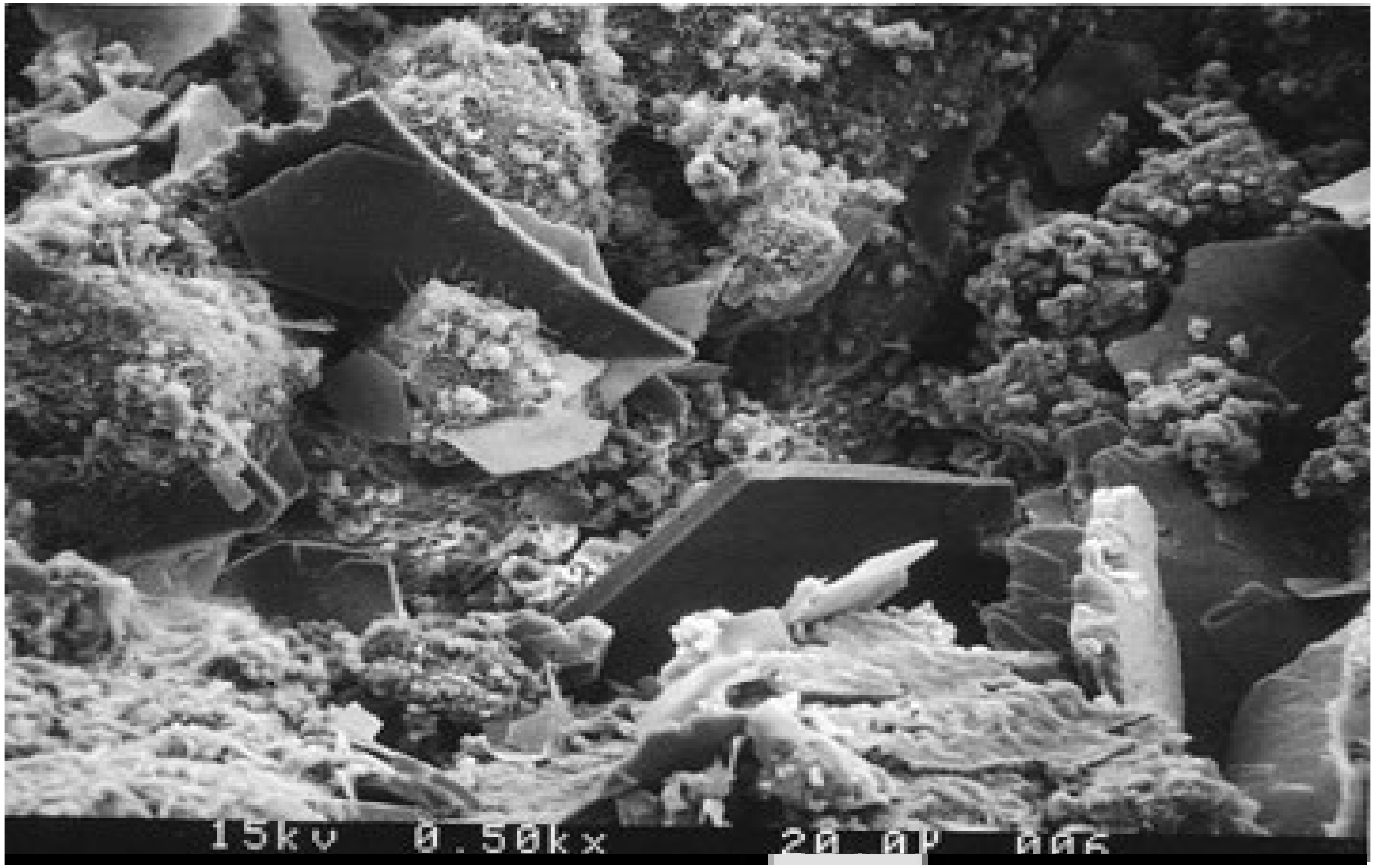
Cementitious Materials

Hydraulic cements

Supplementary cementitious materials (SCMs)

Hydraulic cement – reacts (hydrates) and hardens under water
Pozzolan – reacts with cement and water

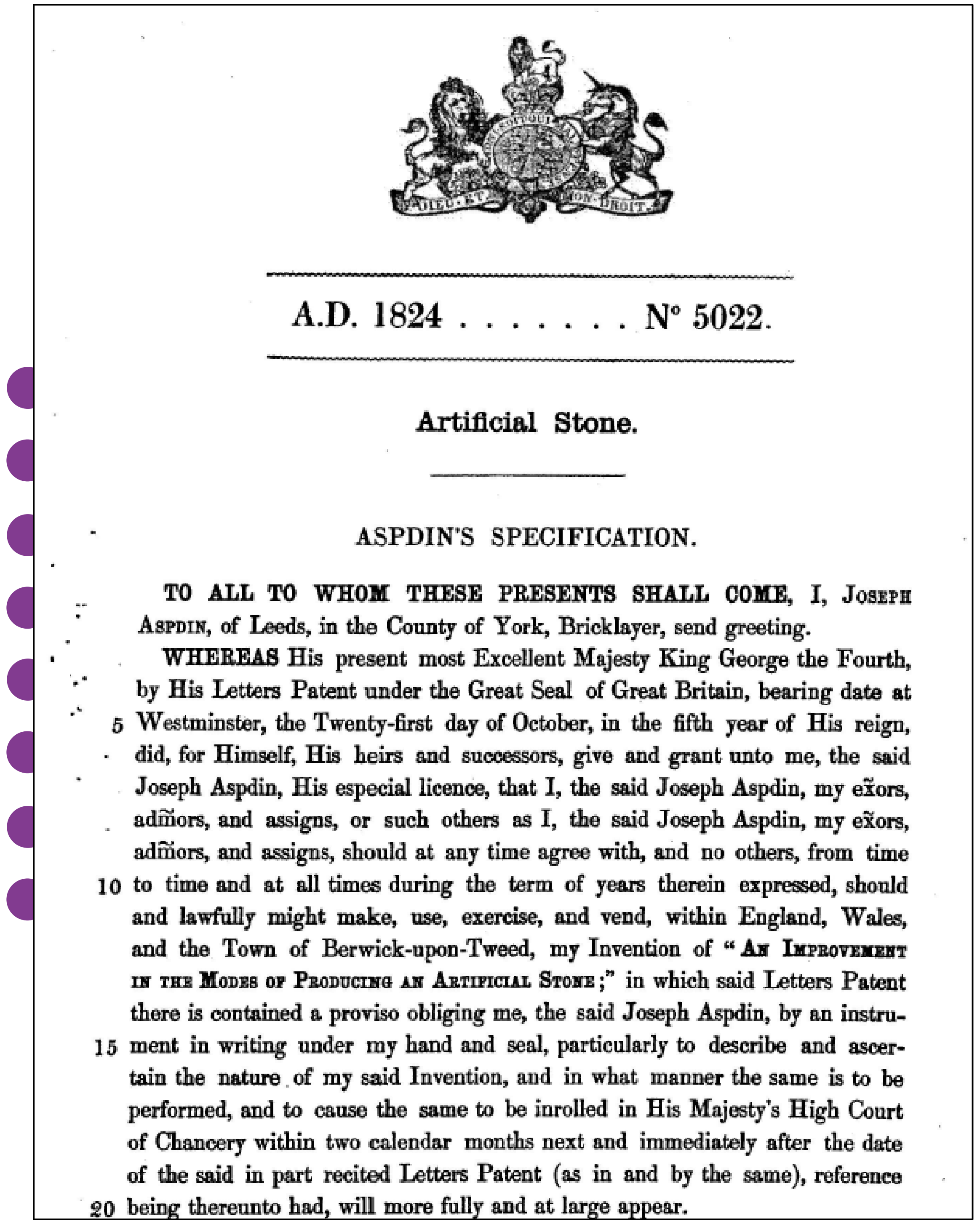
Hydration



Cement + Water

$$C_3S + H_2O = C\text{-}S\text{-}H + CH$$
$$C_2S + H_2O = C\text{-}S\text{-}H + CH$$

History of Modern Portland Cement



A.D. 1824 . . . . N° 5022.

Artificial Stone.

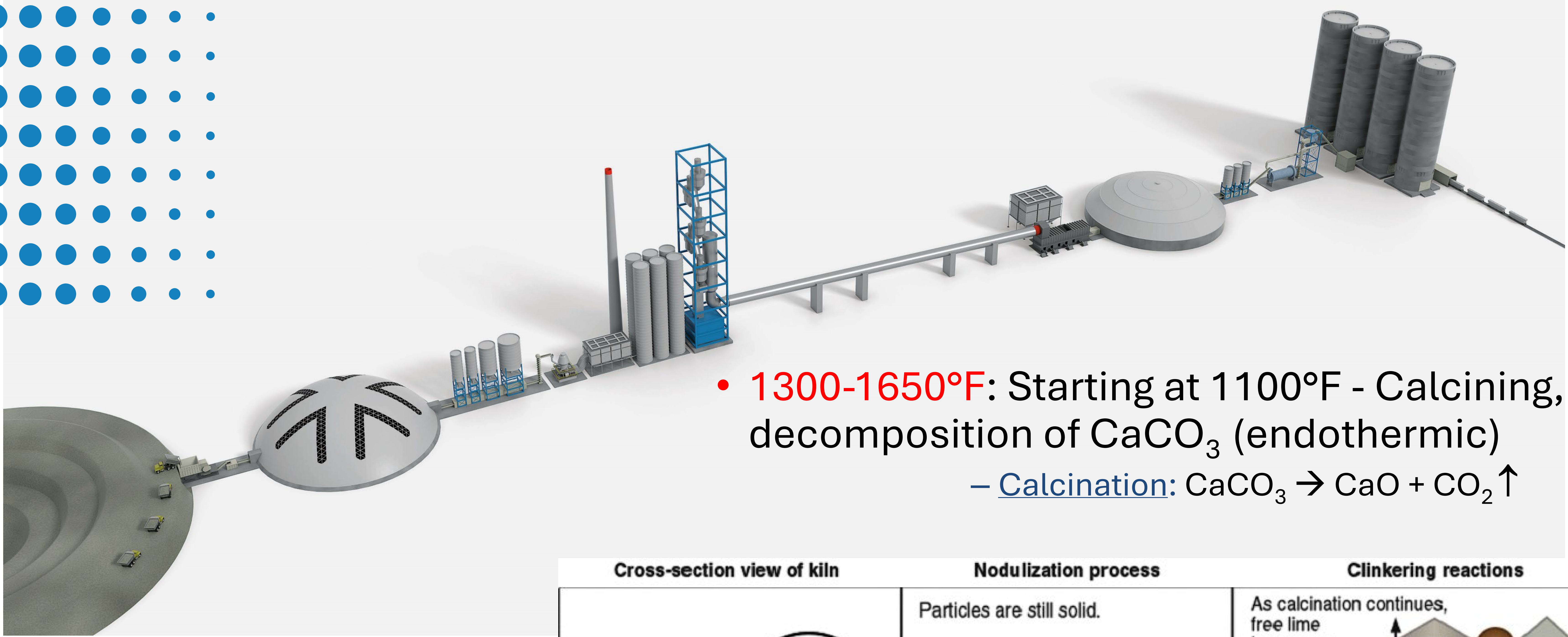
ASPDIN'S SPECIFICATION.

TO ALL TO WHOM THESE PRESENTS SHALL COME, I, JOSEPH ASPDIN, of Leeds, in the County of York, Bricklayer, send greeting.

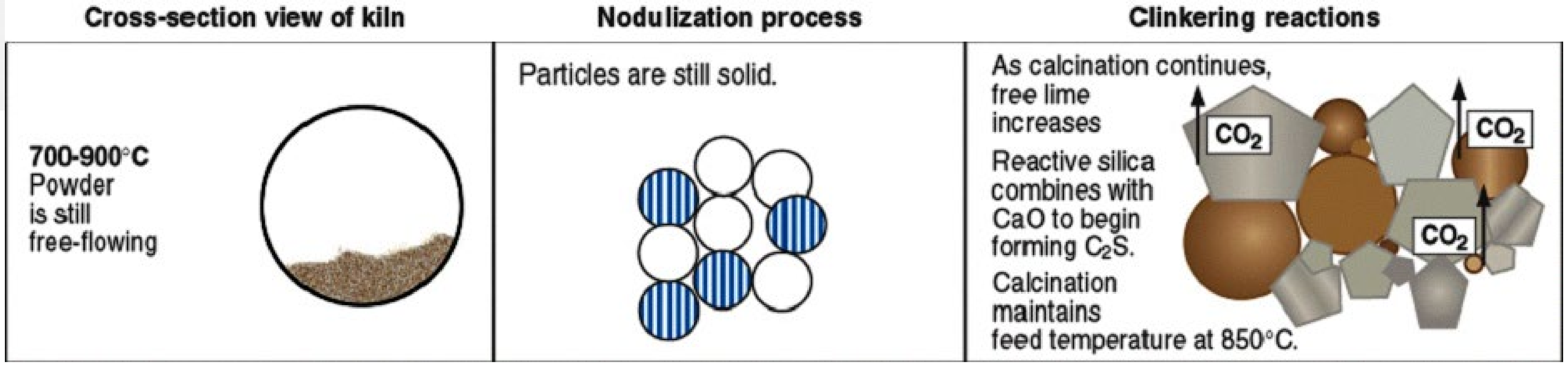
WHEREAS His present most Excellent Majesty King George the Fourth, by His Letters Patent under the Great Seal of Great Britain, bearing date at Westminster, the Twenty-first day of October, in the fifth year of His reign, did, for Himself, His heirs and successors, give and grant unto me, the said Joseph Aspdin, His especial licence, that I, the said Joseph Aspdin, my ex̃ors, adm̃ors, and assigns, or such others as I, the said Joseph Aspdin, my ex̃ors, adm̃ors, and assigns, should at any time agree with, and no others, from time to time and at all times during the term of years therein expressed, should and lawfully might make, use, exercise, and vend, within England, Wales, and the Town of Berwick-upon-Tweed, my Invention of "AN IMPROVEMENT IN THE MODES OF PRODUCING AN ARTIFICIAL STONE;" in which said Letters Patent there is contained a proviso obliging me, the said Joseph Aspdin, by an instrument in writing under my hand and seal, particularly to describe and ascertain the nature of my said Invention, and in what manner the same is to be performed, and to cause the same to be inrolled in His Majesty's High Court of Chancery within two calendar months next and immediately after the date of the said in part recited Letters Patent (as in and by the same), reference being thereunto had, will more fully and at large appear.

- 1824 – Hydraulic cement patent issued in England, named after a premier quality of limestone quarried from the Isle of Portland in the English Channel
- 1871 – First portland cement is produced in the United States in Coplay, Pennsylvania
- 1916 – Portland Cement Association is founded in Chicago
- 2021 – PCA publishes its Roadmap to Carbon Neutrality
- 2024 – Portland cement turns 200 years old
- Present- US uses about 110 million metric tons/year

Manufacturing Portland Cement



- 1300-1650°F: Starting at 1100°F - Calcining, decomposition of $CaCO_3$ (endothermic)
  - [Calcination](#): $CaCO_3 \rightarrow CaO + CO_2\uparrow$



Wilson and Tennis, 2021

CO_2 and Sustainability

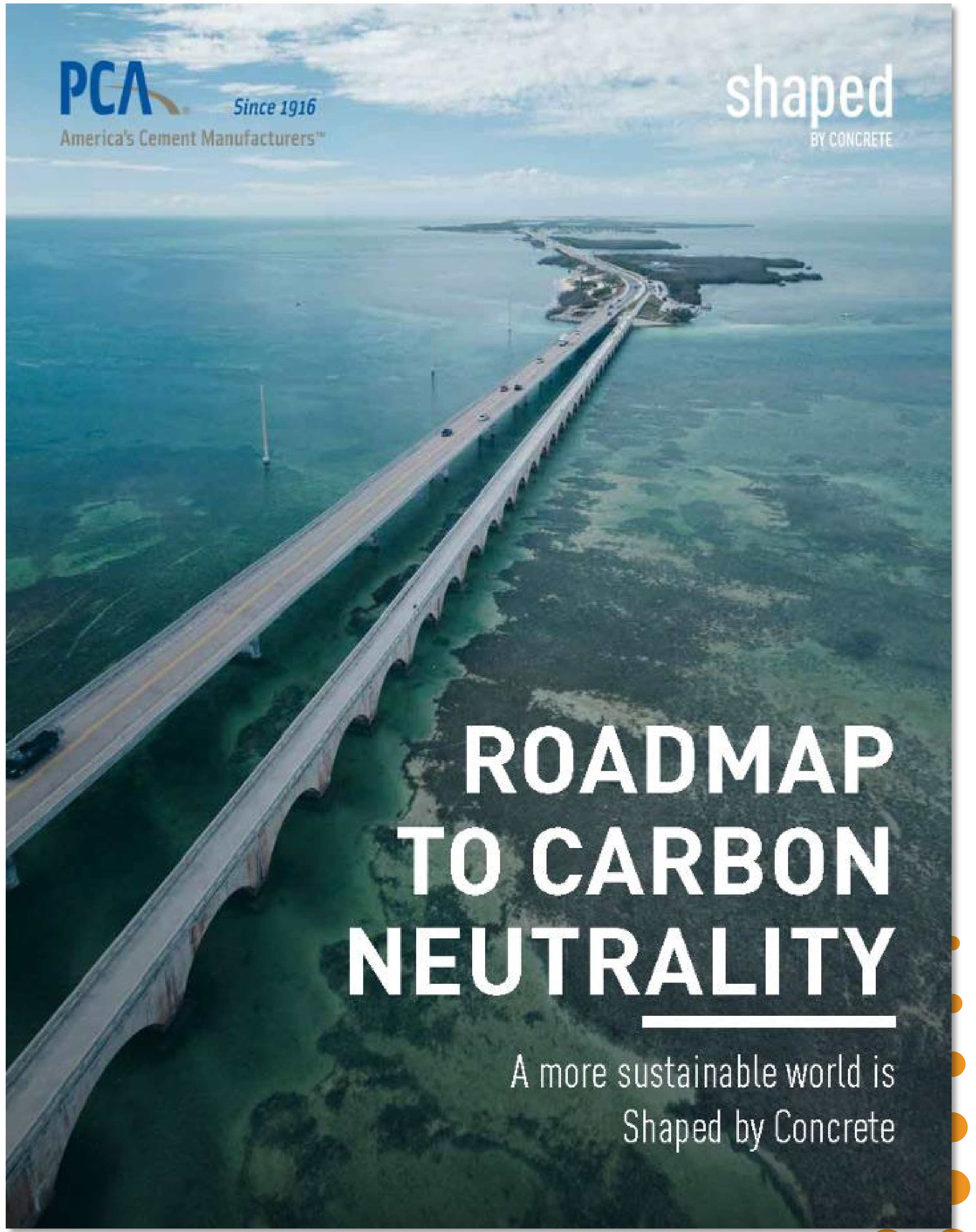
We can't ignore this

Increased pressure from many groups: designers, regulators, and the public.

$$CaCO_3 \rightarrow CaO + CO_2$$

$$C + O_2 \rightarrow CO_2$$

Roadmap to Carbon Neutrality

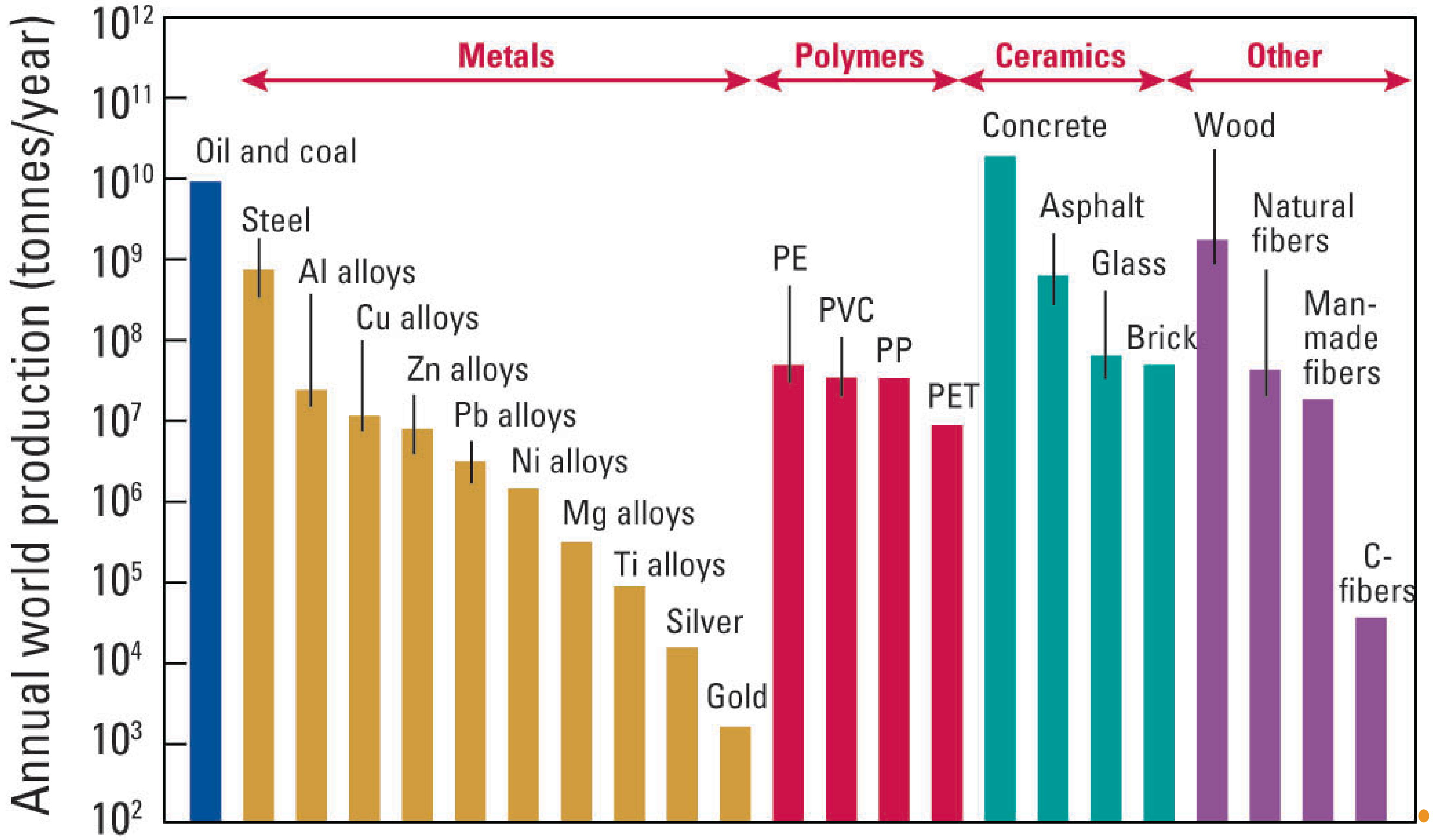


ROADMAP TO CARBON NEUTRALITY

Portland Cement Association

Embodied Carbon

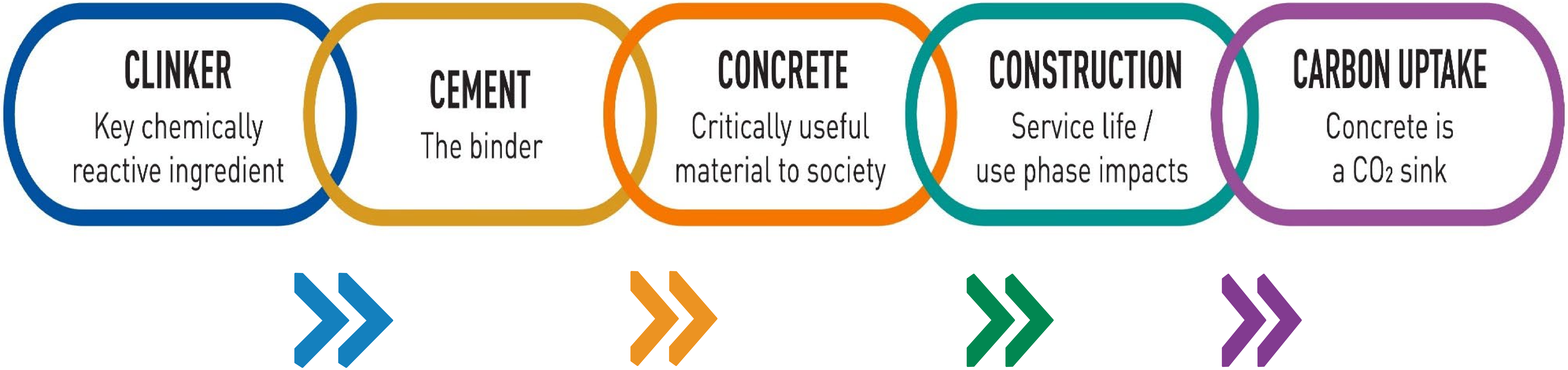
Concrete and CO_2



(after Ashby 2009)

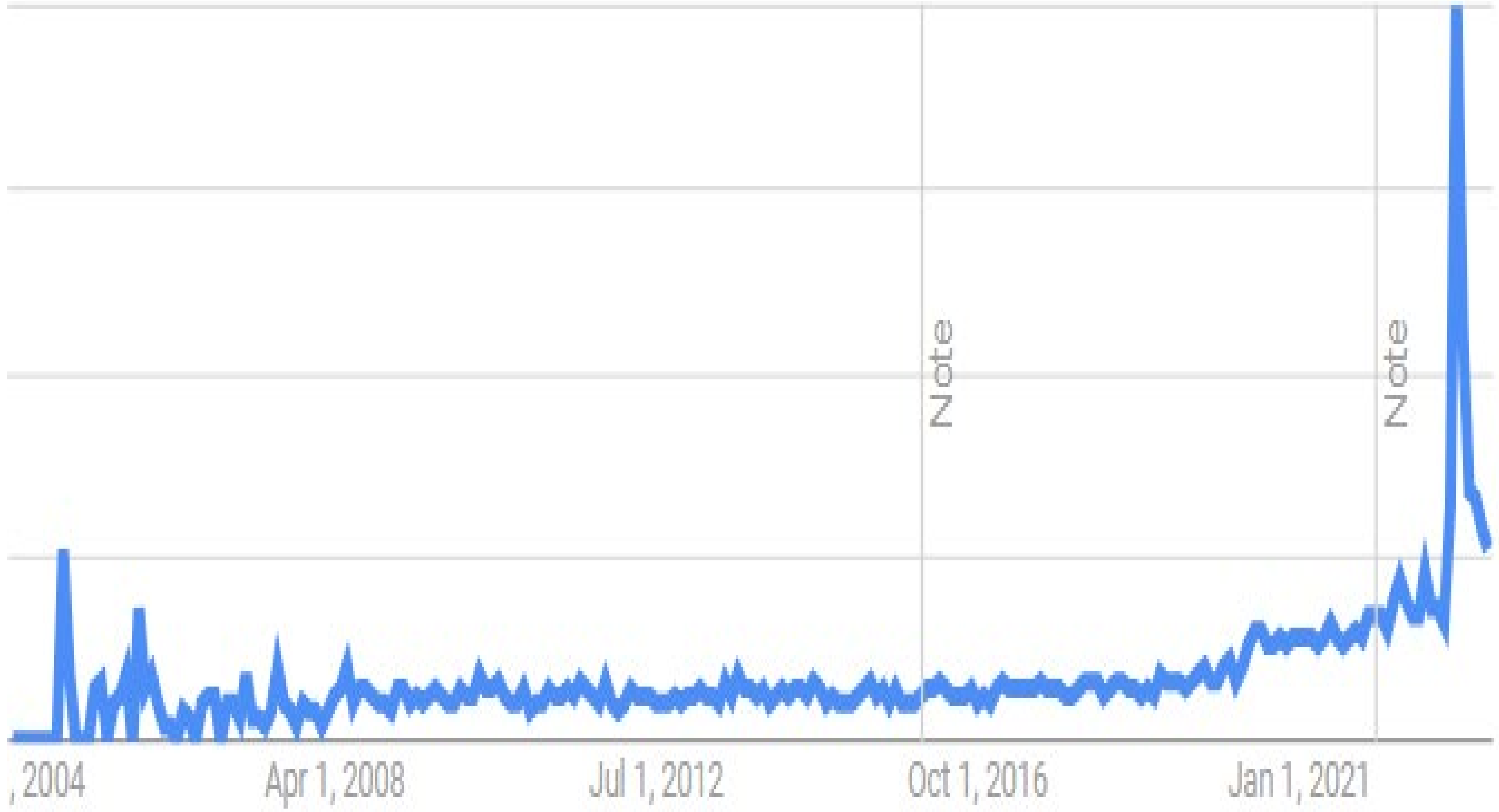
- Concrete is the most widely used construction material, by more than a factor of ten.
- The United States consumes about 340 million cubic yards of ready mixed concrete each year.

The Value Chain

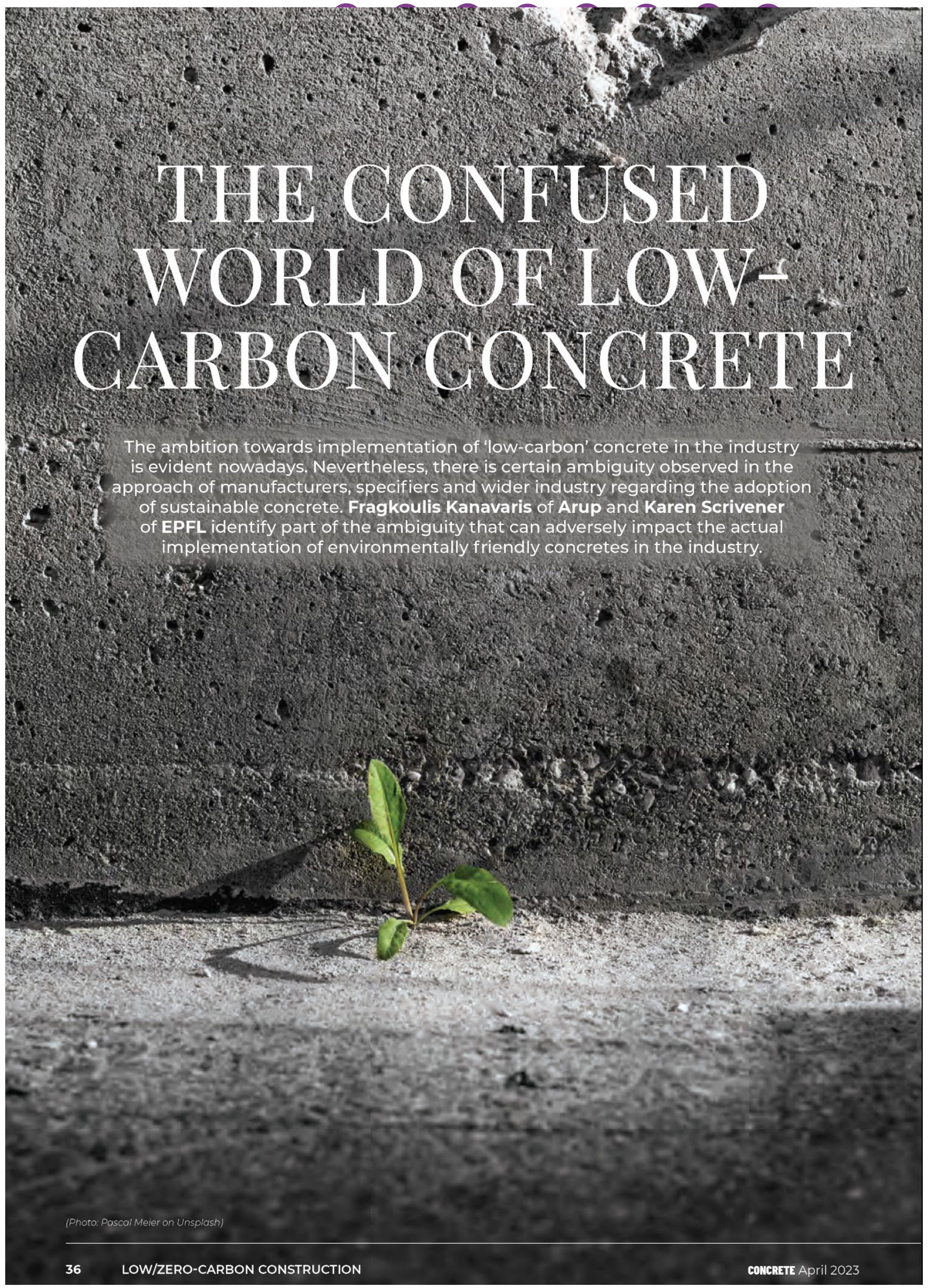


Low Carbon Concrete

Increasing Public Interest - 'Green Cement'
Google Searches, 2004-2024



Google Trends, September 2024.


THE CONFUSED WORLD OF LOW-CARBON CONCRETE

The ambition towards implementation of 'low-carbon' concrete in the industry is evident nowadays. Nevertheless, there is certain ambiguity observed in the approach of manufacturers, specifiers and wider industry regarding the adoption of sustainable concrete. **Fragkoulis Kanavaris** of **Arup** and **Karen Scrivener** of **EPFL** identify part of the ambiguity that can adversely impact the actual implementation of environmentally friendly concretes in the industry.

(Photo: Pascal Meier on Unsplash)

36 LOW/ZERO-CARBON CONSTRUCTION CONCRETE April 2023

Low-Carbon Cement and Concrete Protocol

AT THE CEMENT PLANT

- Increase the use of decarbonated raw materials
- Decrease the use of traditional fossil fuels by 5X
- Increase the use of alternative fuels
- Push efficiency and decrease energy intensity for one metric ton of clinker
- Utilize carbon capture to avoid the release of CO_2 emissions
- Reduce clinker production emissions

OPTIMIZING THE DESIGN AND CONSTRUCTION OF THE BUILT ENVIRONMENT

- Lower concrete manufacturing emissions to zero at the plant
- Transition to zero emission fleets
- Optimize concrete mixes
- Reduce overdesign
- Construct concrete structures for durability, resiliency, stiffness, and thermal mass benefits

CONCRETE IN USE

- 10% — The amount of CO_2 that concrete buildings, structures, and pavements can permanently absorb from the air is 10%
- A reduction of 46.5 million metric tons of GHG emissions per year could be realized if the entire U.S. road system used concrete pavement according to the MIT Concrete Sustainability Hub (MIT CSHUB)

Optimizing Clinker

AT THE CEMENT PLANT

- Increase the use of decarbonated raw materials
- Decrease the use of traditional fossil fuels by 5X
- Increase the use of alternative fuels
- Push efficiency and decrease energy intensity for one metric ton of clinker
- Utilize carbon capture to avoid the release of CO_2 emissions
- Reduce clinker production emissions

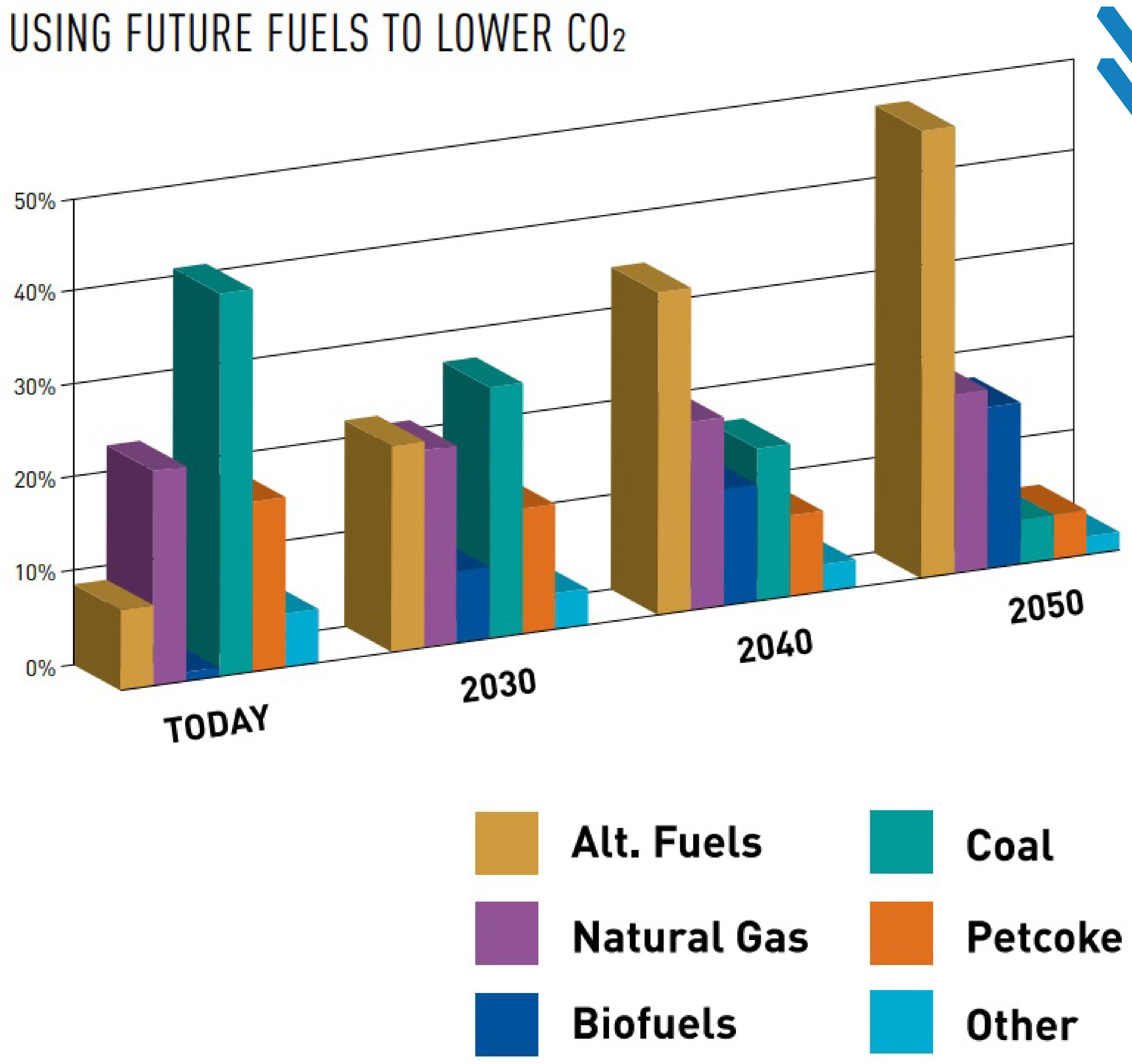
Alternative Fuels

TABLE 12-3. Waste Materials Used as Alternative Fuels in Cement Kilns

Gaseous waste	Landfill gas
Liquid waste	Cleansing solvents
	Paint sludges
	Solvent contaminated waters
	"Slope" – residual washing liquid from oil and oil products storage tanks
	Used cutting and machining oils
	Waste solvents from chemical industry
Solid or pasty waste	Farming residues (rice husk, peanut husk, etc.)
	Municipal waste
	Plastic shavings
	Residual sludge from pulp and paper production
	Rubber shavings
	Sawdust and wood chips
	Sewage treatment plant sludge
	Tannery waste
	Tars and bitumens
	Used catalyst
	Used tires

Wilson and Tennis, 2021

Alternative Fuels



- Today's fuel mix for production is ~60% coal and petcoke.
- U.S. uses ~14% Alternative Fuels
- Goal is 50% in U.S. by 2050
- Europe uses ~60% Alternative Fuels

Carbon Capture (CCUS)

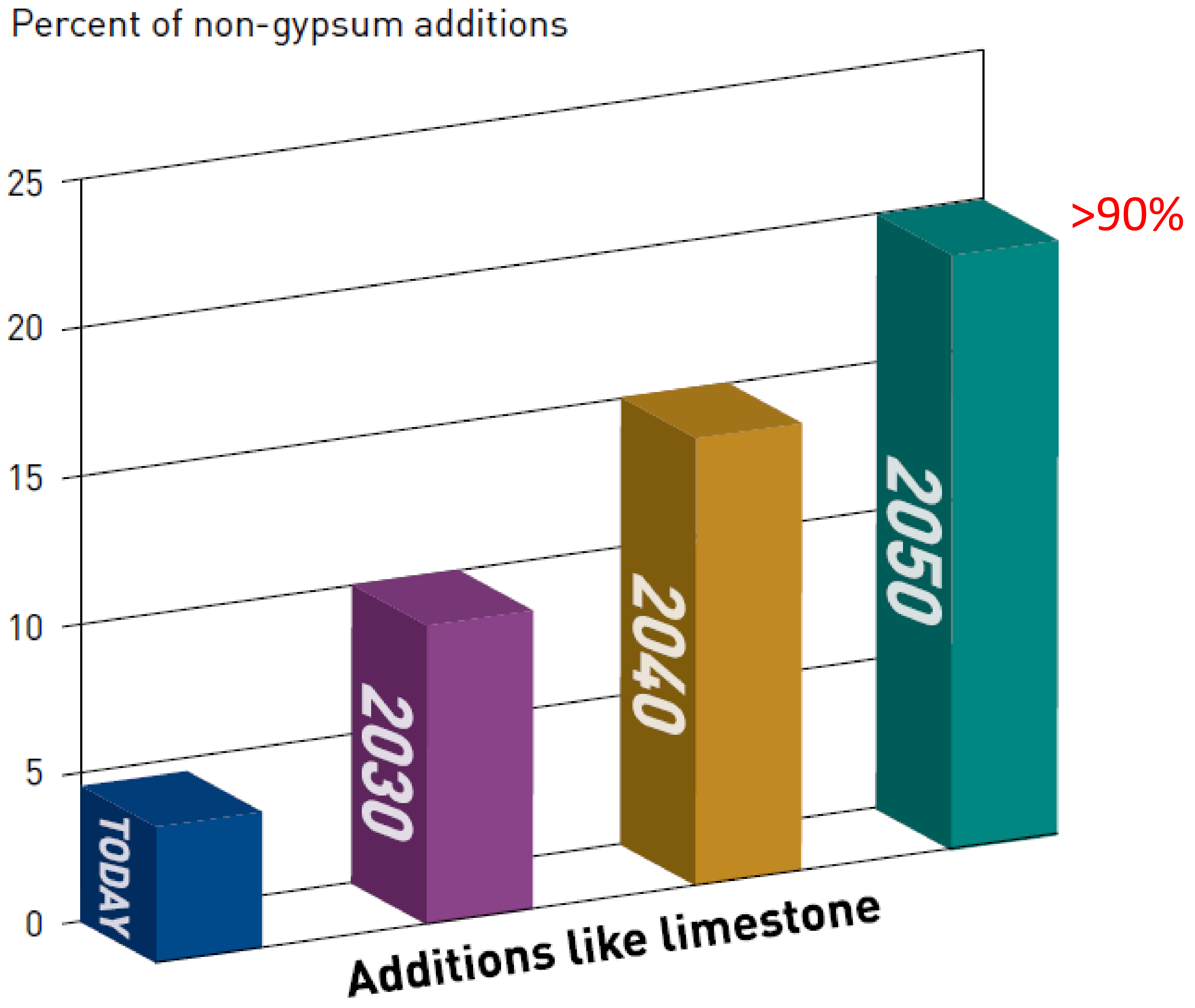
- Chemical absorption
- Physical adsorption
- Membrane technologies and mineralization
- Studies in U.S. underway at plants in Texas, Missouri, Colorado, Arkansas, and Indiana

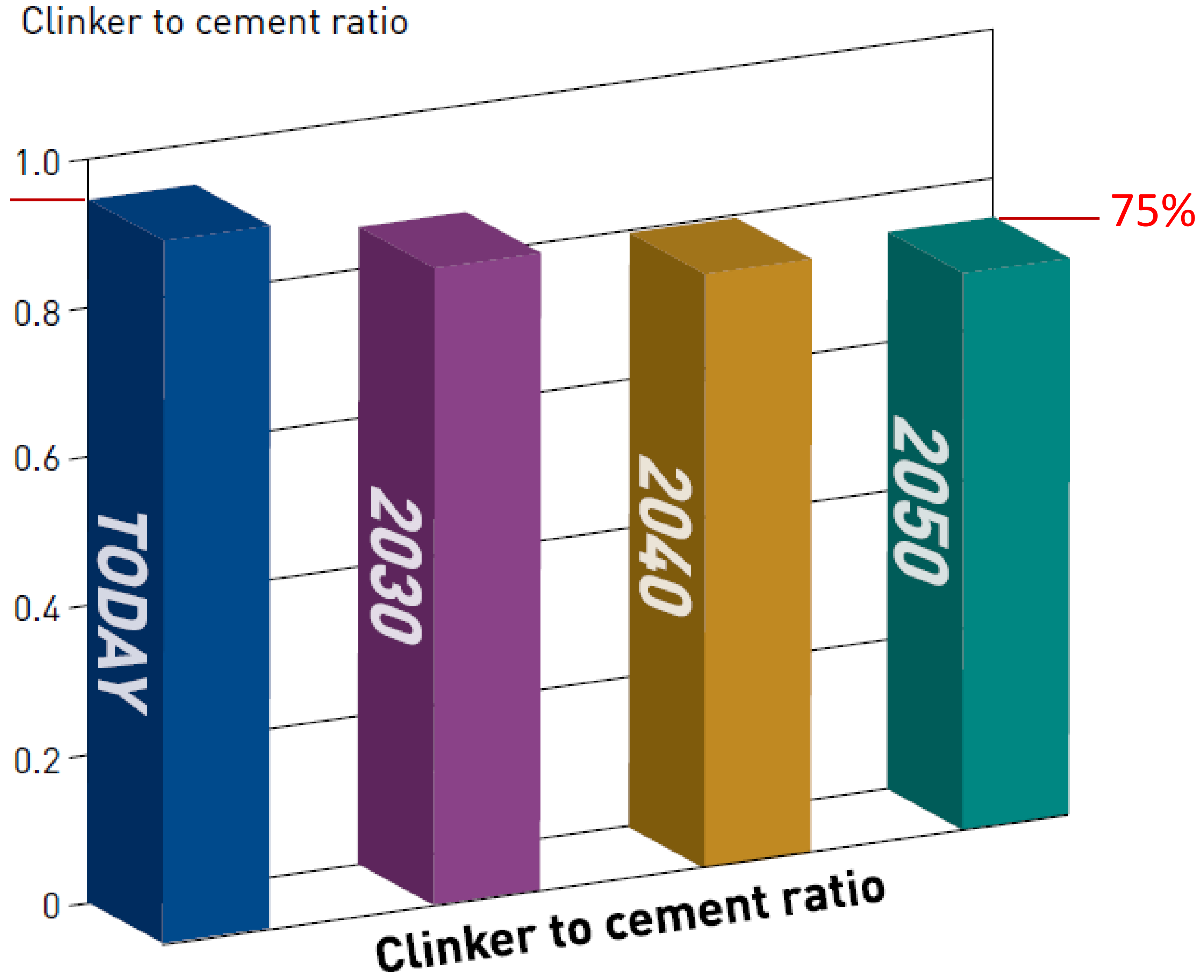
Optimizing Cement

ASTM C150, ASTM C595, and ASTM C1157

- Right sizing the amount of clinker in cement
- Using more non-gypsum additions
- Choosing the right cement specification for specific application

Optimizing Cement





Specifying Cements

C150	**Portland Cements**
C595	**Blended Hydraulic Cements**
C1157	**Performance Hydraulic Cements**

M 85
M 240

- Portland Cement (ASTM C150 / AASHTO M 85)
- Blended Cements (ASTM C595 / AASHTO M 240)
- Performance specification for hydraulic cements (ASTM C1157)

Evolving Cement Specifications

1940
ASTM C150 Published

1967
ASTM C595 Published

1992
ASTM C1157 Published

2004
ASTM C150: Up to 5% limestone

2006
ASTM C595 & AASHTO M 240: Nomenclature Consolidation (Types IP and IS)

2007
AASHTO M 85: Up to 5% limestone

2009
ASTM C150 & AASHTO M 85: Up to 5% IPA

ASTM C595 & AASTHTO M 240: Type IT

2012
ASTM C595 & AASHTO M 240: Type IL

Cement Types and Special Property Designations

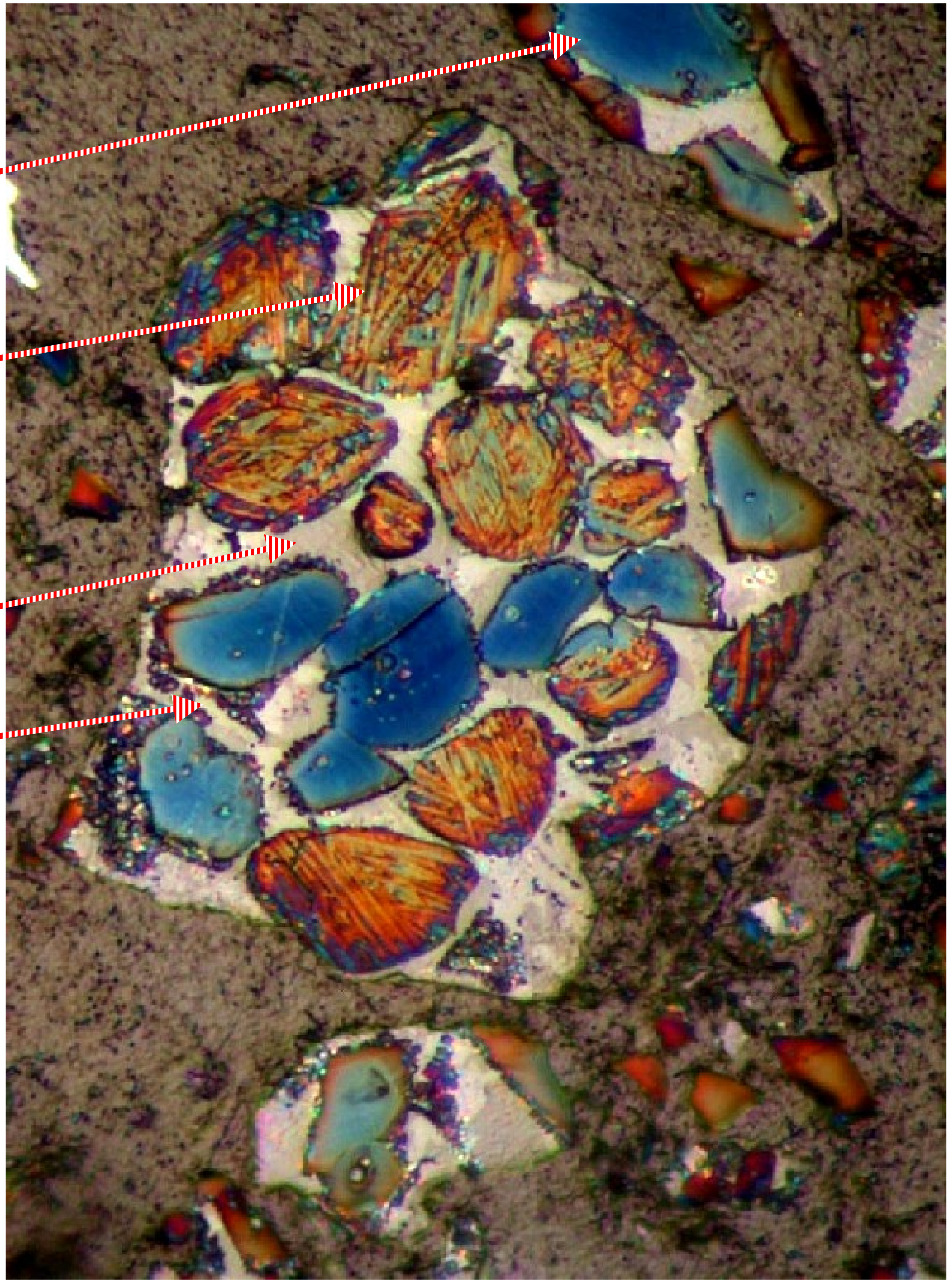
Description	ASTM/AASHTO Standards		
	Portland Cement ASTM C150/ AASTHTO M 85	**Blended Cement** ASTM C595/ AASHTO M 240	**Performance-Based Cement** ASTM C1157
General Use	I	IL, IS, IP, IT	GU
Moderate Sulfate-Resistant	II	MS^	MS
High Early Strength	III	HE^	HE
High Sulfate-Resistant	V	HS^	HS
Moderate Heat of Hydration	*	*	MH
Low Heat of Hydration	*	*	LH

*Designations replaced in 2024 with heat of hydration reporting requirement.

^Special property designations in ASTM C595 and AASHTO M 240.

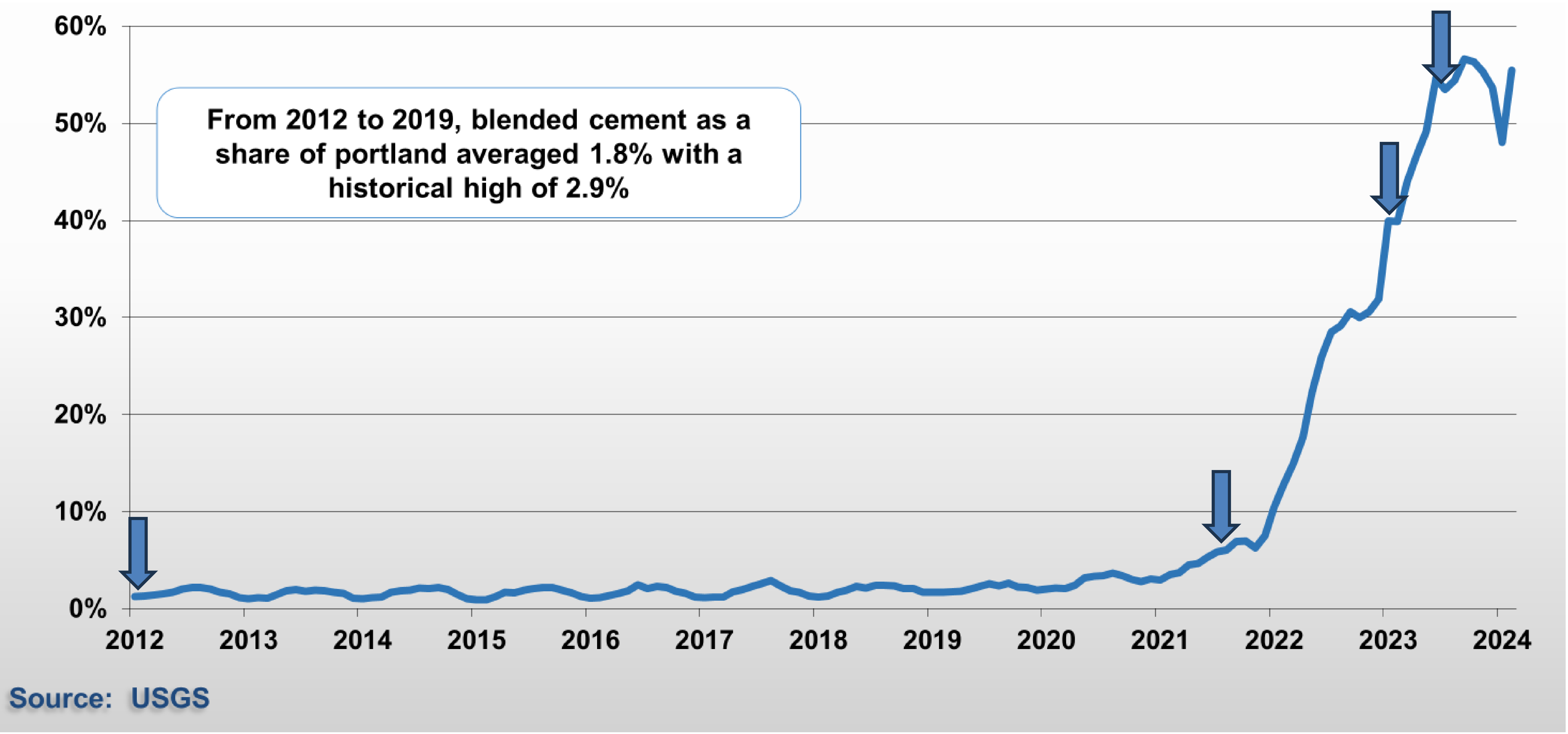
What is Portland Cement?

- C_3S – alite
- C_2S – belite
- C_3A – calcium aluminate
- C_4AF –ferrite



Blended Cement Share in U.S.

- 2012 – Type IL in standard
- October 2021 – *PCA Roadmap*
- Early 2023 – USGS survey
- June 2023 – >50%



Blended Cement Nomenclature

IL	IP	IS	IT	
Portland cement or clinker	Portland cement or clinker	Portland cement or clinker	Portland cement or clinker	
Limestone (5% to 15%)	Pozzolan (up to 40%)	Slag (up to 70% or 95%*)	Plus 2 extra ingredients:	Limestone + pozzolan
				Limestone + slag
				2 pozzolans
				Pozzolan + slag

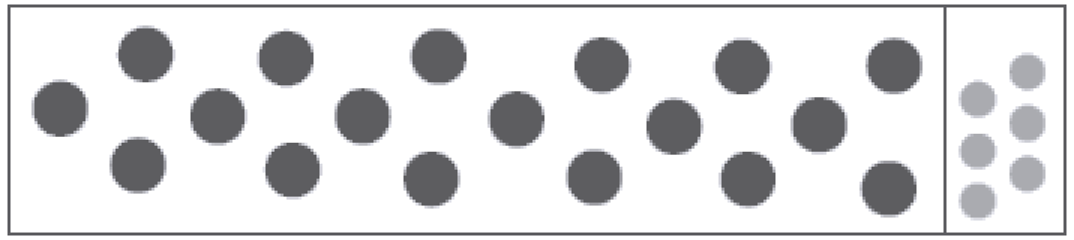
** Some specifications restrict >70% slag to non-structural applications*

Portland-limestone Cement

PORTLAND CEMENT

> 95% Ground Clinker + Gypsum

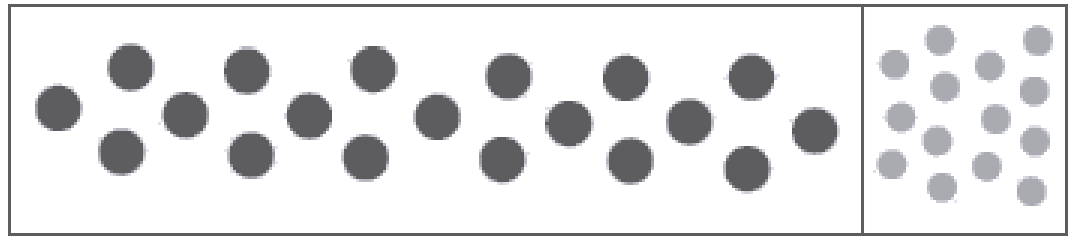
≤5% Limestone



PLC

85 - 95% Ground Clinker + Gypsum

5 to15% Limestone

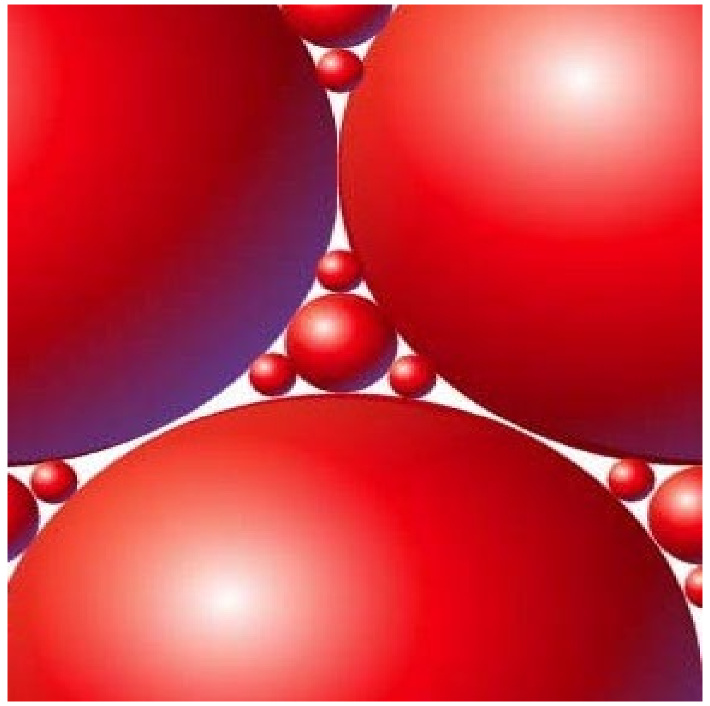


	Portland Cement ASTM C150 AASHTO M85	**Portland-Limestone Cement** ASTM C595 AASHTO M240
Clinker (typical)	90-95%	80-90%
Gypsum (typical)	4-6%	4-6%
Limestone (allowed)	0-5%	5-15%

Benefits of Limestone

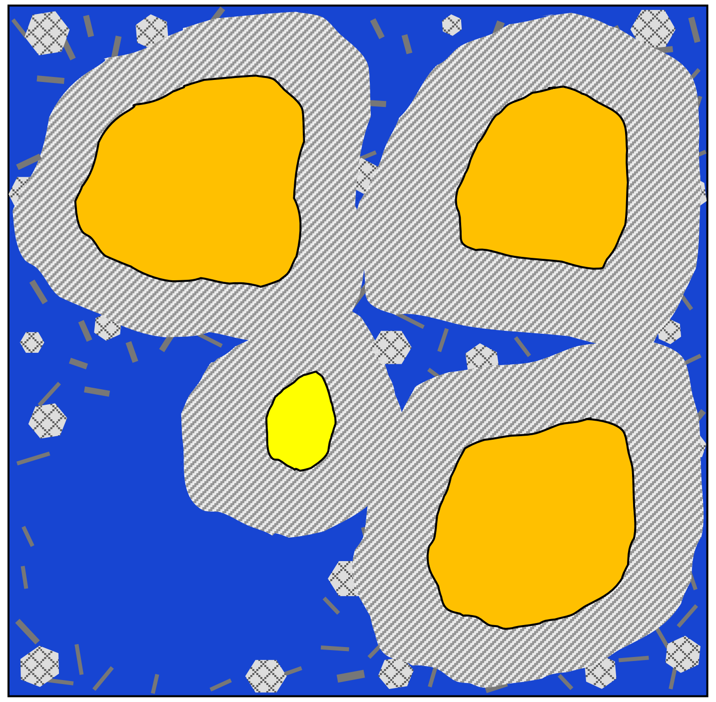
Particle packing

Improved particle size distribution



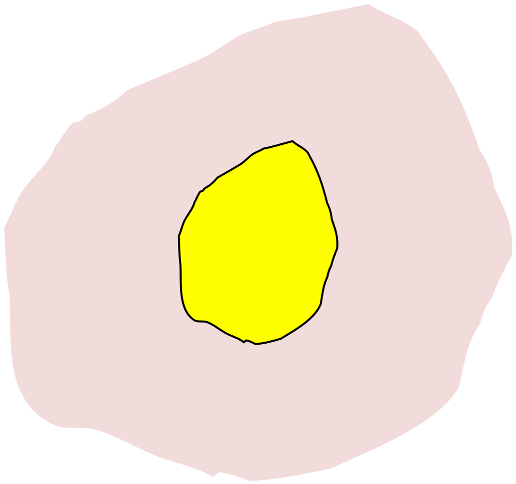
Nucleation

Surfaces for precipitation

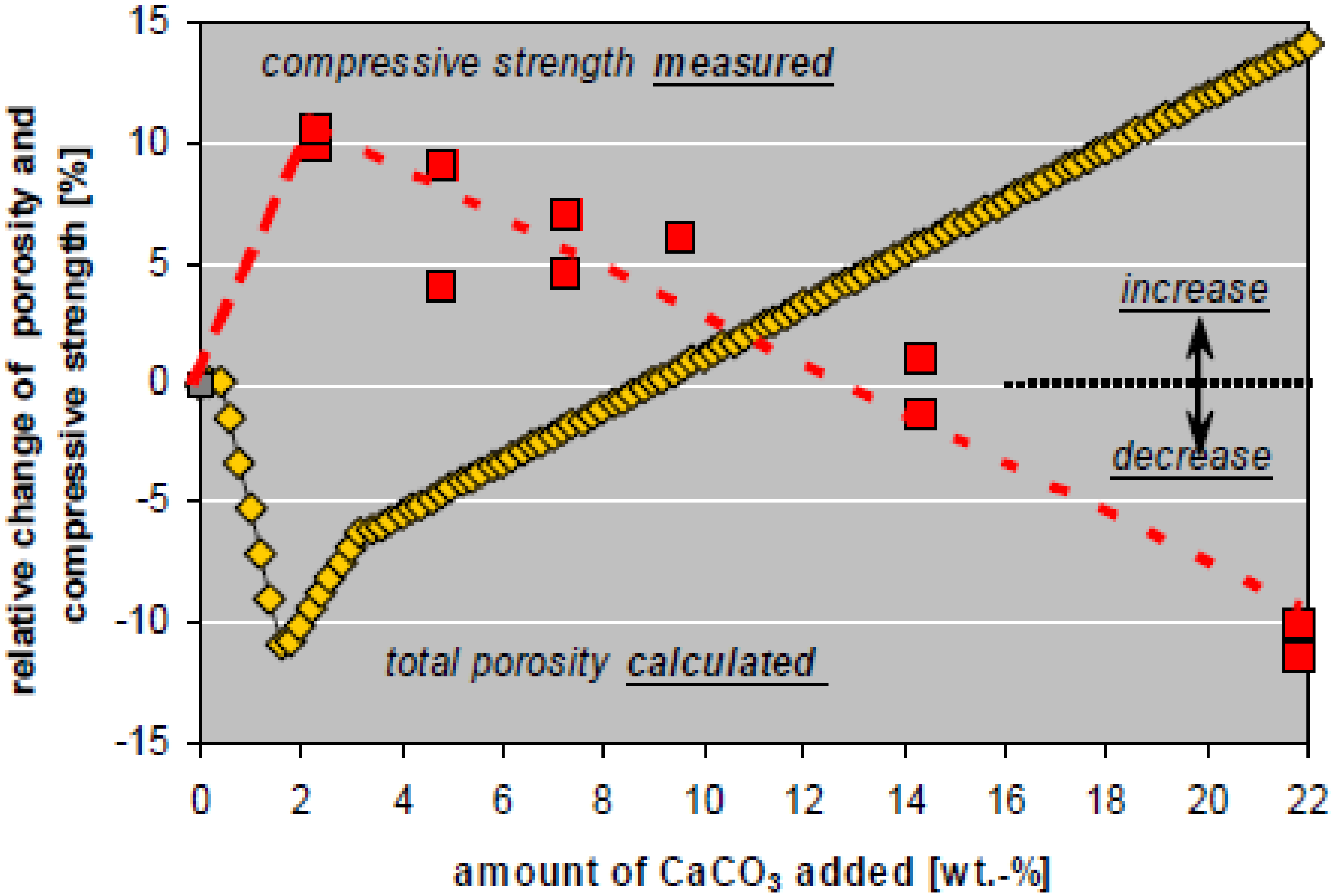


Minor Contribution from Chemical reactions

$CaCO_3 + C_3A =$ Carboaluminates



Why 15%?


compressive strength measured
total porosity calculated
increase
decrease
relative change of porosity and compressive strength [%]
amount of $CaCO_3$ added [wt.-%]
15
10
5
0
-5
-10
-15
0
2
4
6
8
10
12
14
16
18
20
22

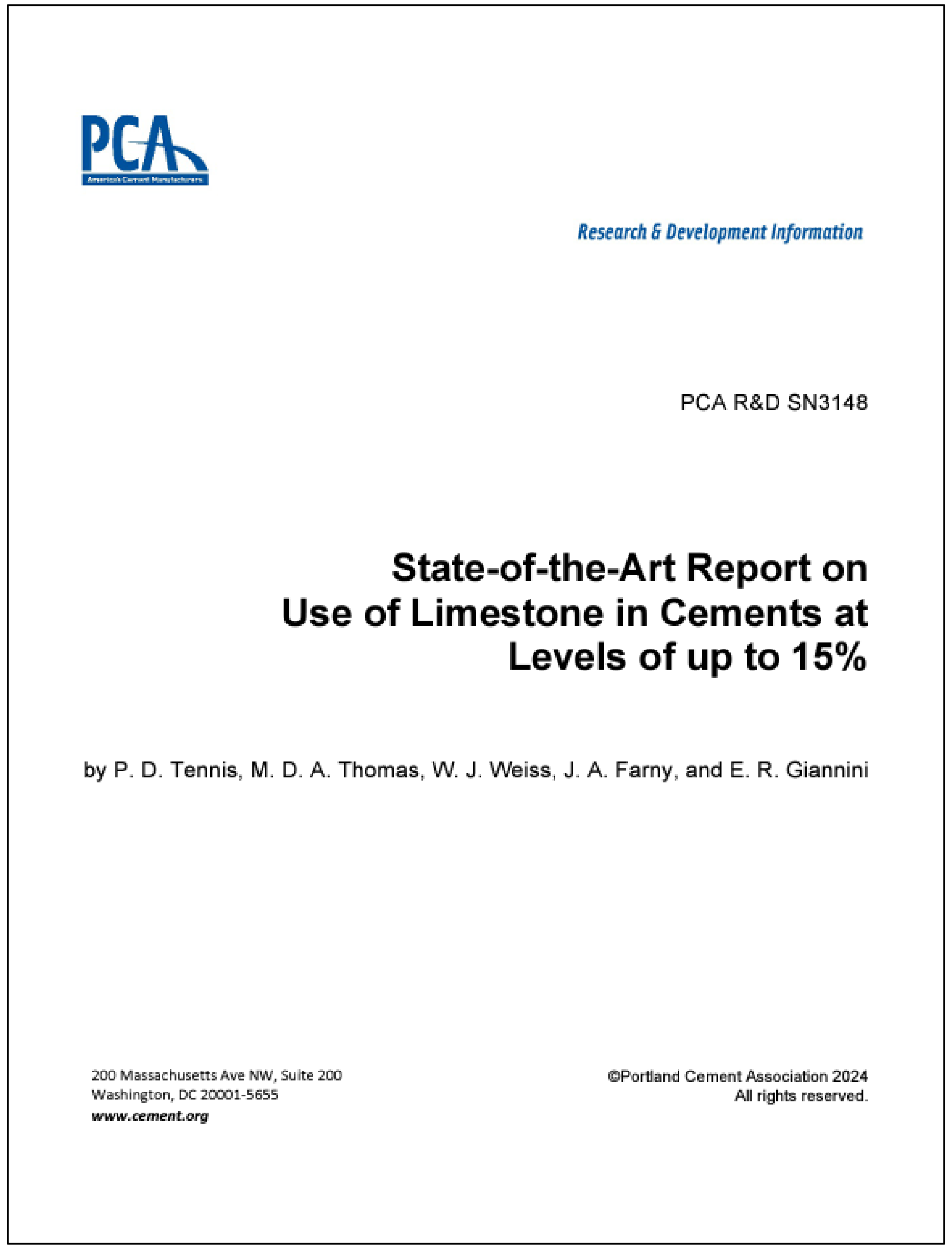
Mix Designs With PLC

- PLC typically replaces ordinary portland cement in equal amounts
- PLC allows for the same dosages of SCMs: fly ash or other pozzolans, and slag cement
- Testing is warranted to confirm effects on fresh and hardened properties

Impact of Cement on Strength

	Early	Later
Increasing C_3S (decreasing C_2S)	↑	↑↓
Increasing C_3A (decreasing C_4AF)	↑	↔
Increase in alkali content	↑	↓
Increase in portland cement clinker fineness	↑	↑
Increase in limestone fineness	↑	↑
Increase in PSD (Steeper Curve)	↑	↔
Increase in cement content	↑	↑

State of the Art Report on PLC


Research & Development Information

PCA R&D SN3148

State-of-the-Art Report on Use of Limestone in Cements at Levels of up to 15%

by P. D. Tennis, M. D. A. Thomas, W. J. Weiss, J. A. Farny, and E. R. Giannini

200 Massachusetts Ave NW, Suite 200
Washington, DC 20001-5655
www.cement.org

PCA SN3148

- Workability, bleeding, placing and finishing
- Setting time, hydration, HOH
- Strength, strength development
- Deicer scaling, freeze-thaw resistance
- Chloride permeability
- ASR resistance
- Sulfate resistance
- Abrasion resistance

Why Bogue Calculations are Not Applicable for Blended Cements

PCA IS791

- Bogue calculations from ASTM C150 are **NOT Applicable** to Blended Cements
- The oxide composition of finished blended cements yields **inaccurate** and even **nonsensical** (<0% and >100%) results
- **Sulfate resistance** of blended cements is characterized by **performance testing** (ASTM C1012)

Supplementary Cementitious Materials (Scms)

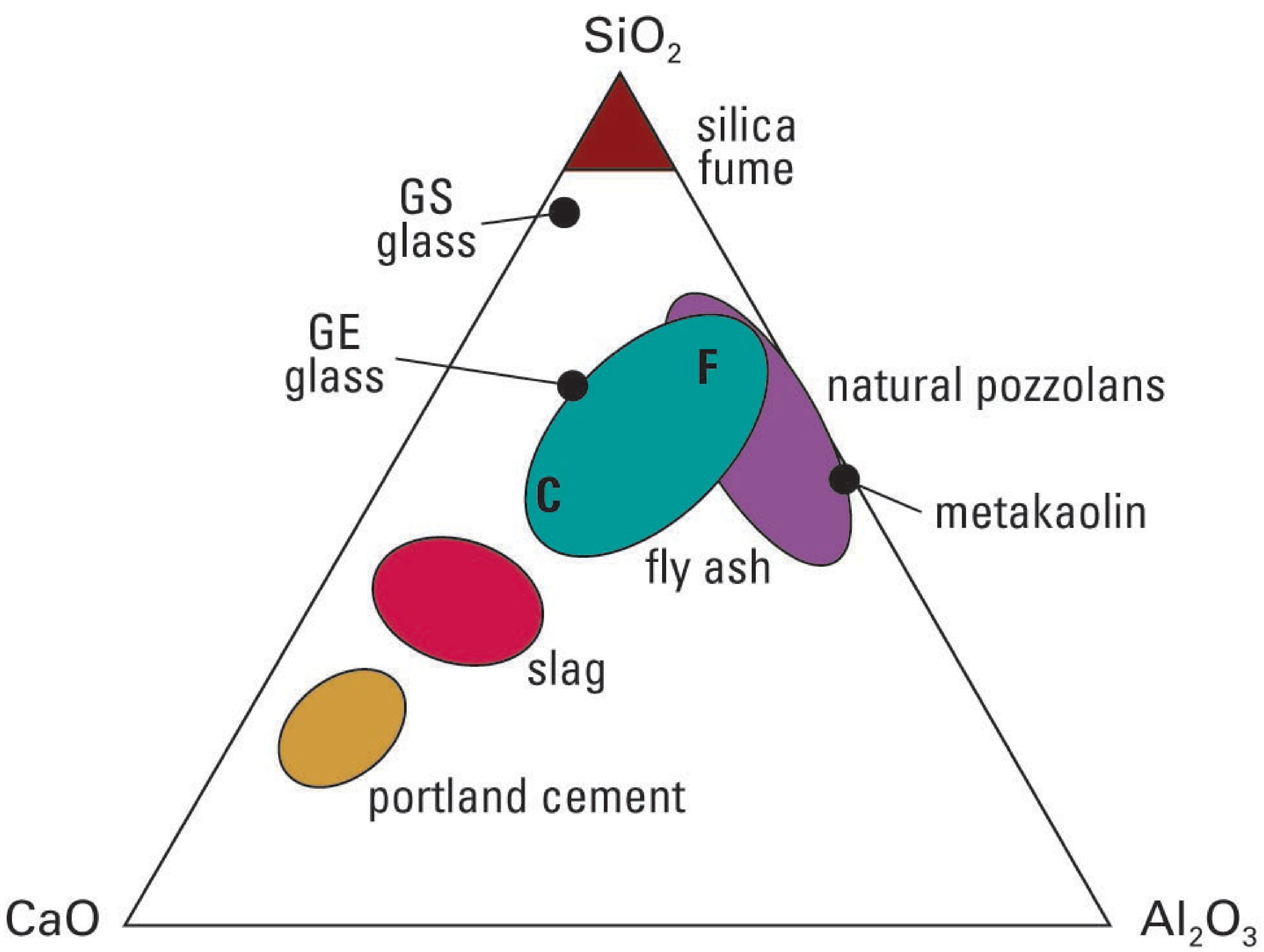
ASTM C618 Coal Ash and Natural Pozzolans

ASTM C989 Slag Cement

ASTM C1240 Silica Fume

ASTM C1866 Ground Glass

ASTM CXXX Performance-Based SCMs



Use of Supplementary Cementing Materials

- Silicates in SCMs react with Calcium Hydroxide (CH)
- More C-S-H, less CH formation!

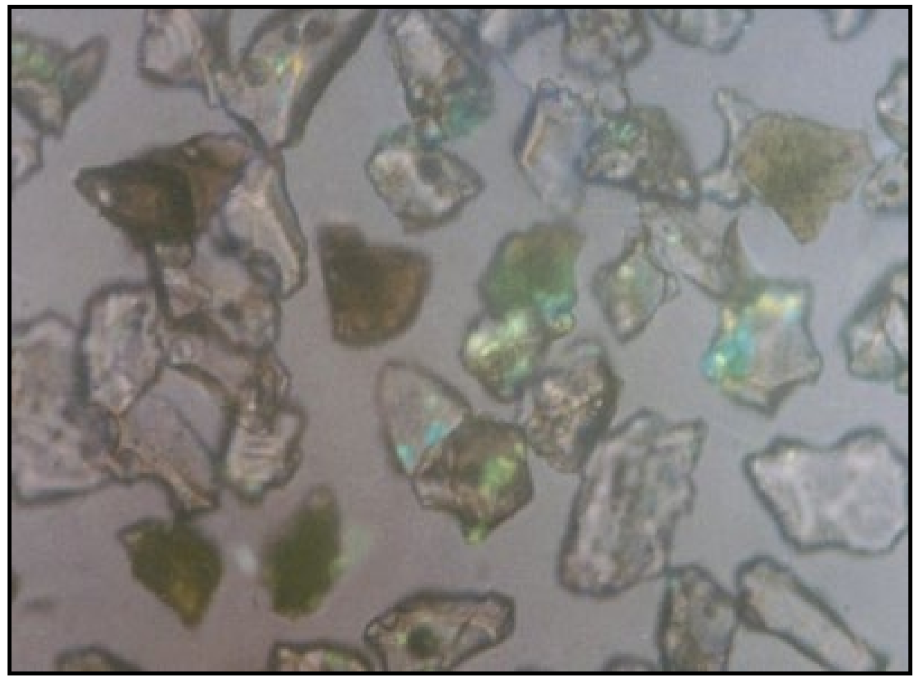
Pozzolanic Reaction

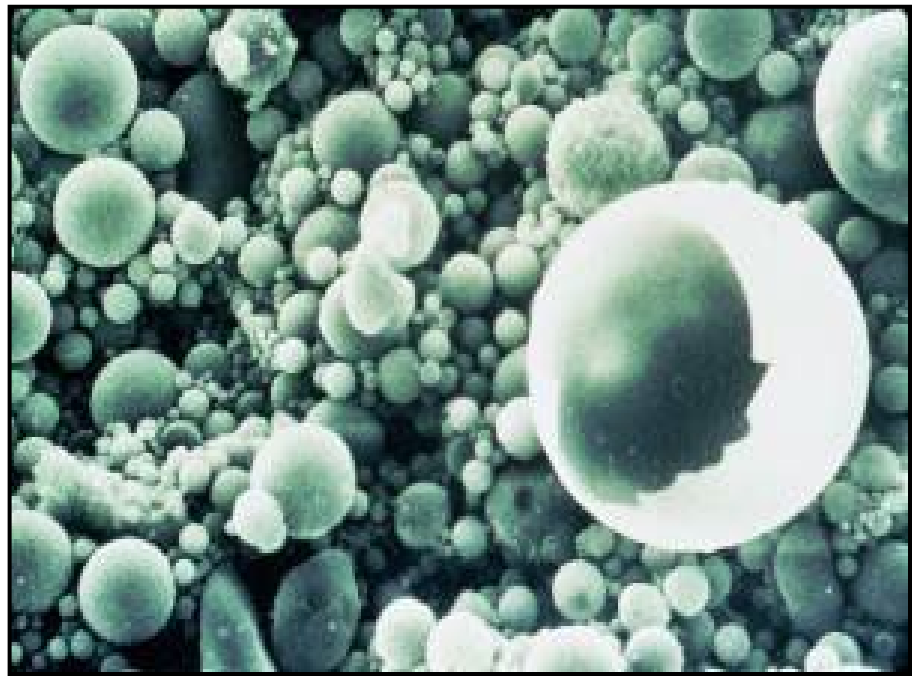
The rate of pozzolanic reaction is influenced by:

- Fineness and surface area
- Glass composition
- Temperature
- pH
- Concentration of alkalies

SCM	POZZOLANIC BEHAVIOR	HYDRAULIC BEHAVIOR	CALCIUM CONTENT
Silica fume, metakaolin	♦♦♦♦♦		Low (<1%)
Low-CaO fly ash, natural pozzolans, Type GS ground glass	♦♦♦♦		↓
Type GE ground glass	♦♦♦	♦	↓
High-CaO fly ash	♦♦♦	♦♦	↓
Slag cement	♦	♦♦♦♦	High (> 30%)

*Adapted from Thomas and Wilson 2002.





SCMs Effects on Freshly Mixed Concrete

	FLY ASH		SLAG CEMENT	SILICA FUME	NATURAL POZZOLANS			GROUND GLASS
	CLASS F	CLASS C			RAW	CALCINED CLAY/SHALE	METAKAOLIN	
Water demand	↓	↓	↓	↑	↔	↔	↑	↓
Workability	↑	↑	↑	↓	↑	↑	↓	↑
Bleeding and segregation	↓	↓	↕	↓	↔	↔	↓	↓
Setting time	↑	↕	↑	↔	↔	↔	↔	↔
Air content	↓	↓	↔	↓	↔	↔	↓	↔
Heat of hydration	↓	↕	↓	↕	↓	↓	↔	↓

Wilson and Tennis, 2021

SCMs Effects on Hardened Concrete

	FLY ASH		SLAG CEMENT	SILICA FUME	NATURAL POZZOLANS			GROUND GLASS
	CLASS F	CLASS C			RAW	CALCINED CLAY/SHALE	METAKAOLIN	
Early age strength gain	↓	↔	↕	↑	↔	↔	↑	↓
Long term strength gain	↑	↑	↑	↑	↑	↑	↑	↑
Abrasion resistance	↔	↔	↔	↑	↔	↔	↔	↔
Drying shrinkage and creep	↔	↔	↔	↔	↔	↔	↔	↔
Permeability and absorption	↓	↓	↓	↓	↓	↓	↓	↓
Corrosion resistance	↑	↑	↑	↑	↑	↑	↑	↑
Alkali-silica reactivity	↓	↓	↓	↓	↓	↓	↓	↓
Sulfate resistance	↑	↕	↑	↑	↑	↑	↑	↑
Freezing and thawing	↔	↔	↔	↔	↔	↔	↔	↔
Deicer scaling resistance	↔↓	↔↓	↔↓	↔↓	↔↓	↔↓	↔↓	↔↓

Wilson and Tennis, 2021

Barriers and Challenges to Adoption

Industry conservatism and market acceptance

- Resistance to adopting new materials in the construction sector

Technical challenges

- Variability in SCM availability and performance
- Compatibility issues with traditional materials and methods

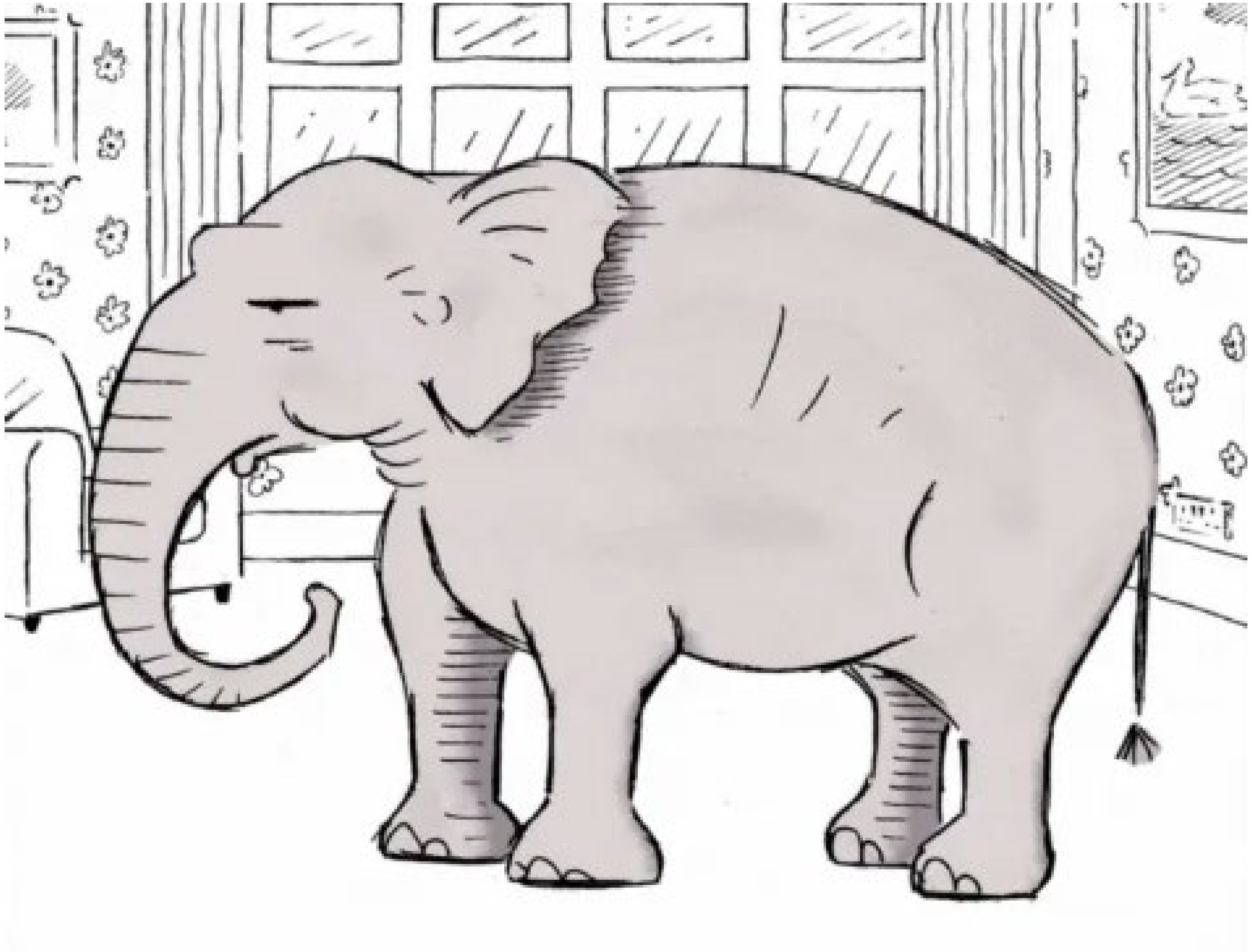
Regulatory and standardization issues

- Need for updated codes and standards for blended cements

Supply chain limitations

- Ensuring a reliable supply of SCMs across different regions

Barriers and Challenges to Adoption



"Just pretend I'm not here..."

Options for Adding SCMs

Blended Cements

- About 100 cement plants
- Optimize addition rates, overall chemistry, and properties of blended cements
- Multiple SCMs in 1 product
- ASTM C1157 augments potential for adding higher volumes of SCMs to cement

Concrete Mixtures

- 1000s of ready-mix plants
- Vary addition rates based on project needs
- Plant footprint – only 1 silo needed for blended, multiple silos for cement plus 1 or more SCMs

Technology Readiness Level (TRL)

TRL	1	2	3	4	5	6	7	8	9
Science & Engineering	Basic idea	Concept developed	Experimental proof of concept	Lab demonstration	Lab scale validation (early prototype)	Prototype demonstration	Capability validated on economic runs	Capability validated over range of parts	Capability validated on full range of parts over long periods
							Pilot system demonstrated	System incorporated in commercial design	Proven system ready for full deployment
				Component and/or system validation in laboratory environment	Laboratory scale, similar system validation in relevant environment	Engineering/pilot scale, similar (prototypical) system validation in relevant environment	Full-scale, similar (prototypical) system demonstrated in relevant environment	Actual system completed and qualified through test and demonstration	Actual system operated over the full range of expected mission conditions
Phase	Research			Translation/Development				Commercialization	

University of Capetown, 2018

Future Prospects for Blended Cements

New SCM sources and materials

- Exploring alternative industrial by-products
- Potential for agricultural waste and other novel SCMs

Technological advances

- AI and machine learning for optimizing mix designs
- 3D printing with blended cements

Evolving SCM Specifications

Standard Specification for
Coal ~~Fly~~ Ash and Raw or Calcined Natural Pozzolan for Use in Concrete[1]

This standard is issued under the fixed designation C618; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

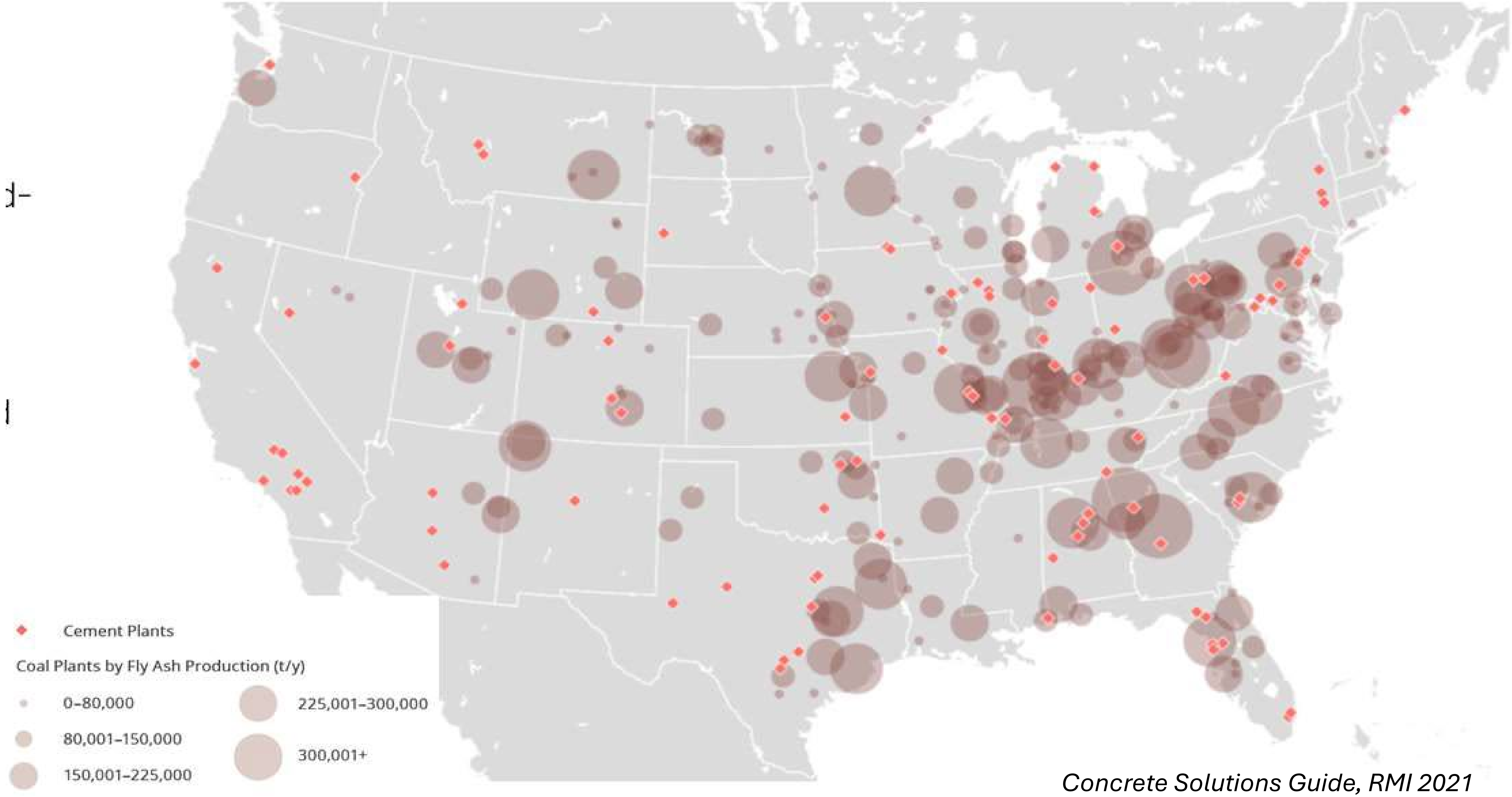
This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope *

1.1 This specification covers coal ~~fly~~ ash resulting from the combustion of coal, and raw or calcined natural pozzolan, for use in concrete where cementitious or pozzolanic action, or both, is desired, or where other properties normally attributed to ~~fly~~ coal ash or natural pozzolans may be desired, or where both objectives are to be achieved.

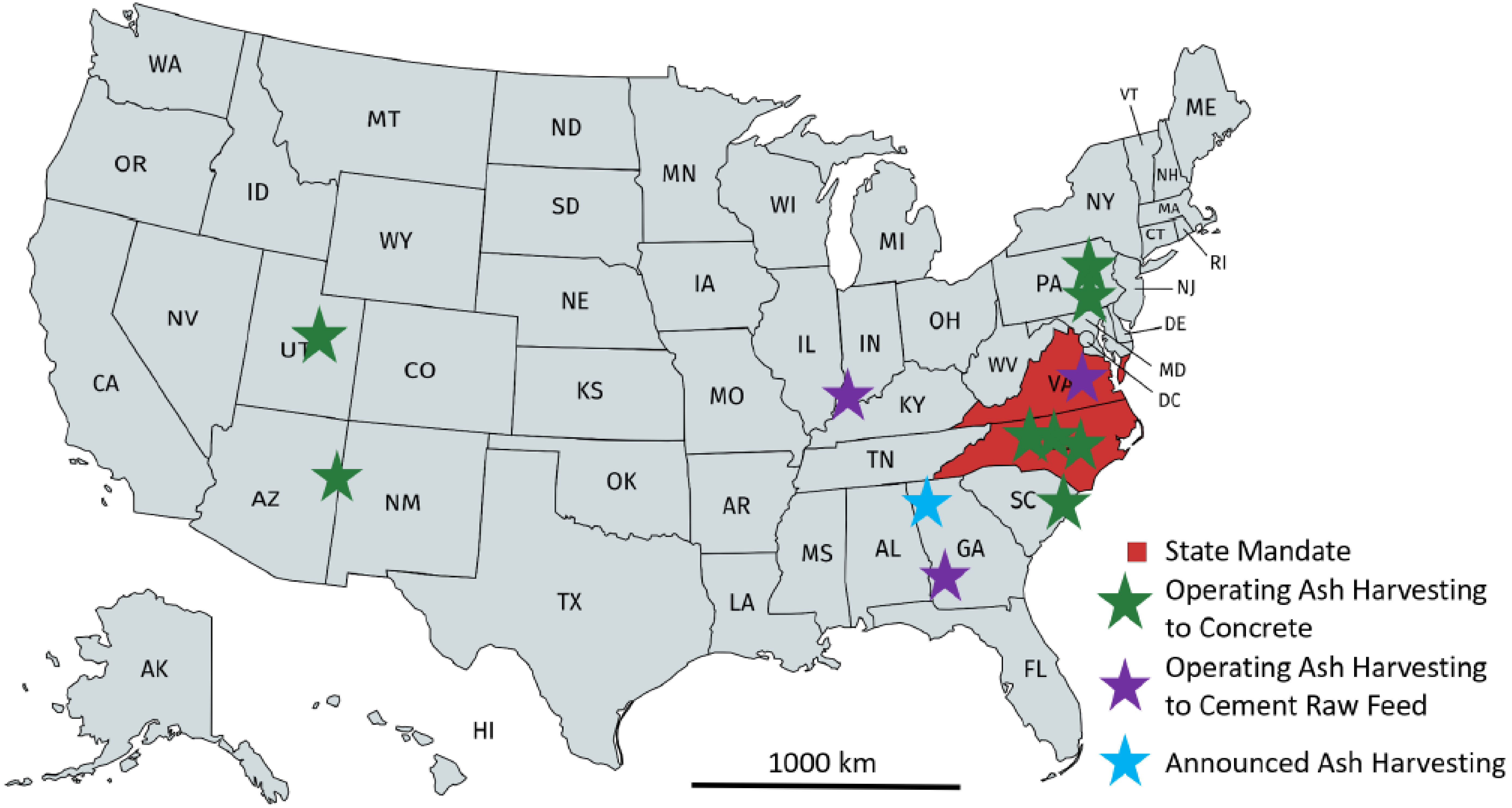
NOTE 1—Finely divided materials may tend to reduce the entrained air content of concrete. Hence, if a coal ~~fly~~ ash or natural pozzolan is added to any concrete for which entrainment of air is specified, provision should be made to ensure that the specified air content is maintained by air content tests and by use of additional air-entraining admixture or use of an air-entraining admixture in combination with air-entraining hydraulic cement.

Coal Ash (Fly Ash)



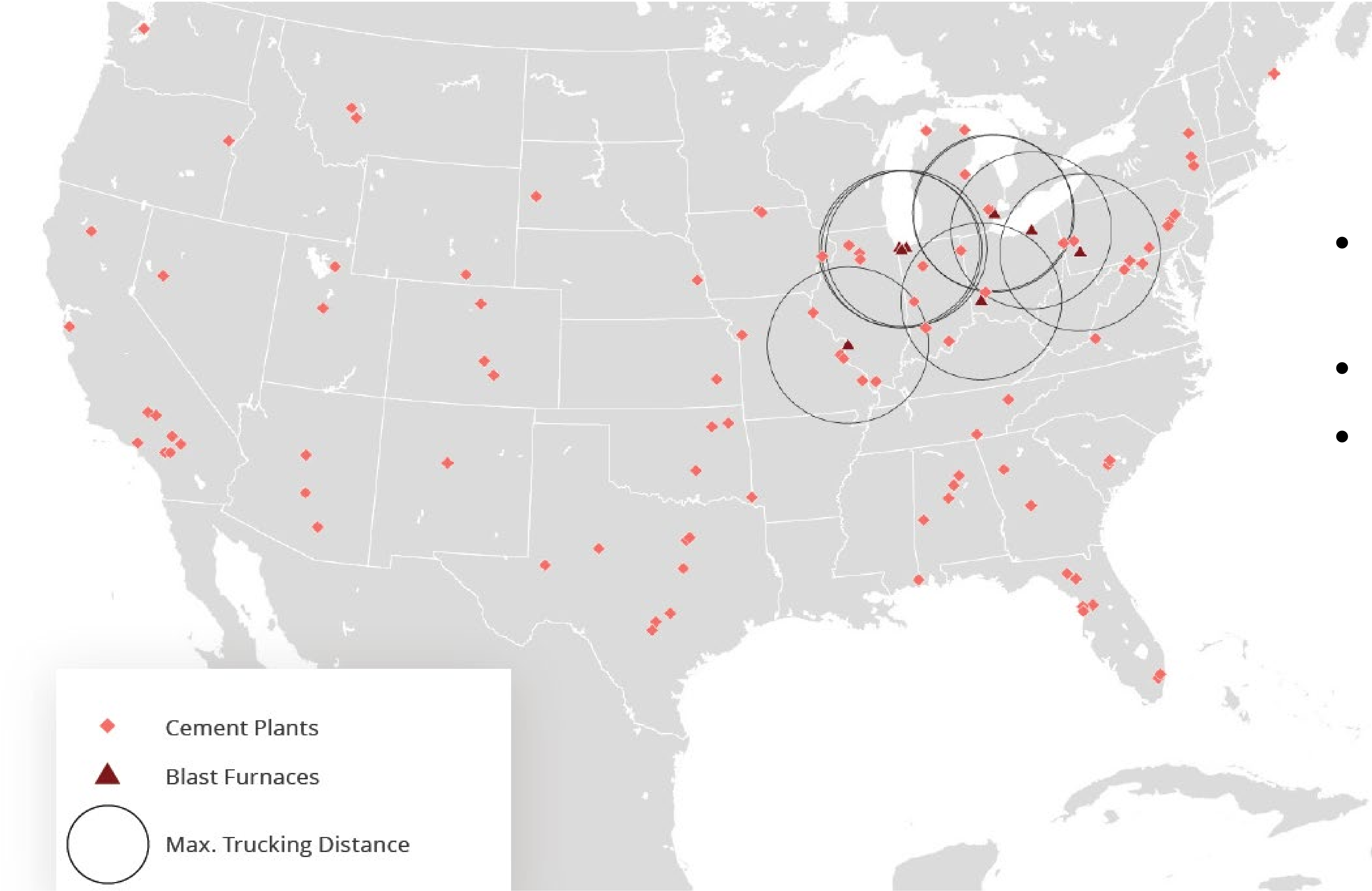
Concrete Solutions Guide, RMI 2021

Harvested Coal Ash



EPRI, 2023

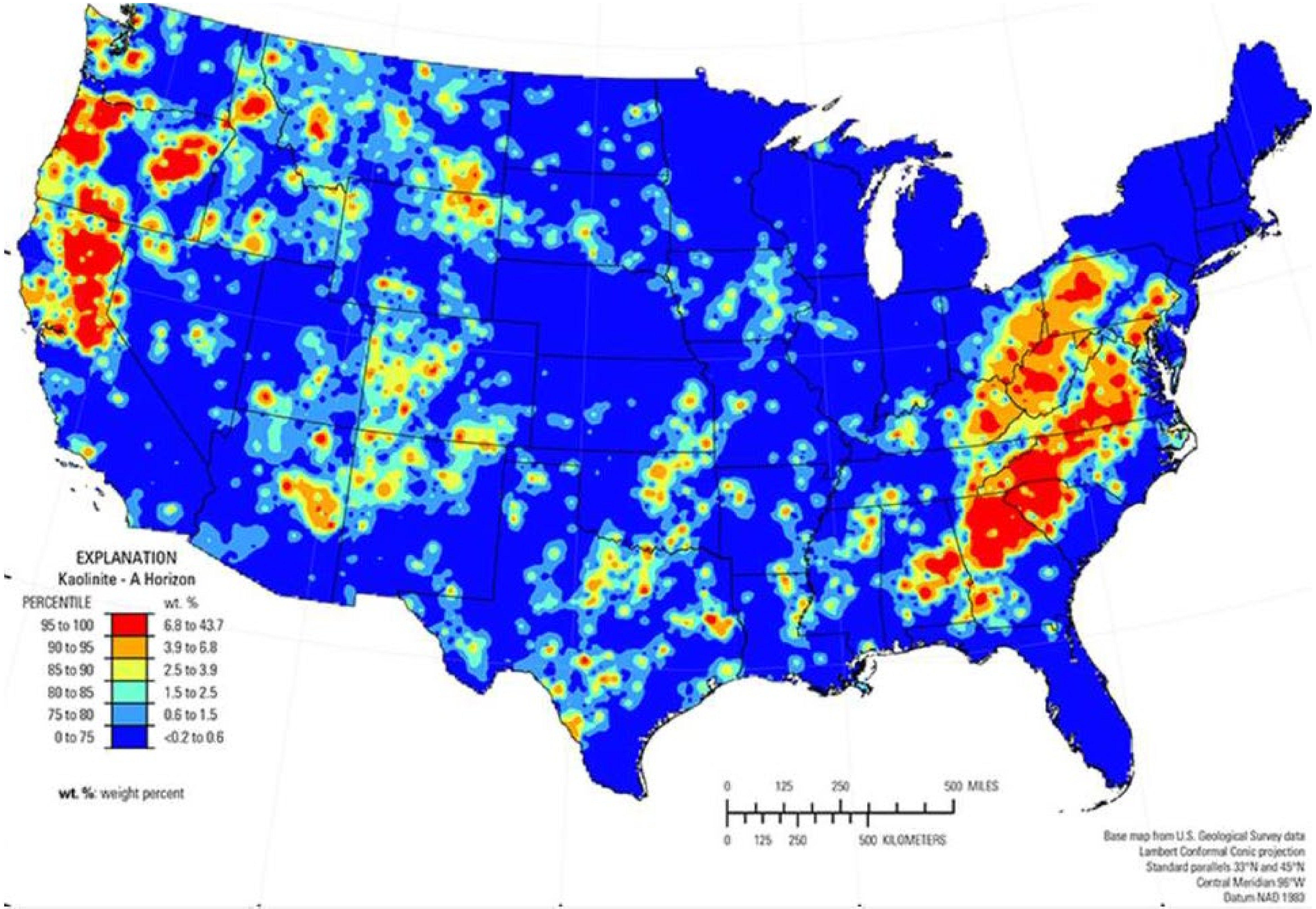
Slag Cement



RMI, 2021

- Domestic blast furnaces are geographically concentrated
- Logistics of transportation
- Imports are significant source for U.S.

Calcined Clay



USGS

- Kaolinite deposits for potential calcined clay production
- And limestone calcined clay cements

Other Natural Pozzolans

Natural Pozzolans Association

- ~10 production facilities
- ~10 more in development
- 5-6 MMT raw (natural) pozzolans
- Plus additional calcined clays and shales by 2030

Emerging Trends and Innovations in Cement

Optimized Blend Ratios

Balancing SCMs for Specific Applications

Nanomaterials and additives

Nanoparticles (e.g., nanosilica) for enhanced strength and hydration

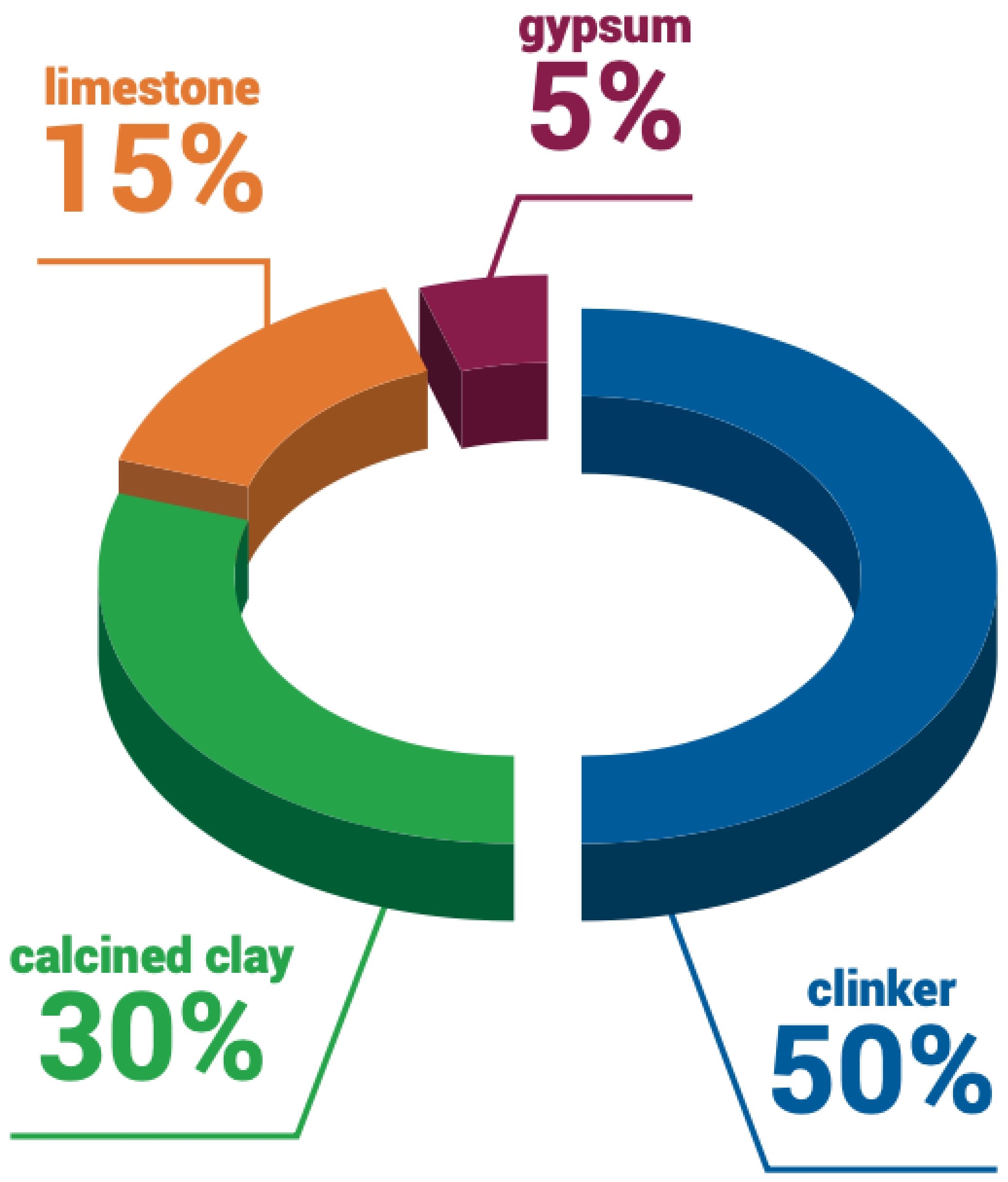
Self-healing and smart materials

Incorporating materials that improve longevity and reduce maintenance

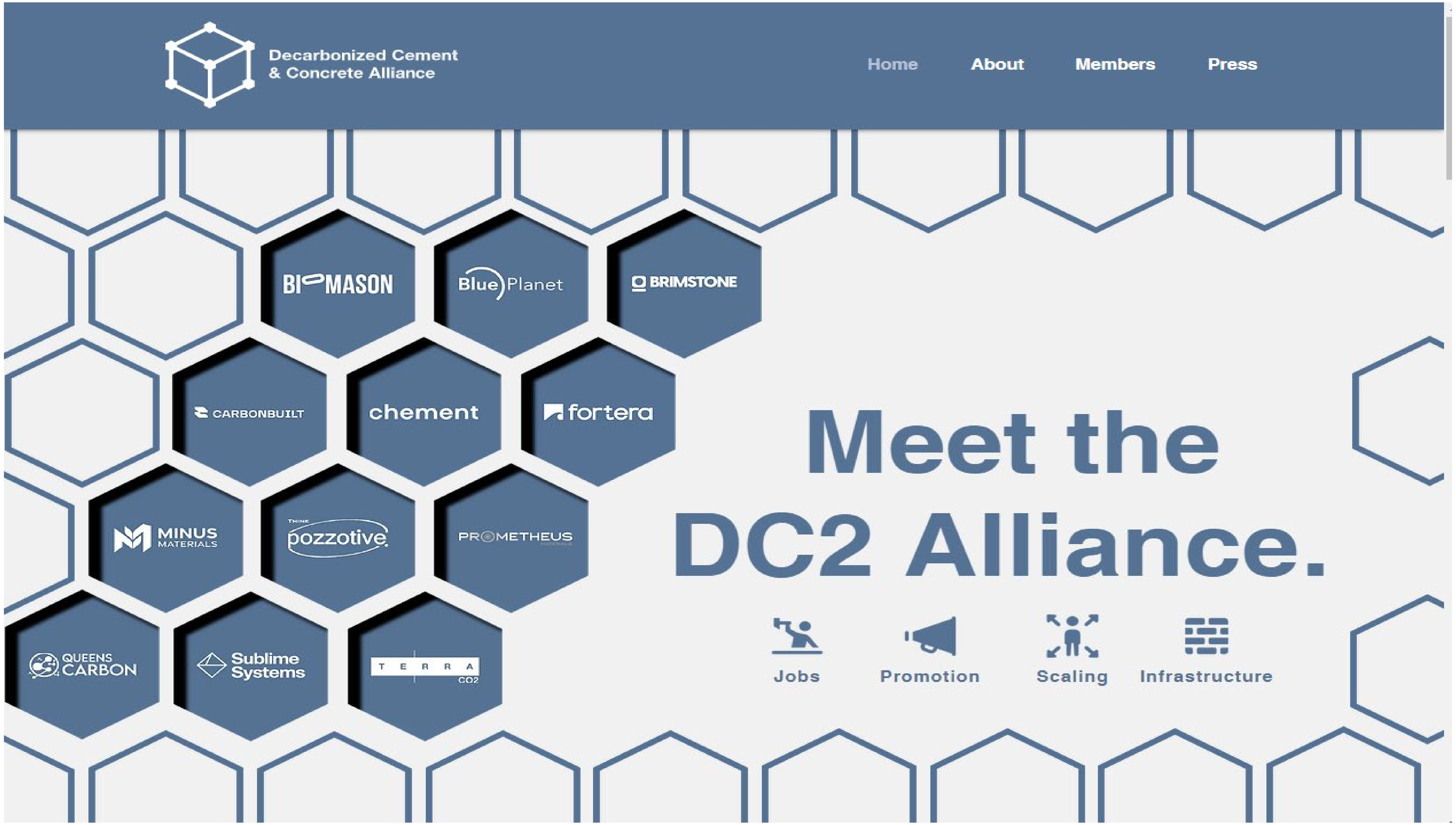
Limestone Calcined Clay Cement

(Such as LC^3):

- Much reduced clinker content with replacement by limestone and calcined clay (regional availability)
- Calcined clays can be produced in existing rotary kiln or in a flash calciner
- Lower temperature for calcined clay (<800°C) vs. clinker (~1450°C)
- Reduce CO_2 emissions by up to 40%



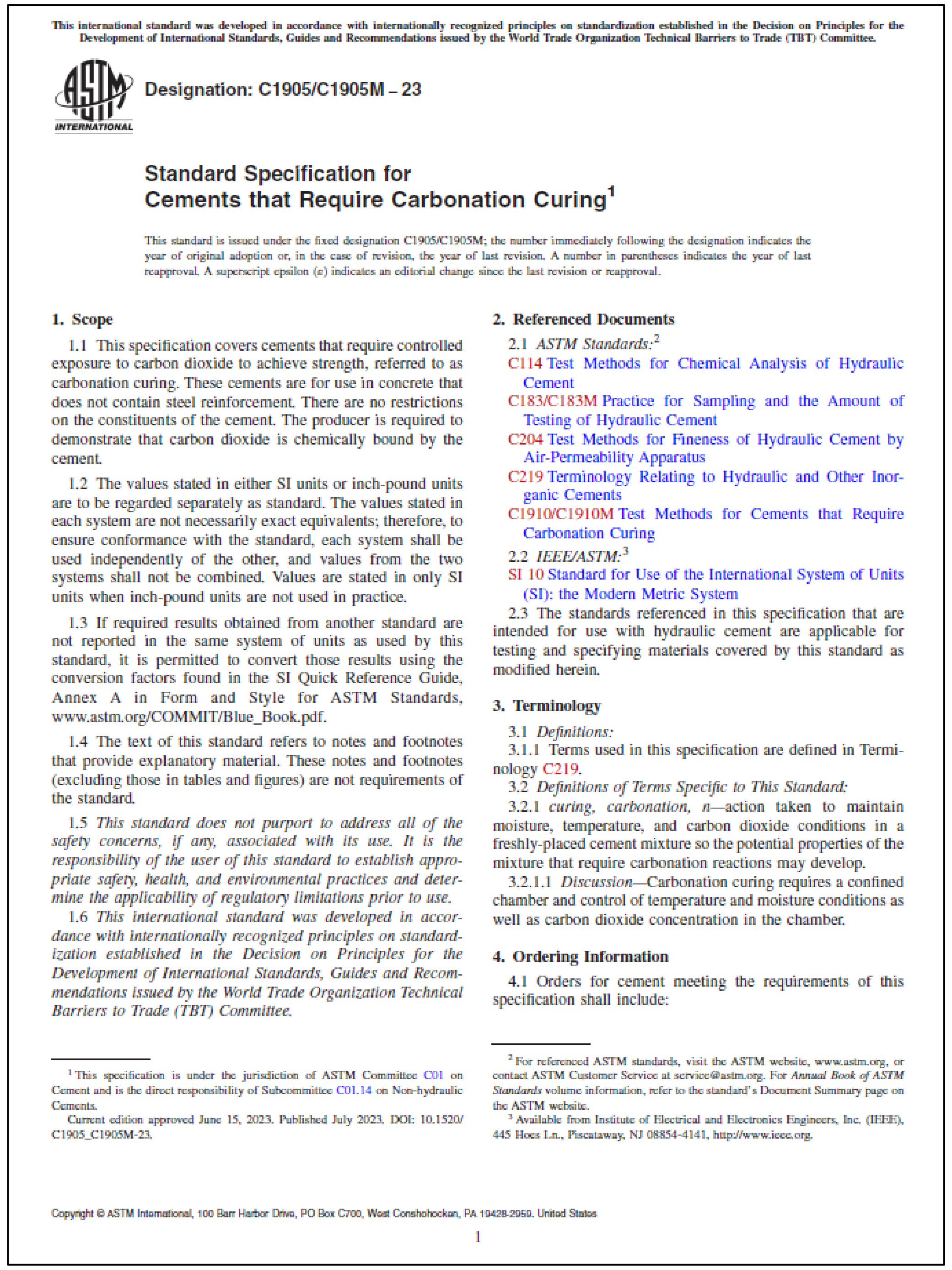
Alternative Cementitious Materials



Cements that Require Carbonation Curing

- Lower temperatures and fewer calcination emissions = about 30% lower CO_2 from manufacture
- Requires curing in a temperature- and moisture-controlled chamber with CO_2
- ASTM C1905-23

  Cements must bind 8% minimum CO_2



This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

Designation: C1905/C1905M – 23

Standard Specification for Cements that Require Carbonation Curing[1]

This standard is issued under the fixed designation C1905/C1905M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers cements that require controlled exposure to carbon dioxide to achieve strength, referred to as carbonation curing. These cements are for use in concrete that does not contain steel reinforcement. There are no restrictions on the constituents of the cement. The producer is required to demonstrate that carbon dioxide is chemically bound by the cement.

1.2 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system are not necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the other, and values from the two systems shall not be combined. Values are stated in only SI units when inch-pound units are not used in practice.

1.3 If required results obtained from another standard are not reported in the same system of units as used by this standard, it is permitted to convert those results using the conversion factors found in the SI Quick Reference Guide, Annex A in Form and Style for ASTM Standards, www.astm.org/COMMIT/Blue_Book.pdf.

1.4 The text of this standard refers to notes and footnotes that provide explanatory material. These notes and footnotes (excluding those in tables and figures) are not requirements of the standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C114 Test Methods for Chemical Analysis of Hydraulic Cement

C183/C183M Practice for Sampling and the Amount of Testing of Hydraulic Cement

C204 Test Methods for Fineness of Hydraulic Cement by Air-Permeability Apparatus

C219 Terminology Relating to Hydraulic and Other Inorganic Cements

C1910/C1910M Test Methods for Cements that Require Carbonation Curing

2.2 *IEEE/ASTM:*[3]

SI 10 Standard for Use of the International System of Units (SI): the Modern Metric System

2.3 The standards referenced in this specification that are intended for use with hydraulic cement are applicable for testing and specifying materials covered by this standard as modified herein.

3. Terminology

3.1 *Definitions:*

3.1.1 Terms used in this specification are defined in Terminology C219.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *curing, carbonation, n*—action taken to maintain moisture, temperature, and carbon dioxide conditions in a freshly-placed cement mixture so the potential properties of the mixture that require carbonation reactions may develop.

3.2.1.1 *Discussion*—Carbonation curing requires a confined chamber and control of temperature and moisture conditions as well as carbon dioxide concentration in the chamber.

4. Ordering Information

4.1 Orders for cement meeting the requirements of this specification shall include:

[1] This specification is under the jurisdiction of ASTM Committee C01 on Cement and is the direct responsibility of Subcommittee C01.14 on Non-hydraulic Cements.

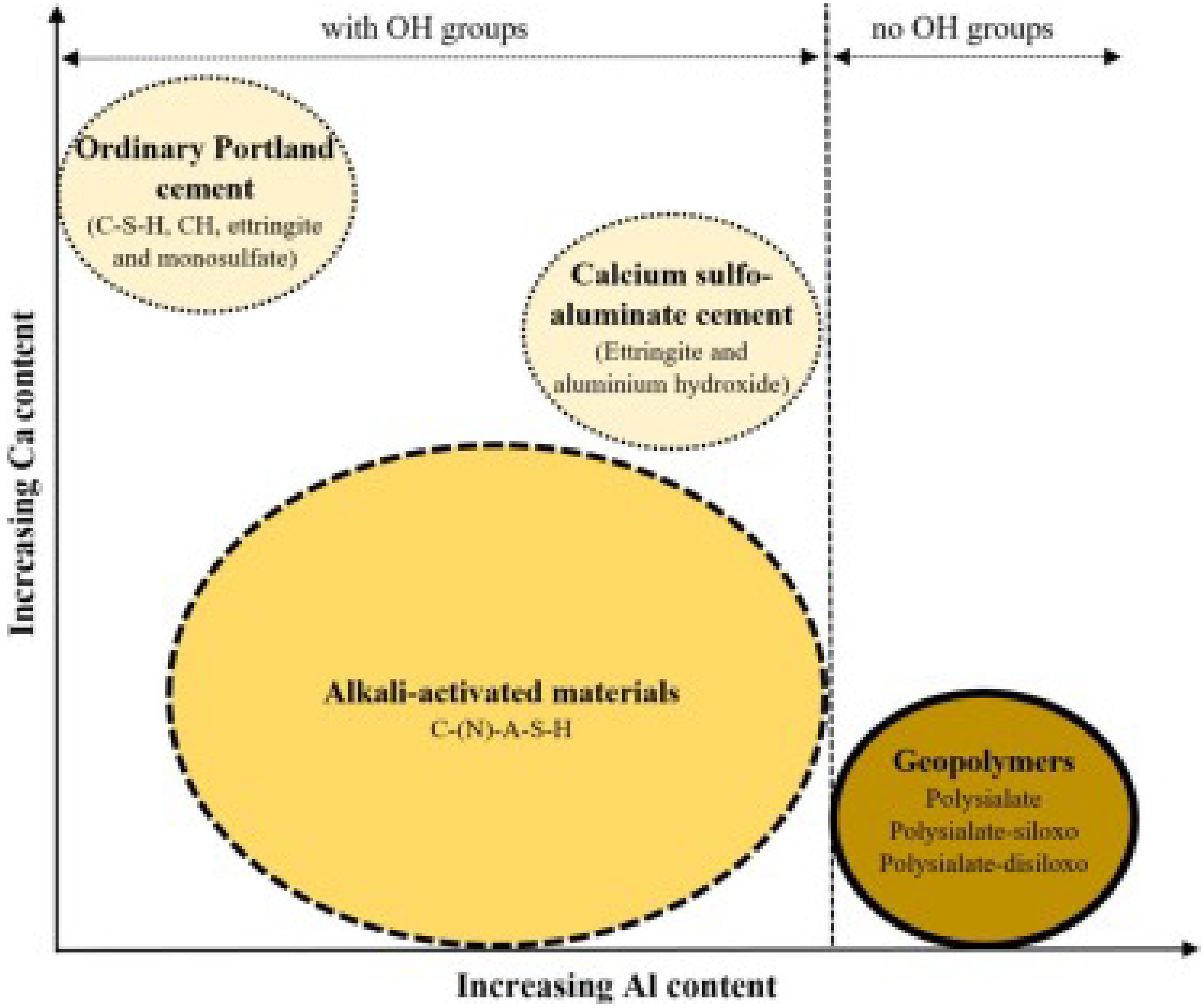
Current edition approved June 15, 2023. Published July 2023. DOI: 10.1520/C1905_C1905M-23.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from Institute of Electrical and Electronics Engineers, Inc. (IEEE), 445 Hoes Ln., Piscataway, NJ 08854-4141, http://www.ieee.org.

Geopolymers and Alkali-Activated Materials

- Using industrial waste to create low-carbon alternatives
- Durability
- Thermal Resistance



H.S. Gökçe et al 2021

Near and Long-Term Solutions

NEAR-TERM

Replace raw materials with recycled materials

Produce low-carbon cement blends

Optimize designs for the lowest life cycle emissions

MID-TERM

Increase the use of alternative fuels

Use renewable energy

LONG-TERM

Carbon capture

Introduce new cement blends

Call to Action

- Research, Development & Innovation
- Regulations, Permitting & Guidance
- Financial Incentives & Support
- Performance-Based Material Standards
- Market-Based Carbon Pricing
- Market Acceptance
- Community Acceptance
- Cradle to Cradle Life Cycle-Based Procurement
- Low-Carbon Infrastructure
- Level Playing Field

Questions and Further Information

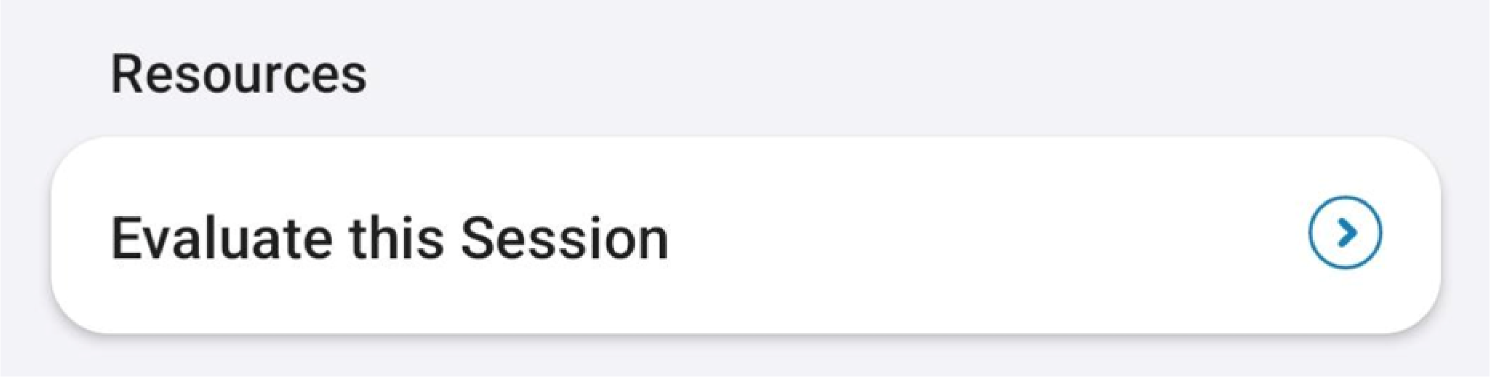
CONCRETE REPAIR
Restore | Repurpose | Renew

Blended Cement Resource:
greenercement.com

Roadmap Updates:
cementprogress.com

ICRI CONCRETE REPAIR
Restore | Repurpose | Renew

SESSION EVALUATION



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