Advancements in Limestone Calcined Clay Cement (LC3)

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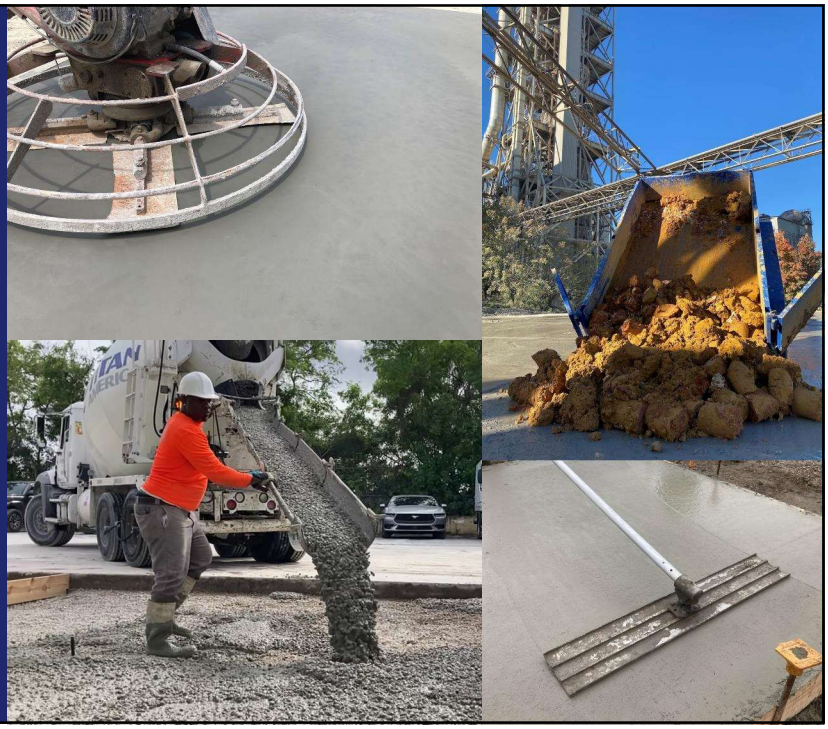
Calcined Clay

- ✓ High Strength and Highly Durable Cementitious Material
- ✓ Made with Widely Available Raw Materials
- ✓ Meets Existing Specifications
- ✓ >50% Lower Energy*
- ✓ >80% Lower CO_2 *

*Compared to clinker



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Outline

- Low Carbon Codes and Specifications
- Levers to Low Carbon Concrete
- Blended Cements
- Limestone Calcined Clay Cement (LC3)
  - Raw Materials
  - Manufacturing Process
  - Concrete Performance
- Global Deployments of Calcined Clay
- Recommendations for Implementing Blended Cements
  - Specifications
  - Mix Changes
- Conclusions

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Low Carbon Concrete Requirements

Today

American Concrete Institute
ACI 323 – Low Carbon Concrete Code

New York
NYS Buy Clean Concrete

New Jersey
Low Embodied Carbon Concrete Leadership Act (LECCLA)

Environmental Protection Agency
EPD Grant Program
Green Labeling Program
Interim Determination on Low Carbon Materials

Federal Highway Administration
$2 billion Low Carbon Transportation Grant Program

General Services Administration
$767 million for low carbon concrete

Coming Soon

US Green Building Council
GWP limits on concrete

American Concrete Institute
ACI 318-25– Appendix N
ACI 301-26 – Sustainability provisions

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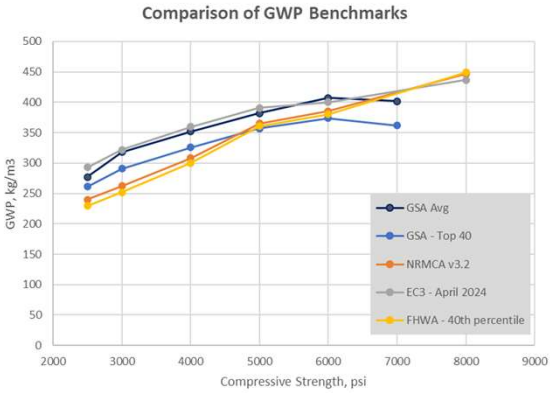
Low-Carbon Concrete Specifications



Recommendations

- Use a Carbon Budget for the entire project, rather than induvial mixes
- Establish the budget in the context of a Whole Building Lifecycle Analysis
- Ensure concrete mixes are “functionally equivalent”, including durability, w/cm, and workability
- Use local values where possible; regional values are too broad
- Consider Means and Methods, including constructability and schedule impact

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Cement and Concrete Industry Roadmaps to Net Zero

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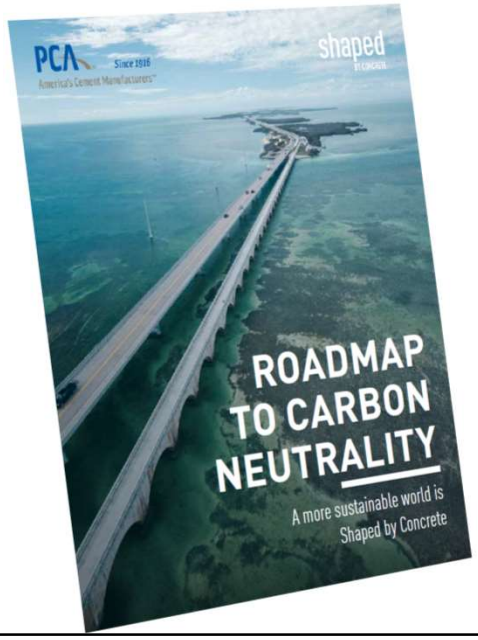

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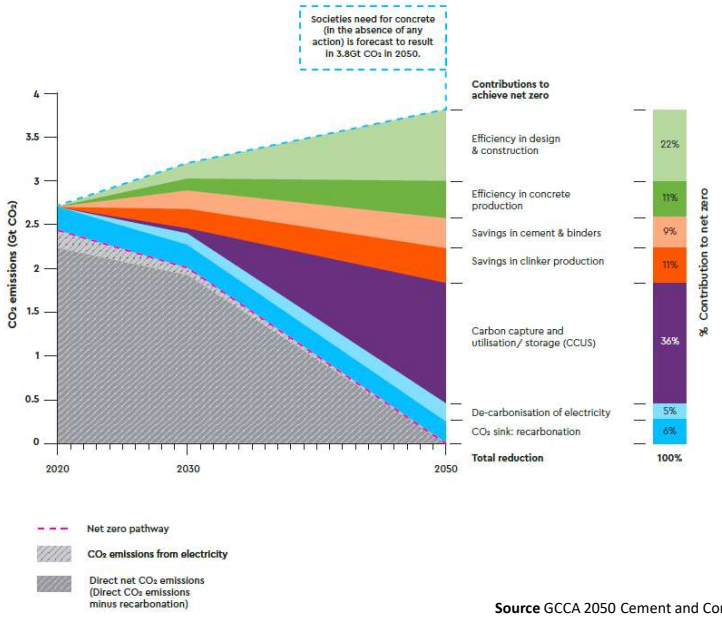
Levers for Achieving Net Zero CO_2



Source GCCA 2050 Cement and Concrete Industry Roadmap to Climate Neutrality

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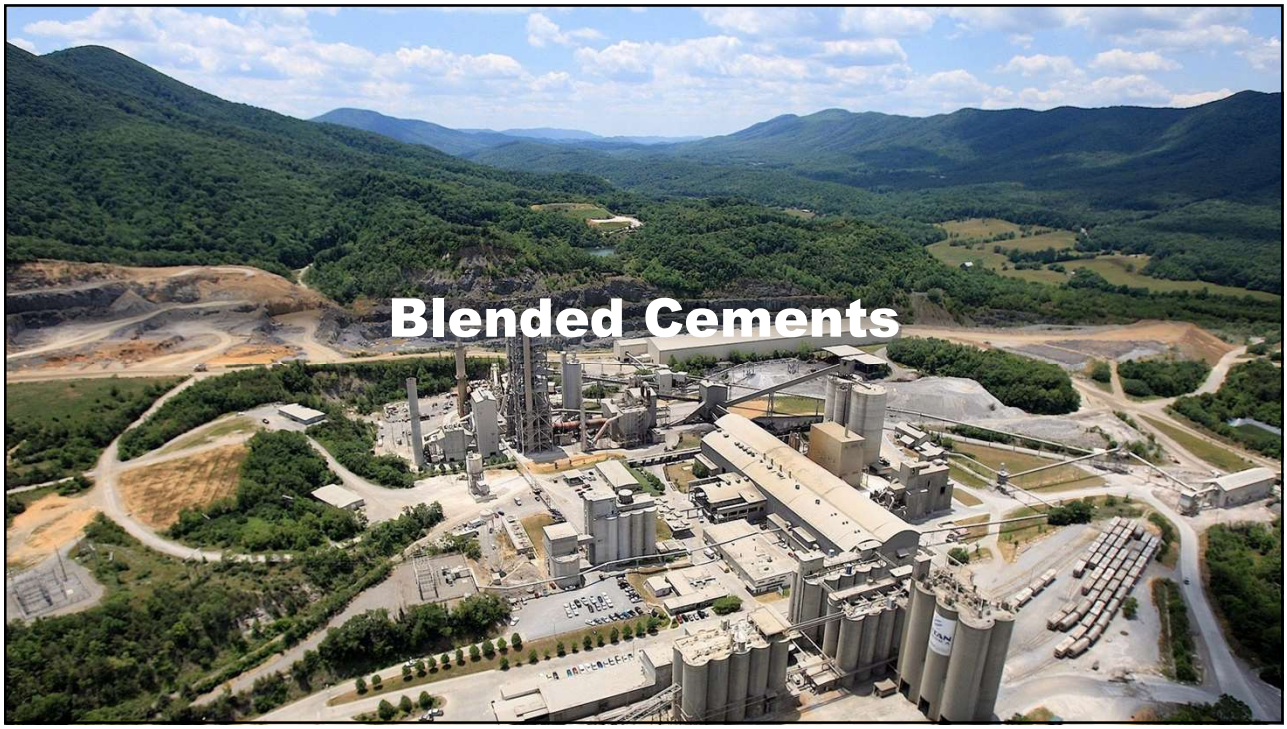

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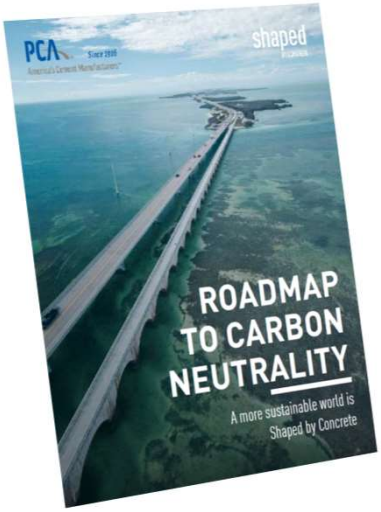
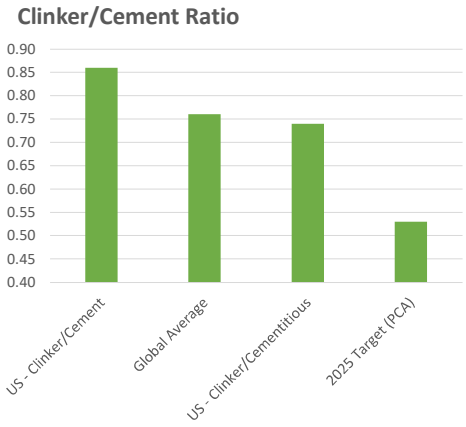
SCMs – Proven Way to Decarbonize





Sources USGS, ACAA, NPA, SCA, PCA

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Blended Cements

	Portland Cement ASTM C150 AASHTO M85	Blended Cement ASTM C595 AASHTO M240			
	(Type I/II)	Portland-Limestone (Type IL)	Portland-Pozzolan (Type IP)	Portland-Slag (Type IS)	Ternary (Type IT)[1]
Clinker (typical)	90-95%	80-90%	60-80%	30-80%	40-70%
Gypsum (typical)	4-6%	4-6%	4-6%	4-6%	4-6%
Limestone	0-5%	5-15%			15% max[2]
Pozzolan (fly ash, silica fume, etc.)			40% max		40% max[2]
Slag				95% max	95% max[2]
Potential CO_2	Standard	Lower	Lower	Lower	Lowest
Sulfate Resistance	C3A Limit	ASTM C1012	ASTM C1012	ASTM C1012	ASTM C1012
Heat of Hydration	C3A & C3S Limit	ASTM C1702	ASTM C1702	ASTM C1702	ASTM C1702

[1]Can use up to two of pozzolan, limestone, and slag
[2]Maximum of pozzolan, slag and limestone is 70%

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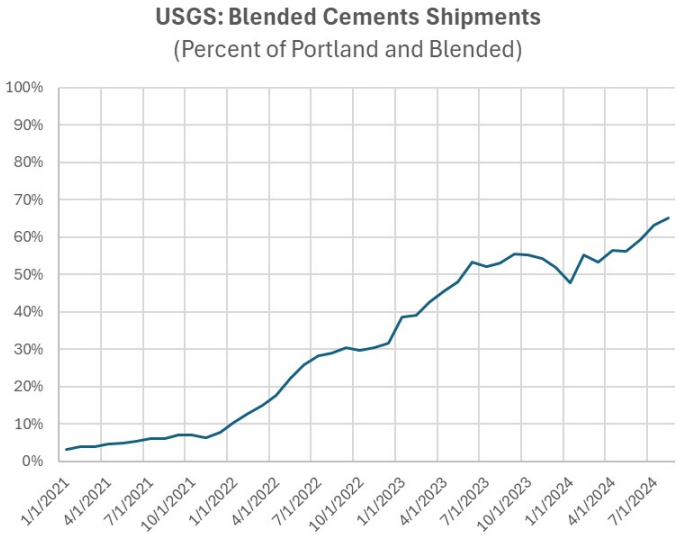
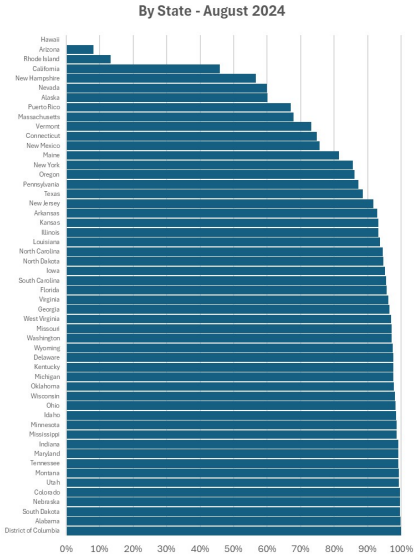
Blended Cements





Source USGS

Note: 96.7% is Type IL

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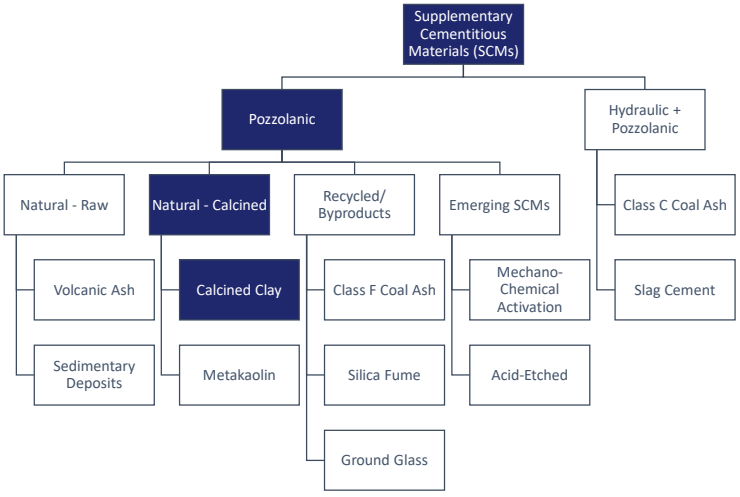
Pozzolan Defined

ASTM C125 Definition
Pozzolan, *n*—a finely divided siliceous or siliceous and aluminous material that will not react chemically with water, but will react with calcium hydroxide and water at ordinary temperatures to form compounds possessing cementitious properties



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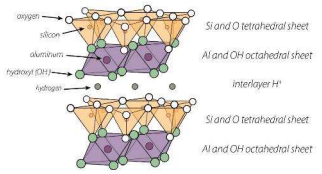
Types of Clay for Calcined Clay

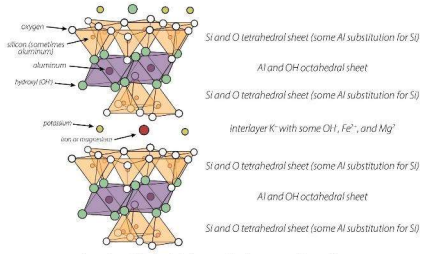
The three major clay minerals can be calcined; with calcined kaolin clays having the highest reactivity in cement.

Kaolinite group (1:1 clays)



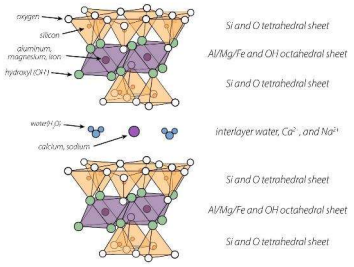
includes kaolinite, it's polymorphs, and the hydrated form halloysite; common in areas with intense weathering and/or Al-rich parent

Illite (2:1 non-swelling clays)



strong bonds in the interlayer potassium prevents swelling; found in temperatue climates as the weathering produce of mica and feldspar

Smectites (2:1 swelling clays)



swelling clays including bentonite, montmorillonite, and vermiculite - closely associated with glauconite (abundant Fe in octahedral sheet); most commonly in temperate and arid climates, forms from weathering of volcanic ash, basalt, gabbro, and other Fe- and Mg-rich parent rock

Source By Page Quinton - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=143745657

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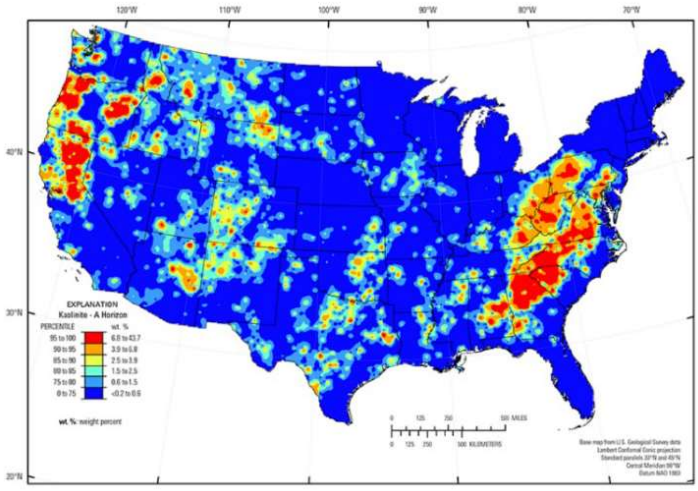
Kaolin Clay Prevalence



Source USGS

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Manufacturing

Mining | Blending | Grinding | Drying | Calcination | Cooling | Grinding | Blending | Shipping

- Raw clays are **calcined** (heated to 650 to 900 C), which results in **de-hydroxylation** (removal of hydroxyl ions (OH^-) and disordering from a crystalline to amorphous structure)
- Calcination is typically accomplished by one of two technologies:

	Rotary Kiln	Flash Calciner
Temperature	Lower	Higher
Residence Time	10s of minutes	Seconds
Energy Use	Higher	Lower
CO_2	Higher	Lower
Color Control	Yes	Yes

- Color control is applied if appreciable iron phases are present, result in a white to gray product
- Clay is ground to optimal fineness for use in cement

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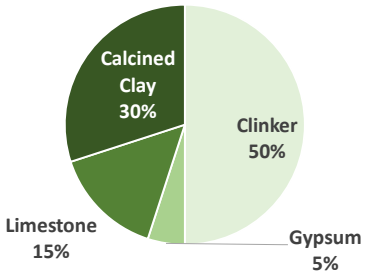
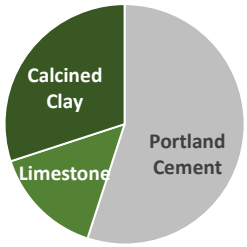
Potential Calcined Clay Products

Limestone Calcined Clay Cement (LC3)

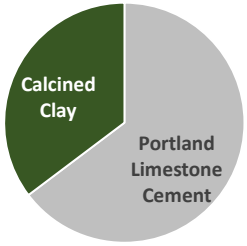


- ✓ Complete system optimized for final hydrated cement chemistry
- ✓ Sulfate (gypsum) balanced for consistent performance
- ✓ Potential for optimized grinding
- ✓ Meets ASTM C595 Type IT
- ✓ Approximately 40% reduction in CO_2 relative to portland cement

Limestone Calcined Clay (LC2)



Calcined Clay (CC)



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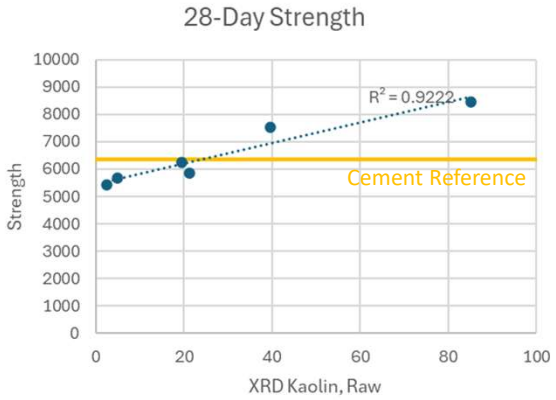
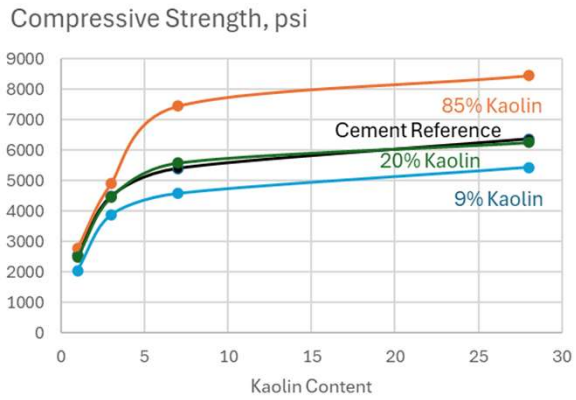
Effect of Kaolin Content on Strength





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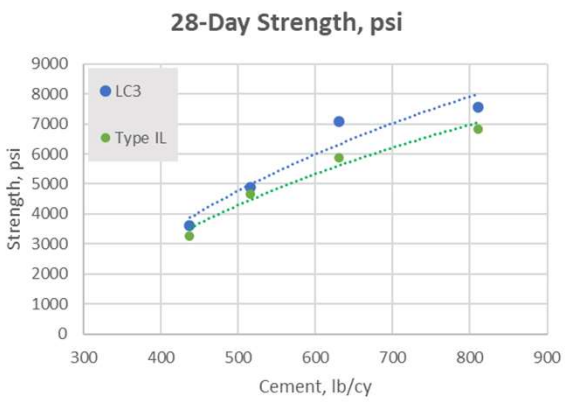
Limestone Calcined Clay Cement in Concrete



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Limestone Calcined Clay Cement in Concrete

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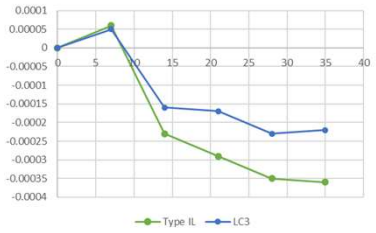
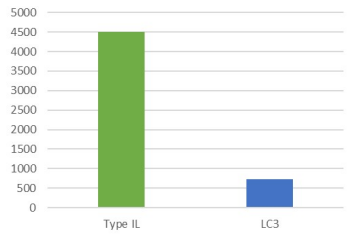
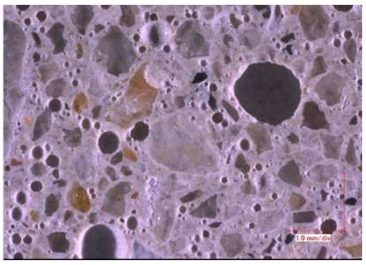
Drying Shrinkage



Rapid Chloride Permeabilty (RCPT)

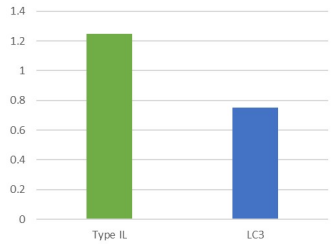


Air Void Characteristics

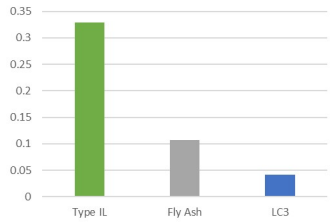


Hardened Air, %	7.9
Specific Surface, in2/in3	668
Spacing Factor	0.006

Abrasion Resistance (ASTM C944)



Alkali Silica Reactivity (ASTM C1260)



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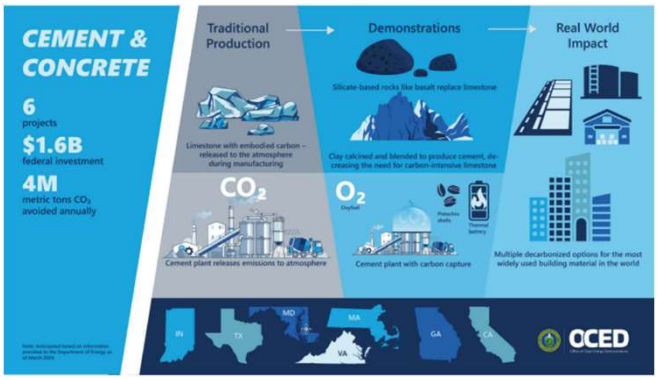
Calcined Clay Deployment Worldwide

Announced Projects Globally (GCCA)

Source https://www.industrytransition.org/green-cement-technology-tracker/

March 2024 - DOE Industrial Demonstration Projects



As part of its $6 Billion Industrial Demonstrations Program, the US Department of Energy announced funding of 3 first-of-a-kind, full scale calcined projects in the US

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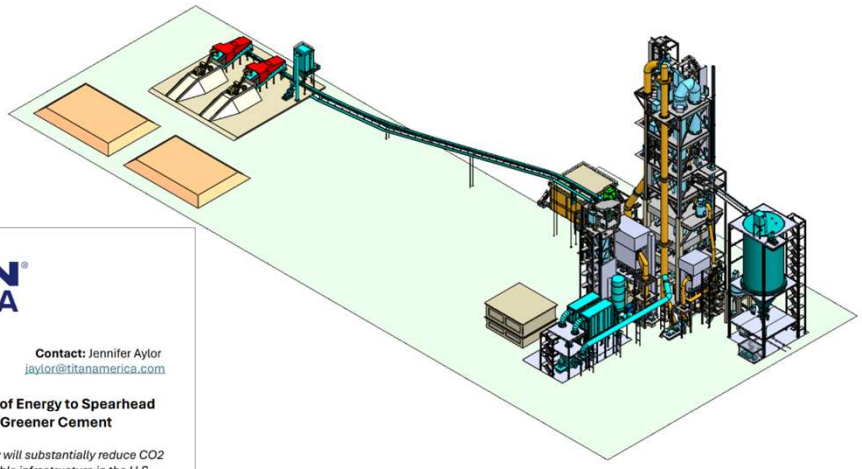
Roanoke Cement to Build First-of-a-Kind Calcined Clay Project



FOR IMMEDIATE RELEASE

Contact: Jennifer Aylor
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Titan America LLC Selected by U.S. Department of Energy to Spearhead New Innovation in Producing Cleaner and Greener Cement

First-of-its-kind deployment of innovative cement technology will substantially reduce CO2 emissions and become a model for building more sustainable infrastructure in the U.S.

TROUTVILLE, Va., March 25, 2024 – Titan America LLC today announced that its Roanoke Cement Company (RCC) business has been selected by the U.S. Department of Energy (DOE) to begin negotiations for a $61.7 million award to support the first-of-a-kind deployment of a calcined clay production line at its Troutville facility. The project is part of the $6.3 billion Industrial Demonstrations Program, which is managed by DOE's Office of Clean Energy Demonstrations (OCED).

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Specification Recommendations

- Ensure specifications allow all types of ASTM C595 cements
  - Type IL
  - Type IP
  - Type IS
  - Type IT
- Allow use of all SCM's that are permitted by ASTM
  - Natural pozzolan (i.e. volcanic deposits) – ASTM C618 and ASTM C1945
  - Calcined clay – ASTM C618 and ASTM C1945
  - Harvested fly ash – now permitted in ASTM C618
- Allow use of SCM both at batch plant and in blended cement
- Replace prescriptive with performance specification requirements

Prescriptive	Performance
Target amount (%) of specific SCM	Strength
Use of fly ash or slag only	ASR – ASTM C1260 or ASTM C1293
Minimum cementitious content	Sulfate – MS or HS designation
Maximum cementitious content	Chloride – RCPT or surface resistivity
	Heat – MH or LH designation
	GWP Limits

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Product Performance Scorecard

Property	Test
Slump & Slump Loss	ASTM C143
Air	ASTM C231
Setting Time	ASTM C403
Strength	ASTM C39
Hot Weather	ACI PRC-305
Cold Weather	ACI PRC-306
Finishability	Mock-up
Pumpability	Mock-up
Bleeding	ASTM C232
Heat of Hydration	ASTM C1702
Chloride Resistance	ASTM C1202, C1556
Shrinkage	ASTM C157
Cracking Potential (Restrained Shrinkage)	ASTM C1581
Sulfate Resistance	ASTM C1012
Alkali Silica Reactivity Mitigation	ASTM C1260, C1293, C441
Freeze-Thaw Resistance	ASTM C66
Scaling Resistance	ASTM C672
Abrasion Resistance	ASTM C944

Best Practices for Implementing New Cements

- Test typical mixes representing range of conditions
  - Air and non-air entrained
  - With and without SCM
  - Strength levels
- Perform field mockups for key applications
- Select optimal percentage for equivalent or enhanced performance relative to conventional materials
- Evaluate consistency within a source
- Prepare new submittals
- Ensure best practices are followed throughout concrete construction
  - Hot weather
  - Cold weather
  - Finishing
  - Quality control

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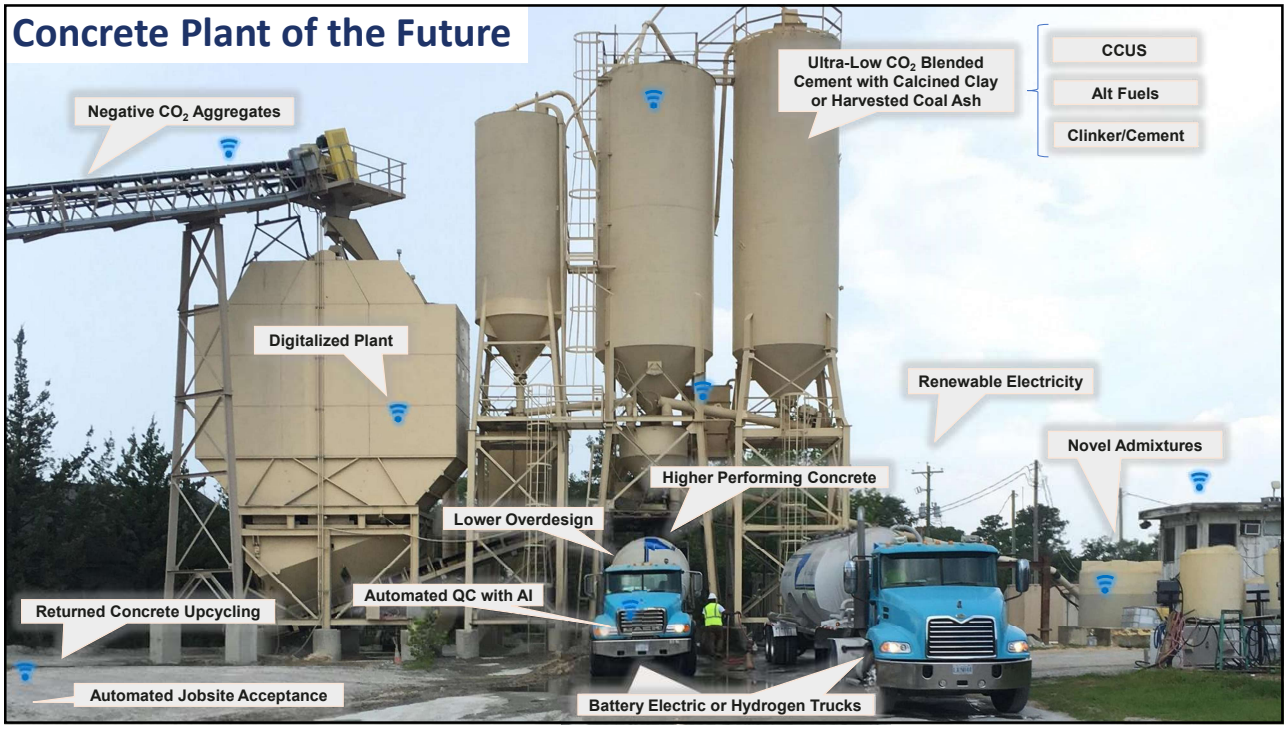
Concrete Plant of the Future



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Conclusions

- SCMs are a proven way to decarbonize concrete
- Calcined clay is a high-performing cementitious material made with widely available materials and with lower embodied energy and CO_2
- Although calcined clay meets ASTM C595 and ASTM C618, revisions to concrete specifications will accelerate the implementation of Type IT

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