U.S. DEPARTMENT OF ENERGY

Fossil Energy and Carbon Management

Industry Guide to Carbon Capture and Storage at Cement Plants

Cement is an ingredient in concrete—a critical material that is fundamental to the construction of buildings and infrastructure around the world.

THE RELATIONSHIP BETWEEN CEMENT AND CONCRETE

Cement, when activated with water, is the binder that holds the concrete mixture together and provides the functional strength. For example, portland cement is the basic ingredient of concrete, mortar, stucco, and most non-specialty grout.

Concrete is formed with a varying mixture of sand, gravel, water, and cement, depending on the desired properties of the concrete. Typically, most mixes comprise of about 7-15% cement by volume.[1]

Cement is produced at large-scale facilities, while most concrete is generally mixed in small-scale batch plants for local uses. In the United States, there are 98 facilities (92 are required to report GHG emissions to EPA's Greenhouse Gas Reporting Program) that produce cement and over 8,500 concrete plants. More than half of the facilities in the U.S. are owned by multinational corporations that also have cement production plants across the world.

DID YOU KNOW?

14 billion cubic meters of concrete are used annually, the second most consumed material on a per capita basis after water and is predicted to increase to 20 billion cubic meters by 2050.[2]

HOLCIM Portland Cement Plant in Florence, Colorado, U.S.

CEMENT PRODUCTION IS CARBON INTENSIVE

Cement production is both emissions- and energy-intensive. In 2021, the U.S. cement industry produced approximately 93 million metric tons (MT) of portland cement and masonry cement, with sales at approximately $13.4 billion.[3] For the same year, U.S. cement production facilities reported 69 million MT carbon dioxide equivalents (CO_2e).[4] This represents nearly 5% of U.S. industrial sector total greenhouse gas (GHG) emissions and just over 1% of U.S. total GHG emissions.[5]

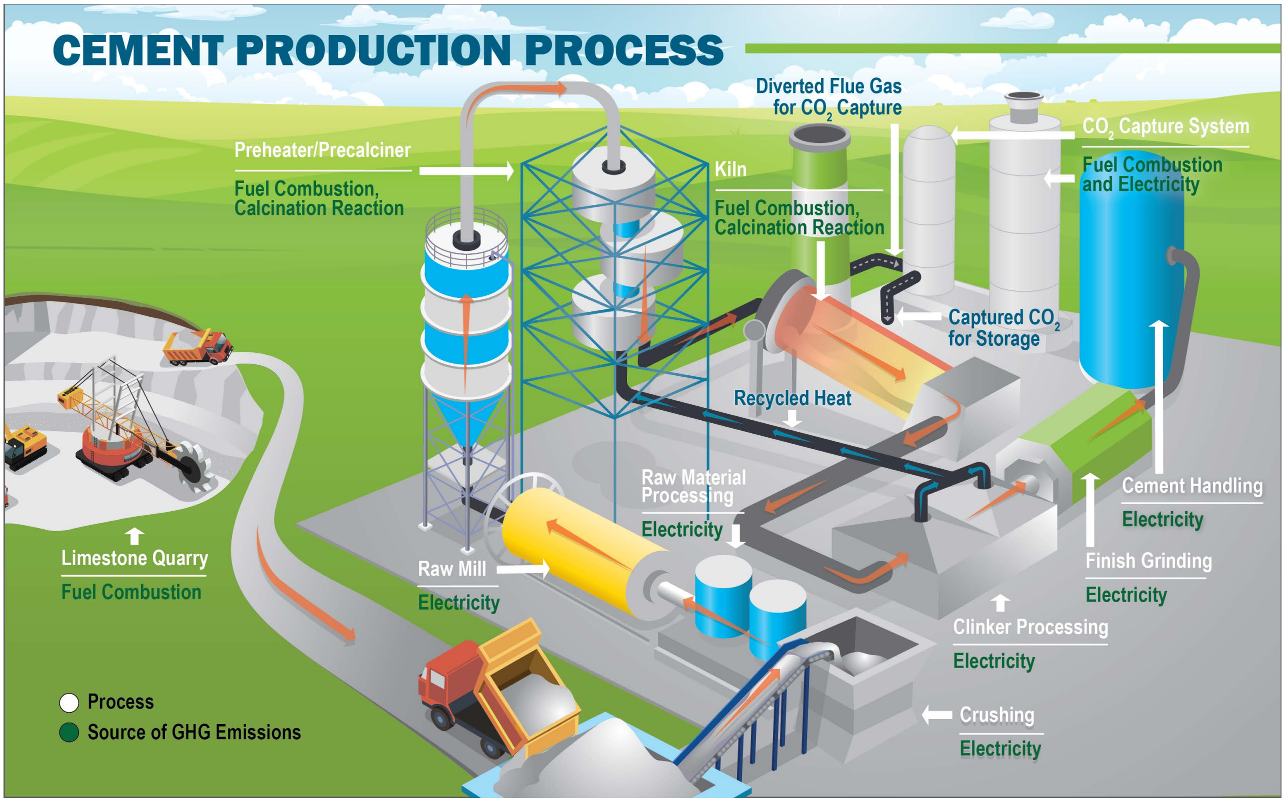
Globally, 4,400 million MT of cement were produced in 2021, accounting for approximately 7% of global industrial energy use and 8% of total carbon dioxide emissions.[6, 7, 8] By 2050, cement production is expected to increase by more than 10%.[9]

The unique functional advantages, ubiquity of its use, and the emissions intensity make cement production a critical sector to decarbonize. The U.S. Department of Energy (DOE) is evaluating a variety of approaches to decarbonize cement and other industrial sectors,[10] including the Office of Fossil Energy and Carbon Management's (FECM) efforts focused on point-source carbon capture.[11]

2021 Production and Emission Rates at Cement Facilities, U.S. and Globally

U.S. Facilities Reporting GHG Emissions to EPA	U.S. Production *(million MT)*	U.S. GHG Emissions *(million MT CO_2e)*	% of U.S. Industrial Sector GHG Emissions	% of Total U.S. GHG Emissions
92	93	69.0	4.6	1.1

Global Facilities	Global Production *(million MT)*	Global GHG Emissions *(million MT CO_2e)*	% of Global Industrial Sector GHG Emissions	% of Total Global GHG Emissions
~3,400[12, 13]	4,400	~2,600[14, 15]	30%[16]	8



CEMENT PRODUCTION PROCESS

During the cement production process, calcium carbonate (usually from limestone and chalk) is combined with silica-containing materials (such as sand and shale) in a cement kiln. Inside the kiln, the raw materials are heated to 2,600–3,000 °F (1,430–1,650 °C) causing a chemical reaction (calcination) that fuses the raw materials into portland cement clinker. Clinker is an intermediate product of rock-like nodules that are eventually ground into a powder and mixed with calcium sulfate and other minor constituents to produce the portland cement.

CARBON CAPTURE CAN HELP SIGNIFICANTLY REDUCE CEMENT PLANTS CARBON DIOXIDE EMISSIONS

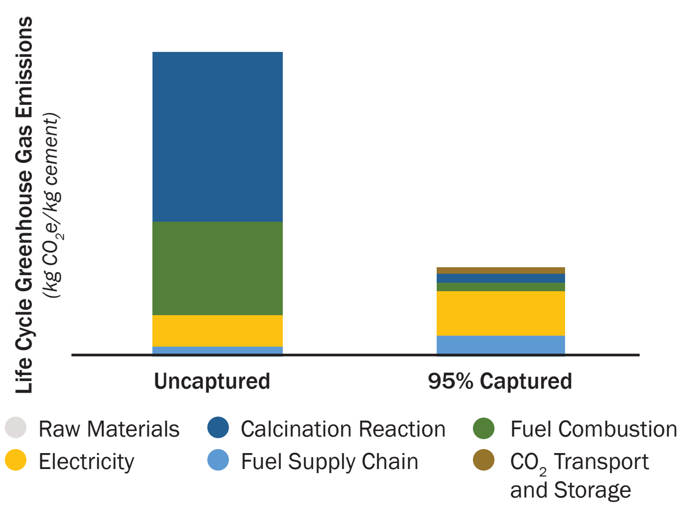
Over 85% of the life cycle greenhouse gas emissions associated with the production of cement come from two primary contributors:[17]

1. Carbon dioxide as a byproduct of the calcination reaction
2. Carbon dioxide from the combustion of fuels (e.g., coal, natural gas, municipal solid waste, tires, and biomass) to heat the cement kiln to facilitate the reaction

The remaining life cycle emissions are mostly attributed to electricity used to run machinery and the fuels combusted on-site. As shown in the figures, carbon capture with 95% capture efficiency can reduce cement production's life cycle carbon dioxide emissions by nearly 70%[18], which accounts for the additional energy required to operate the carbon capture equipment.

It is important to note that even if a cement plant electrified all its heat and power and/or used bio-derived fuels, about half of the current carbon dioxide emissions would still be emitted due to the chemical reactions that occur during the calcination process of cement production. Development of electrification options for the precalciner and kiln processes is still underway (TRL 5-6), whereas carbon capture use and storage technologies are further advanced and can be deployed in the near future to catalyze decarbonization of the cement sector.

Carbon dioxide emission rates throughout the life cycle of the cement production process with and without carbon dioxide capture



	Greenhouse Gas Emissions (kg CO_2e/kg cement)		Change in CO_2 Emissions
	Uncaptured	95% Captured	
Raw Materials	<0.01	<0.01	0.00%
Fuel Supply Chain*	0.03	0.07	118.33%
Electricity*	0.09	0.14	49.77%
Fuel Combustion	0.31	0.03	-91.78%
Calcination Reaction	0.55	0.03	-95.00%
CO_2 Transport and Storage	0	0.02	--
TOTAL	**0.98**	**0.28**	**-71.26%**

*There is an increase in emissions associated with fuel supply chain and electricity in the 95% carbon capture case because additional energy is required by that process.

LOW-CARBON CEMENT AND SCOPE 3 EMISSIONS REPORTING

U.S. companies are taking steps toward establishing and implementing strategies to meet their net-zero greenhouse gas emissions targets.[20] Emissions are often categorized into three bins (referred to as scopes 1, 2, and 3) based on guidance from the GHG Protocol and included as part of the Science-Based Targets Initiative.[21, 22]

- **Scope 1** emissions include direct emissions (often combustion) at facilities owned by a company.
- **Scope 2** emissions are associated with the purchase of electricity, steam, heating, and cooling.
- **Scope 3** emissions include all other emissions from activities not owned by the reporting company, but are a part of their supply chain.

Increasingly, organizations are setting greenhouse gas emissions reduction targets that include their supply chain emissions (scope 3), thereby linking the success of their suppliers to reduce greenhouse gas emissions to their ability to meet ambitious greenhouse gas reduction targets.[23]

Some companies are relying on carbon offsets or carbon removal credits to achieve their reduction targets and offset their scope 3 emissions.[24] An alternative, and potentially more cost-effective approach, could be to procure lower GHG-intensity raw materials by working directly or collaboratively with suppliers. Purchasing low-carbon cement produced at a facility equipped with carbon capture is one way that companies, organizations, and governments can substantially reduce scope 3 emissions.

FECM-FUNDED PROJECTS USING CARBON CAPTURE TECHNOLOGY AT CEMENT PLANTS

FECM is actively funding and managing front end engineering and design (FEED) projects to retrofit cement facilities in the U.S. with carbon capture technology, as well as a small-scale pilot testing of capture approaches. These projects provide critical information required to better understand potential siting considerations and costs and are a necessary step for deployment of carbon capture technology.

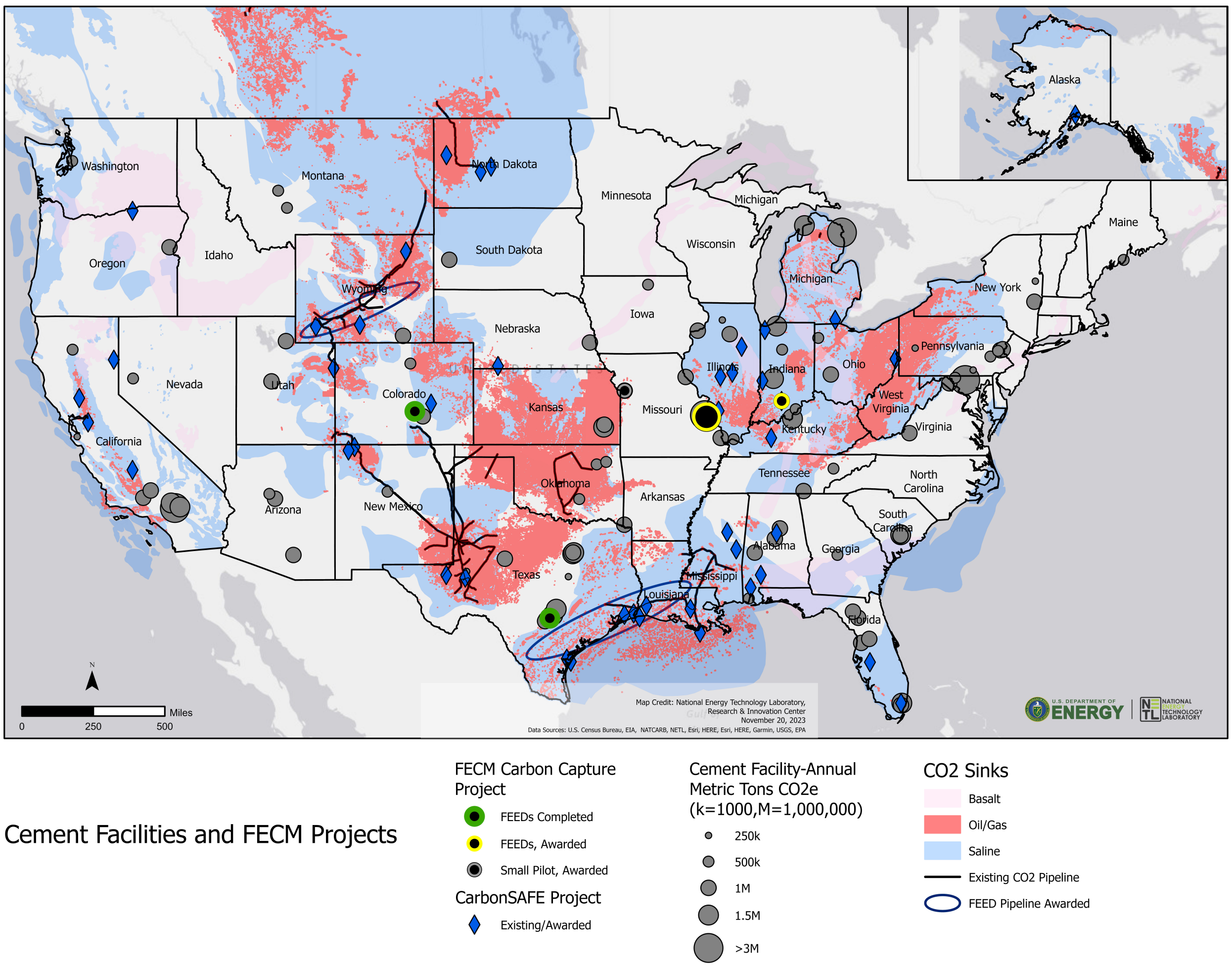
Project Type	Host Cement Plant	Location	Project Performer	Capture Technology *(Vendor)*	Capture Goal *(million MT CO_2e/year)*
FEED study	Holcim Ste. Genevieve Cement Plant	Bloomsdale, MO	University of Illinois	Cryocap™ process that uses PSA to preconcentrate the CO_2 in the feed stream, then a cryogenic step to purify & compress (Air Liquide)	2.8
Small pilot	Eagle Materials/Central Plains Cement Plant	Sugar Creek, MO	Sustainable Energy Solutions (SES), LLC	Cryogenic carbon capture (SES)	N/A**
FEED study	Heidelberg Materials US Inc. Mitchell Cement Plant	Mitchell, IN	Heidelberg Materials US Inc.	Solvent-based capture (Mitsubishi Heavy Industries America Inc. [MHIA])	2
FEED study	CEMEX Balcones Cement Plant	New Braunfels, TX	RTI	Non-aqueous solvent (NAS) capture technology (RTI)	1
*Pre-FEED study	LafargeHolcim Portland Cement Plant	Florence, CO	Electricore, Inc.	Sorbent-based capture (Svante)	1.5+
*Pre-FEED study	CEMEX Balcones Cement Plant	New Braunfels, TX	Membrane Technology and Research Inc.	Membrane-based capture (MTR)	1

**Completed Projects*

***Small-scale pilot capturing 30 metric tons/day*

CEMENT PLANTS IN THE UNITED STATES

The map below depicts the 92 U.S. cement production facilities distributed across the country that report to the U.S. Greenhouse Gas Reporting Program, with the size of the dot representing the annual GHG emissions reported for 2021. Also shown are potential carbon dioxide sinks where captured carbon dioxide could be stored in the subsurface. FECM-funded projects mentioned in the table above are also highlighted in the map.



Cement Facilities and FECM Projects

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1 toward-tradable-low-carbon-cement-standard.pdf (wri.org)
2 https://gccassociation.org/concretefuture/societal-demand-for-cement-and-concrete/
3 USGS, "National Minerals Information Center - Cement Statistics and Information," January 2023. Available: https://pubs.usgs.gov/periodicals/mcs2023/mcs2023-cement.pdf
4 https://www.epa.gov/ghgreporting/ghgrp-minerals
5 https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks
6 https://www.pbl.nl/sites/default/files/downloads/pbl-2016-trends-in-global-co2-emisions-2016-report-2315_4.pdf
7 https://pubs.usgs.gov/periodicals/mcs2023/mcs2023-cement.pdf
8 Technology Roadmap - Low-Carbon Transition in the Cement Industry (wbcsd.org)
9 Technology Roadmap - Low-Carbon Transition in the Cement Industry (wbcsd.org)
10 https://www.energy.gov/eere/doe-industrial-decarbonization-roadmap
11 https://www.energy.gov/fecm/point-source-carbon-capture
12 https://www.cemnet.com/global-cement-report/
13 https://www.globalcement.com/magazine/articles/951-the-cement-industry-of-china-a-new-normal
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