CALIFORNIA
AIR RESOURCES BOARD

3/14/2025

Draft Net-Zero Greenhouse Gas Emissions Strategy for the California Cement Sector

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Abbreviations

°C	Degrees Celsius
AASHTO	American Association of State Highway and Transportation Officials
AB	Assembly Bill
ACI	American Concrete Institute
ACM	alternative cementitious material
AMC	advanced market commitment
AQMD	Air Quality Management District
ARL	Adoption Readiness Level
ASTM	American Society for Testing and Materials
BCA	Border Carbon Adjustment
Btu	British Thermal Unit
CalEPA	California Environmental Protection Agency
CalTrans	California Department of Transportation
CARB	California Air Resources Board
CBAM	Carbon Border Adjustment Mechanism
CCR	California Code of Regulations
CCS	carbon capture and sequestration
CCUS	carbon capture, utilization, and storage
CDR	carbon dioxide removal
CEQA	California Environmental Quality Act
CH_4	methane
CN	Combined Nomenclature
CNRA	California Natural Resources Agency
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CPUC	California Public Utilities Commission
CWDB	California Workforce Development Board
DAC	direct air capture
EMSW	engineered municipal solid waste
EPD	environmental product declaration
GCCA	Global Cement and Concrete Association
GGBFS	ground granulated blast furnace slag
GHG	greenhouse gas
GWP	global warming potential
HTS	Harmonized Tariff Schedule
IBC	International Building Code
ICC	International Code Council
IIJA	Infrastructure Investment and Jobs Act
IRA	Inflation Reduction Act
MMBtu	one million British thermal units
MT	metric tons

MMT	million metric tons
$MMTCO_2e$	million metric tons of carbon dioxide equivalent
MRR	The Regulation for the Mandatory Reporting of GHG Emissions
MSW	municipal solid waste
$MTCO_2e$	metric tons of carbon dioxide equivalent
MW	megawatt
MWh	megawatt-hour
N_2O	nitrous oxide
NAICS	North American Industry Classification System
NGO	non-governmental organization
NOx	nitrogen oxides
OEHHA	Office of Environmental Health Hazard Assessment
PCA	Portland Cement Association
PHMSA	Pipeline and Hazardous Materials Safety Administration
PLC	Portland limestone cement
PM_{10}	Fine particulate matter ≤ 10 micrometers in diameter
$PM_{2.5}$	Fine particulate matter ≤ 2.5 micrometers in diameter
SB	Senate Bill
SCM	supplementary cementitious material
TRL	Technology Readiness Level
U.S. DOE	U.S. Department of Energy
U.S. EPA	U.S. Environmental Protection Agency
UIC	Underground Injection Control
USGS	U.S. Geological Survey
WHR	waste heat recovery

Overview and the Role of the SB 596 Cement Strategy

Cement is a crucial ingredient to make concrete, which is one of the most widely used construction materials. California, with seven active manufacturing plants, is one of the largest cement producing states in the United States. California's seven plants collectively produce roughly 10 million metric tons (MMT) of cement and emit about 7.5 MMT of greenhouse gas (GHG) emissions each year, which is about two percent of statewide GHG emissions. Senate Bill (SB) 596 (Becker, Chapter 240, Statutes of 2021) was signed by Governor Newsom in September 2021 and requires the California Air Resources Board (CARB or Board) to develop a comprehensive strategy (SB 596 Cement Strategy) for cement used in California to achieve two GHG intensity targets: 40% below 2019 levels by 2035 and net-zero emissions by 2045. In developing the Strategy, SB 596 requires that CARB:

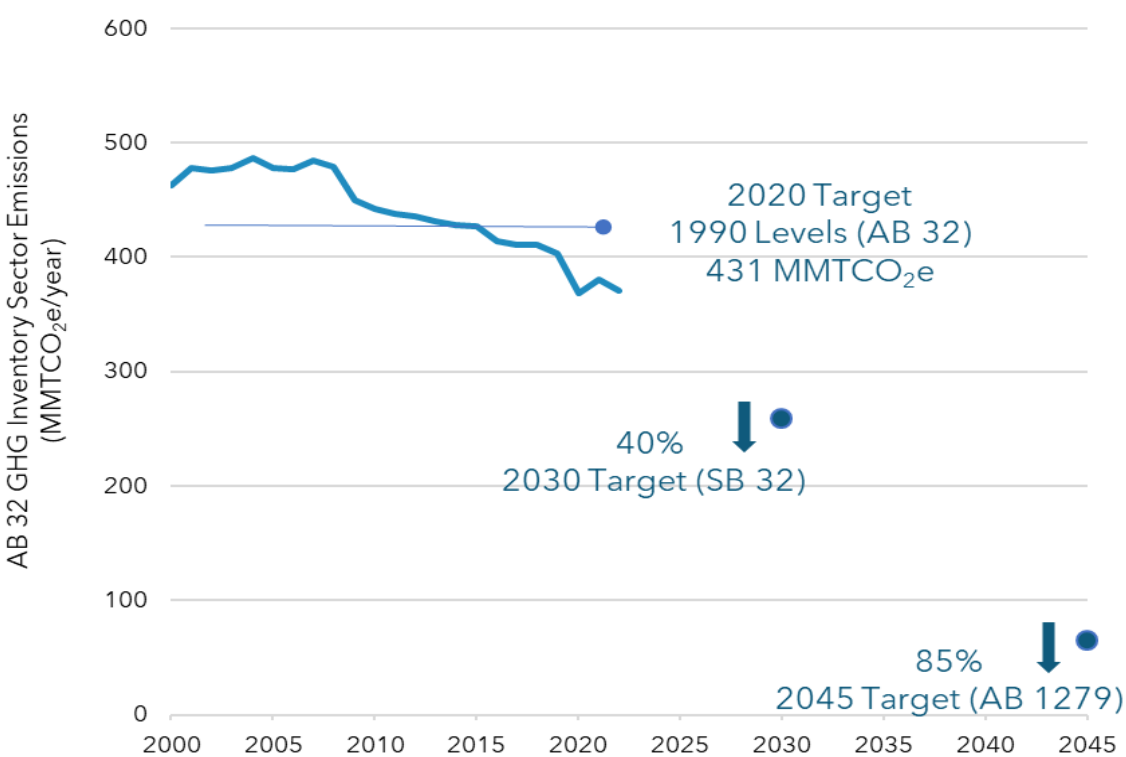
- Define a metric for GHG intensity and evaluate relevant 2019 data to establish a baseline from which to measure GHG intensity reductions.
- Assess existing measures, identify modifications to existing measures, and evaluate new measures to overcome market, statutory, and regulatory barriers that currently inhibit achieving net-zero emissions;
- Evaluate measures to support market demand and financial incentives to encourage the production and use of cement with low GHG intensity, including:
    - Measures to expedite the adoption of Portland limestone cement and other blended cements in projects undertaken by State agencies;
    - Measures to provide financial support and incentives for research, development, and demonstration of technologies to mitigate GHG emissions from cement production to accelerate deployment;
    - Measures to facilitate fuel switching; and
    - Measures to create incentives and remove obstacles for energy efficiency improvements and waste heat recovery;
- Prioritize actions that leverage state and federal incentives;
- Identify actions that reduce adverse air quality impacts; and
- Support economic and workforce development in communities neighboring cement plants.

SB 596 also requires consideration of provisions to minimize emissions leakage and account for GHG emissions embedded in imported cement in a similar manner as GHG emissions from cement produced in the state, such as a border carbon adjustment. Finally, SB 596 requires CARB to coordinate and consult with other state agencies, districts, and experts in academia, industry, and public health, and with local communities.

<u>Overview of California's Climate Policies</u>

SB 596 is one of California's suite of climate policies that started in 2006 with the passage of the Assembly Bill (AB) 32 (Nu?ez and Pavley, Chapter 488, Statutes of 2006), the California Global Warming Solutions Act of 2006, which established statewide greenhouse gas reductions goals for anthropogenic sources of emissions such as energy production, manufacturing sectors, and transportation fuels. The AB 32 goal to return to 1990 levels of greenhouse gas emissions by 2020 was achieved years ahead of schedule in 2014. As Figure 1 shows, California is now implementing policies to achieve a target of 40 percent below 1990 levels by 2030 set by SB 32 (Pavley, Chapter 249, Statutes of 2016), and to achieve carbon neutrality as soon as possible, but no later than 2045 (AB 1279 (Muratsuchi, Chapter 337, Statutes of 2022)). AB 1279 also requires ensuring that statewide anthropogenic GHG emissions are reduced by at least 85 percent below 1990 levels to meet the carbon neutrality goals by 2045. The cement sector is included in the state's overall climate goals and is specifically covered by the Cap-and-Trade Program. The emissions reductions achieved through implementation of SB 596 will contribute to California's state-wide goals, and SB 596 and AB 1279 share a common goal to achieve carbon neutrality by 2045. There are some differences in the mid-term targets -- the SB 596 2035 interim target is 40% below the average 2019 levels (measured as GHG emissions intensity per ton of cement used in California). The SB 32 statewide GHG reduction goal is 40% below the1990 level by 2030.

Figure 1: California's State-wide Climate Goals



The 2022 Scoping Plan for Achieving Carbon Neutrality (2022 Scoping Plan Update), approved by the CARB Board in December 2022, reviewed the suite of California's climate policies to lay out the sector-by-sector actionable plan to achieve the two targets in AB 1279. The 2022 Scoping Plan Update recognizes the cement sector as a hard-to-decarbonize sector, as its manufacturing is associated with high heat to process feedstock, which releases additional inherent carbon dioxide when heated. The 2022 Scoping Plan Update emphasized the need for these sectors to act now, as long-term, strategic planning is required to implement technologically feasible, cost-effective, and equity-focused projects to achieve the state's science-based climate targets.

Development of SB 596 Cement Strategy

SB 596 presents a unique opportunity to develop a framework that helps a hard-to-decarbonize industry reduce emissions at a pace that contributes to the state-wide climate policies while minimizing emissions leakage. To quickly and effectively implement such a framework, it is critical to focus on programs that leverage existing regulations and/or that are simple to administer such that they could also be easily incorporated in other like-minded jurisdictions. Considering the unique nature of industrial decarbonization, it is also conceivable that new programs may be needed. This draft strategy considers three types of program categories that need to be leveraged to support cement decarbonization. For details, see "Tools, Rules, and Potential Measures to Help Achieve Net-zero Emissions Goals" section.

1. **Overarching programs that support economy- and industry-wide decarbonization:** industrial manufacturing consumes substantial amounts of fuels, which need to be decarbonized. Multiple existing statutory directives including Senate Bill 100 (SB 100) (De León, Chapter 312, Statutes of 2018), the California Renewables Portfolio Standard Program, and Senate Bill 1075 (SB 1075) (Skinner, Chapter 363, Statutes of 2022) on hydrogen development, deployment, and use all provide overall guidelines on state-wide transition to cleaner energy. Also, if carbon emissions emitted at industrial plants are captured, they need to be transported and stored safely and permanently. Senate Bill 905 (SB 905) (Caballero, Chapter 359, Statutes of 2022), Carbon Capture, Removal, Utilization, and Storage requires CARB to evaluate, demonstrate, and regulate CCUS projects and technology.
2. **Programs that support GHG emissions reductions at cement plants (supply-side management):** existing programs include Mandatory Reporting Requirements (MRR) and the Cap-and-Trade Program, both of which were established under AB 32 and cover all seven cement plants currently operating in California. Administered by CARB, MRR collects rigorous GHG emissions and production data associated with cement manufacturing, and the Cap-and-Trade Program provides a market-based emission trading system to price GHG emissions for the covered sectors, including cement manufacturers, and collectively achieve cost-effective emissions reductions while minimizing emissions leakage. In addition, multiple funding programs are administered by federal agencies pursuant to the Inflation Reduction Act of 2022 and the Infrastructure Investment and Jobs Act of 2021, providing financial support for cement decarbonization projects in California as well as other states. The California Energy Commission (CEC) administers the Industrial Decarbonization and Improvement of Grid Operations to provide incentives for industrial projects.

3. **Programs to increase demand of low-carbon cement (demand-side management):** cement is primarily used as an ingredient to make concrete, which is one of the key building materials essential for infrastructure. It is important to help create a robust market for low-carbon cement/concrete while ensuring product affordability/accessibility. California Department of Transportation (Caltrans) writes specifications and evaluates and approves new materials for use in Caltrans projects. State/local agencies including Department of General Services (DGS) have authority over concrete used in eligible construction projects. Some newer statutes require quantification of embodied carbon used in buildings. Assembly Bill 43 (AB 43) (Holden, Chapter 316, Statutes of 2023), Greenhouse Gas Emissions: Building Materials Embodied Carbon Trading System, which amended and added to Assembly Bill 2446 (AB 2446) (Holden, Chapter 352, Statutes of 2022), Embodied Carbon of Building Construction Materials, requires CARB to develop a framework for measuring and then reducing the average carbon intensity of the materials used in the construction of new buildings. SB 253 (Wiener, Chapter 385, Statute of 2023), starting in 2027, will require companies doing business in California to publicly disclose annual GHG emissions for scope 1, 2, and 3, to inform investors, empower consumers, and activate companies' action on emissions reductions.

There are existing local, state, and federal environmental policies to protect local air quality, environmental health, and safety. When implementing SB 596 projects, such as fuel-switching, it is always preferrable that they contribute to reducing local and regional cumulative exposure to air pollutants, mitigate environmental/health risks, and are in compliance with all local, state, and federal regulations. This is particularly important if cement plants are located adjacent to frontline communities or in non-attainment air quality regions.

<u>Public Engagement Process for the SB 596 Cement Strategy</u>

To initiate the development of the SB 596 Cement Strategy, staff has been working closely with a wide variety of interested parties. To date, CARB hosted two public workshops (October 20, 2022, and May 31, 2023) and one community meeting (October 18, 2023) and received a total of 28 written public comments in response to those meetings. Staff also met individually with more than 50 organizations and individuals and attended and participated in a variety of conferences and workshops.

As technologies and markets for industrial decarbonization are developing rapidly, this Draft SB 596 Cement Strategy is intended to identify as many potential GHG emissions reductions levers as possible and to seek feedback. Throughout the document, key questions are highlighted for public input, which include:

1. Definitions of key concepts including GHG emission reductions, removals, cement and cementitious products;
2. Potential approaches to calculate the baseline GHG intensity using 2019 data and an interim target for 2035;
3. Potential GHG reduction levers and technology options;
4. Potential measures or programs to address regulatory, statutory, and marker barriers that CARB should consider, both near-term and long-term; and
5. Potential approaches to reduce adverse air quality impacts and support economic and workforce development in communities neighboring cement plants.

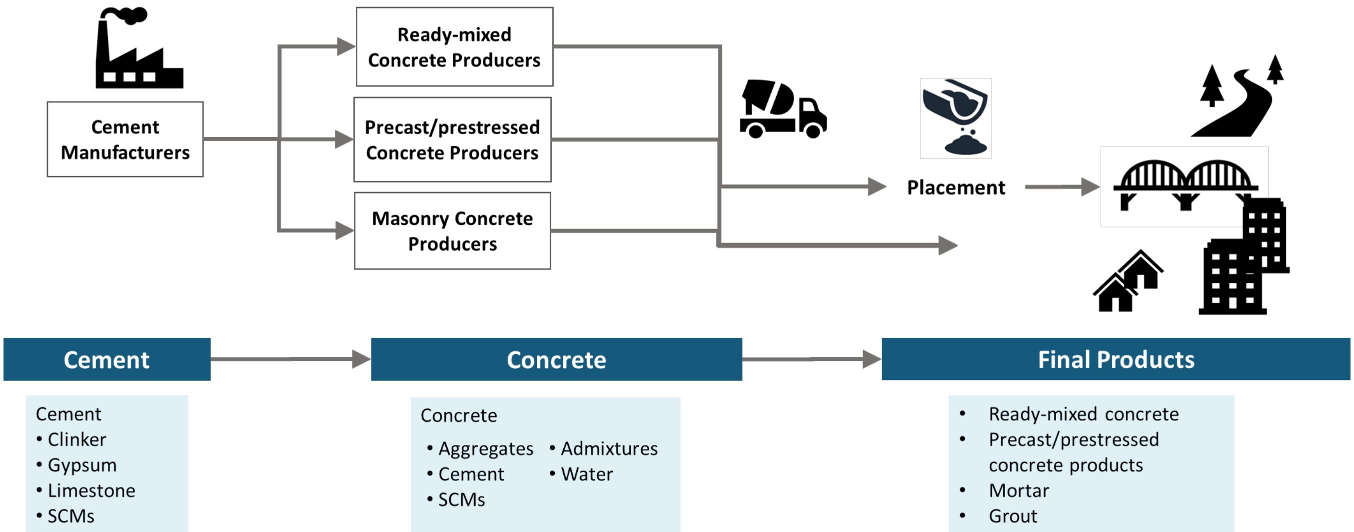
Background Information on Cement and California's Cement Industry

This section discusses the basics of cement, cement manufacturing, GHG emissions associated with cement used in California, and California's concrete industry. Unless terms require specific definitions for SB 596, the SB 596 Cement Strategy references the U.S. Geological Survey (USGS) definitions for cement and concrete-related terms. (Appendix A)

What is cement?

Cement is a finely ground powder that is typically used as an ingredient to make concrete, one of the most widely used building materials throughout the world. The most common type of cement is gray Portland cement, which is a hydraulic cement that reacts with water to form gluey minerals that set and harden to hold together concrete. To produce Portland cement, limestone and other minerals are reacted at high temperatures to make clinker, which is then blended with mineral additives such as gypsum, limestone, and a small amount of supplementary cementitious materials (SCM). As shown in Figure 2, cement is then shipped to ready-mixed concrete producers, precast or prestressed concrete producers, masonry producers, and other customers, where it is blended with SCMs, aggregates, admixtures, and water to become ready-mixed concrete or precast/prestressed concrete. Cement is also used to make other products, such as mortar or grout. Ready-mixed concrete is typically shipped to construction sites and placed to become part of buildings and other infrastructure. Cement typically makes up 7-15% of concrete products, but cement manufacturing is the largest source of GHG emissions associated with concrete.

Figure 2: Schematic Drawing of the Cement-Concrete Supply Chain



Cement Manufacturing Process

The central role of hydraulic cement is to provide cementitious (sticky) properties to bind together aggregates when mixed with water. Clinker provides that functionality, and cement manufacturing is focused on clinker production. Cement plants are typically located adjacent to quarries of limestone and clay, the main materials used to make clinker.

First, quarried rocks including limestone are conveyed to cement plants and crushed to desired sizes. Crushed rocks are then combined with other minerals, such as iron ore, and ground, mixed, and fed to a preheater/precalciner tower to increase the efficiency of the subsequent clinker manufacturing process.

After precalcination, the feedstock is exposed to increasingly higher temperatures as it passes through a long kiln to achieve four major mineral phases: alite, belite, tricalcium aluminate, and ferrite (see Table 1 for chemical formulas for these phases). Today, cement production is optimized to maximize the amount of alite, because it sets quickly once concrete is placed.

At the beginning of the process, calcination occurs at about 800-900 °C. During calcination, limestone (calcium carbonate) becomes calcium oxide by releasing CO_2. After calcination, clinkerization occurs as the temperature continues to rise further into the kiln. During clinkerization, calcium oxide reacts with calcined clay to form di-calcium silicate, which is also called belite, as well as amorphous calcium aluminates. As the materials move through the kiln, the aluminates start forming a liquid phase to become a flux to keep the temperatures high. At about 1250 °C, belite starts reacting with remaining calcium oxide to form tri-calcium silicate, or alite. At the end of the kiln, the temperature reaches 1,450 °C for maximum production efficiency.

After it is discharged from the kiln, the clinker goes through coolers and is ground and blended with gypsum, limestone, and SCMs to become cement. The process of clinker production in cement kilns is the most GHG emissions-intensive process in the entire cement and concrete manufacturing process, and alite production is the most energy-intensive phase of clinker production because a temperature near 1,450 °C is needed to form alite. As Table 1 shows, alite is the most prevalent mineral phase in clinker/cement.

Table 1: Clinker Mineral Phases and Mineral Additives

Mineral Phase	CCN[1]	% By Weight	Characteristics
Alite (tricalcium silicate, or 3 CaO · SiO2)	C_3S	50% - 70%	Readily reacts with water during hydration; contributes to the early age strength of 1~ 3 days
Belite (dicalcium silicate, or 2 CaO · SiO2)	C_2S	15% - 30%	Develops strength more slowly than alite during hydration and contributes to strength after four weeks
Tricalcium aluminate, or 3 CaO · Al2O3	C_3A	5% - 10%	Starts the hydration process quickly and generates a large amount of heat. Contributes to the early age strength of 1~3 days
Ferrite (Tetracalcium aluminoferrite 4 CaO · Al2O3 · Fe2O3)	C_4AF	5% - 15%	Used as a flux to control temperatures during limestone calcination process
Mineral Additives		**% By Weight**	**Characteristics**
Gypsum		About 5%	Slows down the hydration process to allow time to place concrete
Limestone		5% - 15%	Contributes to a better particle size distribution

Even though cement takes up less than 15% of concrete by volume, clinker production is responsible for up to 90% of GHG emissions associated with concrete: no other material used in concrete is a significant source of GHG emissions.

McKinsey and Company estimated general energy requirements and associated GHG emissions for each cement production stage as shown in Table 2.[2]

[1] Cement Chemist Notation (CCN) was developed to simplify chemical formulas commonly used for cement manufacturing.

[2] McKinsey and Company. 2020. Laying the foundation for zero-carbon cement.

Table 2: Estimated Energy Requirements and Associated GHG Emissions from Cement Production

	Total	Quarry	Crusher	Trans-port[1]	Raw mill	Klin and preheater/ precalciner[2]		Cooler [3]	Cement mill	Logis-tics[4]
Energy*	3,895	40	5	40	100	3,150		160	285	115
Emissions	0.925	0.003	0.001	0.007	0.017	Process emissions	0.479	0.028	0.049	0.022
						Fuel	0.319			

1 Assumed with 1kWh/t/100m
2 Assumed global average, data from the Global Cement and Concrete Association, Getting the Numbers Right 2017
3 Assumed reciprocating grate cooler with 5kWh/t clinker
4 Assumed lorry transportation for average 200km
*MJ per ton cement
*Ton CO2 per ton cement

Clinker production is associated with two different types of GHG emissions:

1. Process emissions, which are generated when limestone is treated with high heat and releases CO_2(limestone calcination). The chemical transformation of limestone calcination is:

   Calcium carbonate ($CaCO_3$) + energy = Calcium oxide (CaO) + CO_2

   In California, process emissions are responsible for about 60% of total GHG emissions associated with cement production.
2. Emissions from fuel combustion needed to generate heat (at about 1,450 °C for clinkerization) in kilns. In California, fuel combustion is responsible for about ~35% of total GHG emissions associated with cement production.

Cement production today is optimized to maximize the amount of alite, which sets early but requires clinkerization at about 1,450 °C. As alite is the most emissions intensive mineral phase, cement and concrete can potentially be less GHG-intensive if it includes less alite.

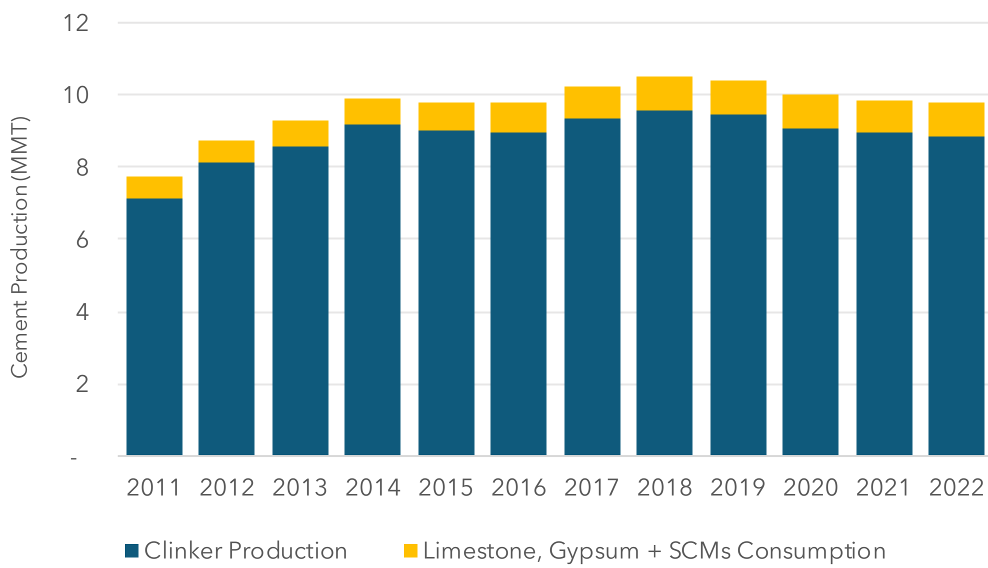
Electricity is also used throughout the cement manufacturing process, including for cooling clinker and grinding materials. Indirect GHG emissions associated with electricity use are less than 5% of total GHG emissions associated with cement manufacturing.

The process described above is for traditional cement manufacturing at incumbent cement plants, but it is possible to produce cement using alternative processes that are associated with lower GHG emissions. For example, there are demonstration projects to produce cement using non-limestone minerals. In addition, cement manufacturing can be altered to yield a clinker with belite, rather than alite, as the prevalent mineral phase to reduce required the temperature to make clinker. It is also possible to produce cement by leveraging chemical reactions without relying on thermal processes. Some of the alternative processes are already commercial on a small scale, whereas others are still in a pre-commercial stage of development. More discussion is in the "Alternative Materials to Reduce Clinker Intensity of Cement and Concrete" section.

Cement Industry in California

Cement plants are typically built adjacent to limestone quarries and continue operating until the reserve in the quarry is depleted. In 2006, 11 cement plants operated in California. In 2019, the baseline year for SB 596, eight cement plants operated in California. As of March 2024, there are seven active cement plants, as one plant ceased operation in 2020. All cement plants operating in California are covered by the Regulation for the Mandatory Reporting of GHG Emissions (MRR) and report annual GHG emissions, electricity consumption, and cement production to CARB. Production data are reported in short tons of material, but in this document, short tons are converted to metric tons in most cases. As Figure 3 indicates, these active cement plants have produced about 10 million metric tons of cement (clinker, gypsum, limestone and SCMs combined) annually over the last decade.

Figure 3: Cement Production in California[3]



The GHG emissions from California's cement sector are part of the state's GHG emissions inventory, which provides an estimate of state-wide emissions associated with fuel combustion, electricity generation, and process emissions.[4] For the cement value chain, the GHG inventory covers emissions associated with cement manufacturing, emissions associated with upstream/downstream activities, such as limestone quarrying and concrete production, and transportation. In 2019, state-wide GHG emissions were 403.7 MMT CO_2e, 1.9% of which came from the cement manufacturers. Table 3 shows GHG emissions from

[3] California Air Resources Board. *Mandatory Greenhouse Gas Emissions Reporting*.

[4] California Air Resources Board. *California Greenhouse Gas Emission Inventory Program.*

California cement plants in 2019. The eight cement plants collectively emitted 7,767,670 metric tons of carbon dioxide equivalent (MTCO_2e) of non-biogenic GHGs.

Table 3: GHG Emissions from Cement Manufacturing in California in metric tons of CO_2e in 2019[5]

Facility Name	Air District	GHG Emissions (MTCO_2e)
Cemex Construction Materials Pacific LLC, Victorville	Mojave Desert AQMD	1,910,079
CalPortland Company, Oro Grande	Mojave Desert AQMD	1,250,996
CalPortland Company, Mojave	Eastern Kern APCD	1,124,475
Mitsubishi Cement 2000, Lucerne Valley	Mojave Desert AQMD	1,068,736
National Cement Company, Lebec	Eastern Kern APCD	795,651
Lehigh Southwest, Cupertino (ceased operation in 2020)	Bay Area AQMD	768,381
Tehachapi Cement Plant	Eastern Kern APCD	556,466
CalPortland Company, Redding	Shasta County AQMD	292,886
Total		**7,767,670**

They are in Mojave Desert Air Quality Management District (AQMD), Eastern Kern Air Pollution Control District (APCD) and Shasta County AQMD. Figure 4 shows the location of the cement plants.

[5] California Air Resources Board. *Mandatory Greenhouse Gas Emissions Reporting*.

Figure 4: Cement Plant Locations and Air District Boundaries

As shown in Table 4, direct emissions in 2019 can be divided into process emissions from limestone calcination (4,917,548 $MTCO_2e$) and combustion emissions (2,850,122 $MTCO_2e$). Cement plants also purchase electricity, and indirect GHG emissions associated with purchased electricity are estimated to be 290,627 $MTCO_2e$ when applying the statewide 2019 average grid GHG emissions factor (0.207 $MTCO_2e/MWh$).[6]

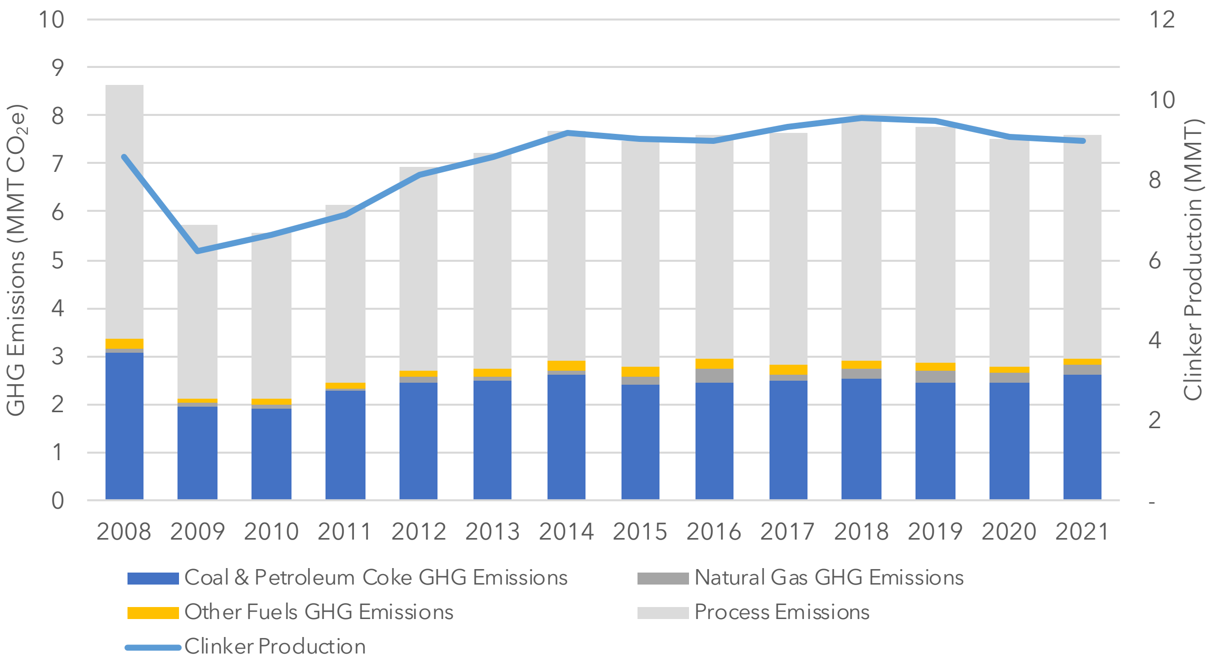
[6] Emissions data were obtained from the CARB GHG Inventory, last updated September 2024 for data year 2019. Available at: *https://ww2.arb.ca.gov/sites/default/files/2024-09/nc-ghg_inventory_scopingplan_all_00-22.xlsx* and generation data were obtained from the CEC Energy Almanac, California Electrical Energy Generation, last updated September 2024 for data year 2019. Available at: *https://www.energy.ca.gov/data-reports/energy-almanac/california-electricity-data/california-electrical-energy-generation*

Table 4: Breakdown of California Cement Sector GHG Emissions in 2019[7]

Process Emissions ($MTCO_2e$)	Combustion Emissions ($MTCO_2e$)	Indirect Emissions from Electricity ($MTCO_2e$)	Total GHG Emissions ($MTCO_2e$)
4,917,548	2,850,122	290,627	8,058,297

Figure 5 shows GHG emissions from California cement plants by fuel type since 2008.[8] There was a large production decrease in 2009, which was caused by the Great Recession.[9]

Figure 5: Direct GHG Emissions from California Cement Plants by Fuel Type[10]



[7] California Air Resources Board. *Mandatory Greenhouse Gas Emissions Reporting*.

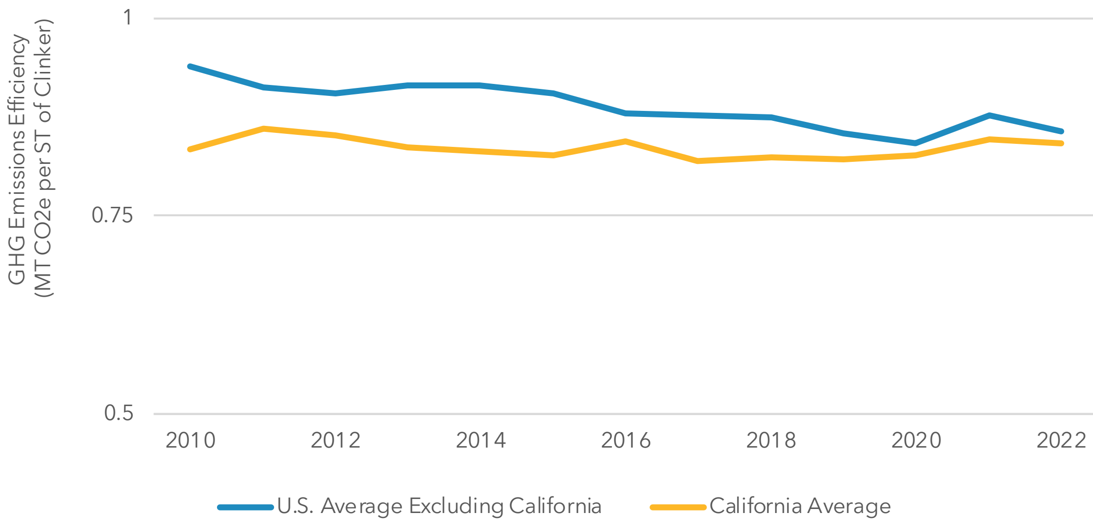
[8] California Air Resources Board. *Mandatory Greenhouse Gas Emissions Reporting*.

[9] The Great Recession began in December 2007 and ended in June 2009. Real gross domestic product (GDP) fell 4.3 percent from its peak in 2007 Q4 to 2009 Q2, the largest decline in the postwar era. Federal Reserve History. 2013. *The Great Recession.*

[10] GHG emissions per fuel type: California Air Resources Board. *Greenhouse Gas Emission Inventory*. Clinker production: California Air Resources Board. *Mandatory Greenhouse Gas Emissions Reporting*.

Figure 6 shows the GHG emissions efficiency trend for California cement plants during 2010-2022. The California cements plants are consistently more efficient compared to the national average, and the efficiency of California's cement plants has generally been improving over the last decade.[11] There are uncertainties related to how the COVID-19 pandemic affected industrial production efficiency during 2020-2021.

Figure 6: GHG Emissions Efficiency for Clinker Production[12]



Cement Industry in California

SB 596 sets a target to achieve net-zero emissions for "cement used within the state," which is interpreted as cement produced in California plus cement imported into California for consumption, minus cement exported to other regions. However, data on the amount of cement moved across California's borders is limited to international transfers. No public data are available for transfers to or from other U.S. states.

Cement consumed in California has also historically included cement imported from other countries, including from China, Mexico, Vietnam, Egypt, Turkey and Thailand, to balance supply and demand. (See Table 7 for the primary countries of origin for cement imported

[11] As different data sources can define "cement" differently, Figure 4 compares the emissions efficiency of clinker production for consistency. Also, GHG emissions data used to generate Figure 4 include direct emissions only, excluding indirect emissions associated with electricity consumption.

[12] California average GHG intensity: California Air Resources Board. *Mandatory Greenhouse Gas Emissions Reporting*. GHG emissions used to calculate US average intensity: U.S. Environmental Protection Agency: *Facility Level Information on Greenhouse Gases Tool (FIGHT)*. Production data used to calculate US average intensity: U.S. Geological Survey. *Minerals Yearbook for cement*.

into California in 2019.) Figure 7 shows cement imported into and exported from California districts of entry[13] (San Francisco, Los Angeles, and San Diego) relative to cement production in California from 2012 through 2021.

Figure 7: Cement Imports and Exports Relative to Domestic Production[14]

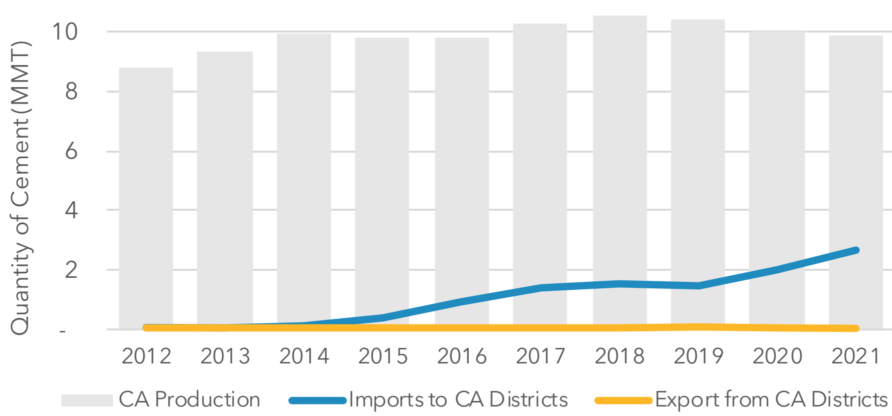
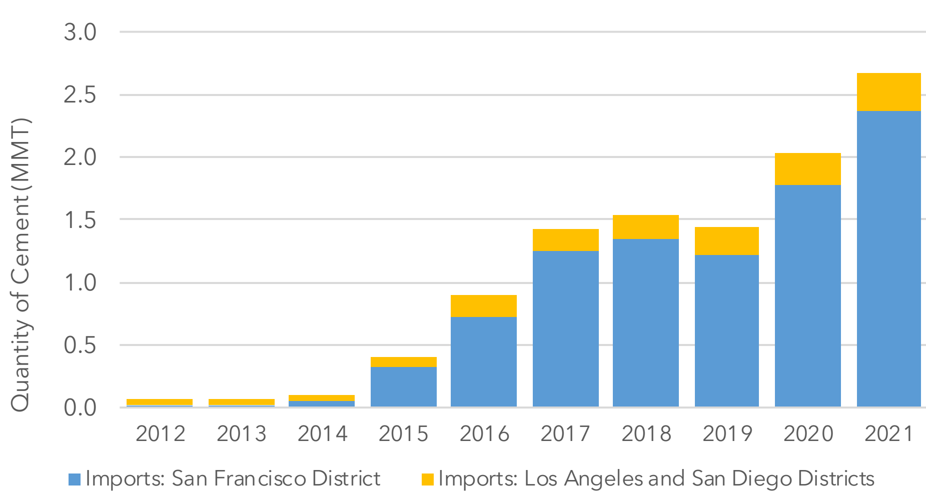


Figure 8 shows the quantity of cement imports at the San Francisco district relative to the total amount of imports to California. Imports increased noticeably at the San Francisco district during and after 2020, in part due to the Leigh Southwest plant in Cupertino, which was the only cement producer in San Francisco Bay Area, ceasing operation in 2020.

Figure 8: Cement Imports into California by District[15]



[13] According to the International Trade Commission, "district" refers to the district of entry (i.e., where the merchandise clears U.S. Customs) for import flows.

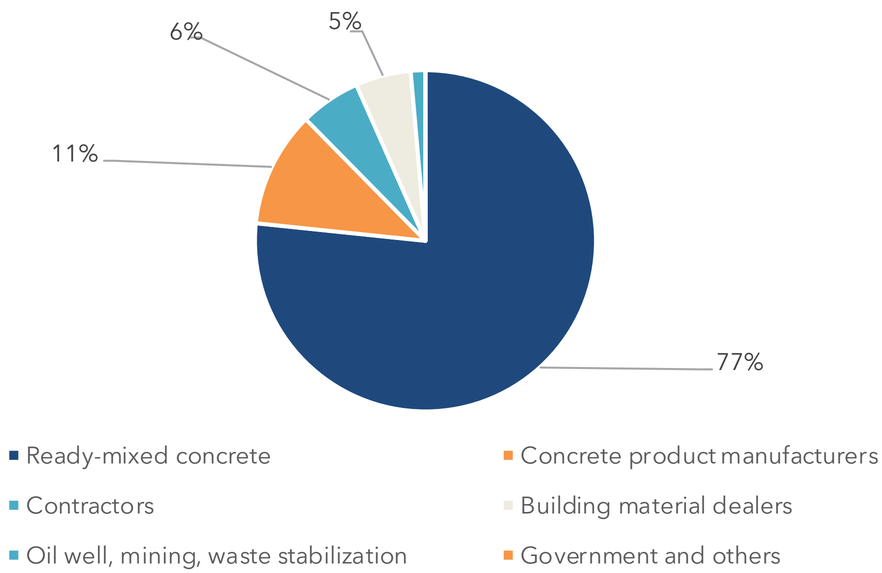
[14] U.S. International Trade Commission. *UTC Dataweb.*

[15] U.S. International Trade Commission. *UTC Dataweb.*

Concrete Industry in California

Cement is a crucial ingredient of concrete. As shown in Figure 9, in 2019, 77% of Portland cement in California was shipped to ready-mixed concrete producers, and 11% was shipped to precast/prestressed concrete producers.[16]

Figure 9: Cement Users in California in 2019[17]



In most cases, cement becomes a final product when concrete is mixed, placed, and hardened. As cement and concrete are interdependent, the concrete industry has an important role in achieving net-zero emissions goals for cement used in California. As 77% of cement is used as ready-mixed concrete, the Draft SB 596 Cement Strategy prioritizes the use case of ready-mixed concrete. Other types of products, such as precast/prestressed concrete and masonry cement, have some different opportunities and barriers for decarbonization.

There are about three hundred ready-mixed concrete producers throughout California.[17] Figure 10 shows the number of ready-mixed producers by Caltrans District.[18] District 7 (Los Angeles) and District 8 (Riverside) have the largest number of ready-mixed concrete producers to serve local markets, including populous areas such as the greater Los Angeles and San Diego areas. District 4 (Alameda), serving the San Francisco Bay Area, has the

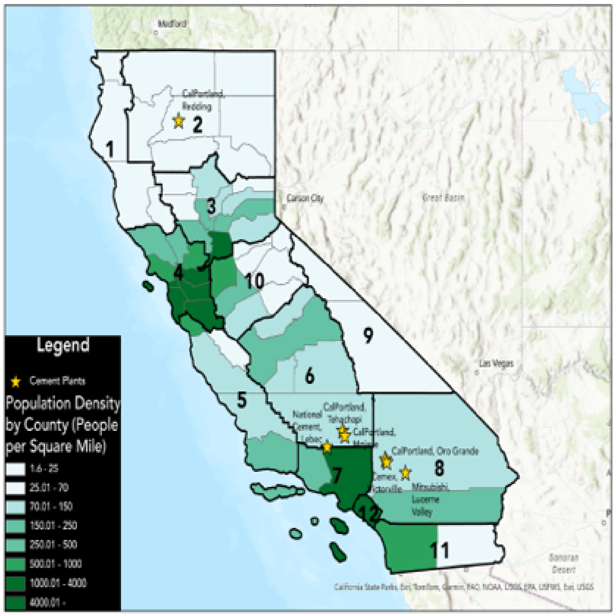
[16] U.S. Geological Survey. *Minerals Yearbook Cement Statistics and Information*.

[17] The number of ready-mixed concrete producers was estimated using the *Number Quarterly Census of Employment and Wages* published by the California Employment Development Department. It is an estimate as the data are withheld in some cases.

[18] California Department of Transportation. *District Map and County Chart*.

largest number of ready-mixed concrete producers in Northern California. However, large construction projects, such as high-speed rail construction or dam repair, can also occur in rural areas.

Figure 10: Number of Ready-mixed Concrete Producers and Population Density by Caltrans District[19]



District #	District Name	Number of Ready-Mix Plants
1	Del Norte	0
2	Lassen	0
3	Butte	19
4	Alameda	42
5	Monterey	0
6	Fresno	24
7	Los Angeles	74
8	Riverside	62
9	Inyo	0
10	Alpine	7
11	Imperial	23
12	Orange	21

Ready-mixed concrete producers are diverse in terms of size, ownership type, and degree of vertical integration. There are some ready-mixed concrete producers that are owned by large vertically integrated companies, while others are independently owned. Some of them are small, family-run businesses serving rural areas. Over the last decade, ready-mixed concrete producers in California have been collectively producing about 40 million cubic yards of concrete annually,[19] which is shipped to construction sites using mixer trucks. Ready-mixed concrete is unique in that it is not a final product until it's placed. On the other hand, precast and prestressed concrete producers blend ingredients and place concrete at their facilities to manufacture beams, girders, walls, pipes, and other products.

In terms of production process, concrete producers mix additional materials with cement to make concrete that meets the requirements of contractors and/or construction project owners. As described in the "Alternative Materials to Reduce Clinker Intensity of Cement and Concrete" section, these requirements can be specific and/or prescriptive regarding which materials can be added and how much of a material can be added. The activities of ready-mixed concrete facilities, such as batching, mixing, and material-handling, is

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[19] The California Construction & Industrial Materials Association. 2023. *Achieving Net Zero Concrete in California*.

estimated to use energy that corresponds to about 4% of total GHG emissions associated with concrete.[20] No ready-mixed concrete producers in California report their GHG emissions to CARB, as they do not exceed the 10,000 $MTCO_2e$ per year threshold[21] to be subject to the MRR.

Potential Approaches to Establishing SB 596 Targets

This section discusses a potential framework to define net-zero emissions for cement used in California.

Key questions for feedback

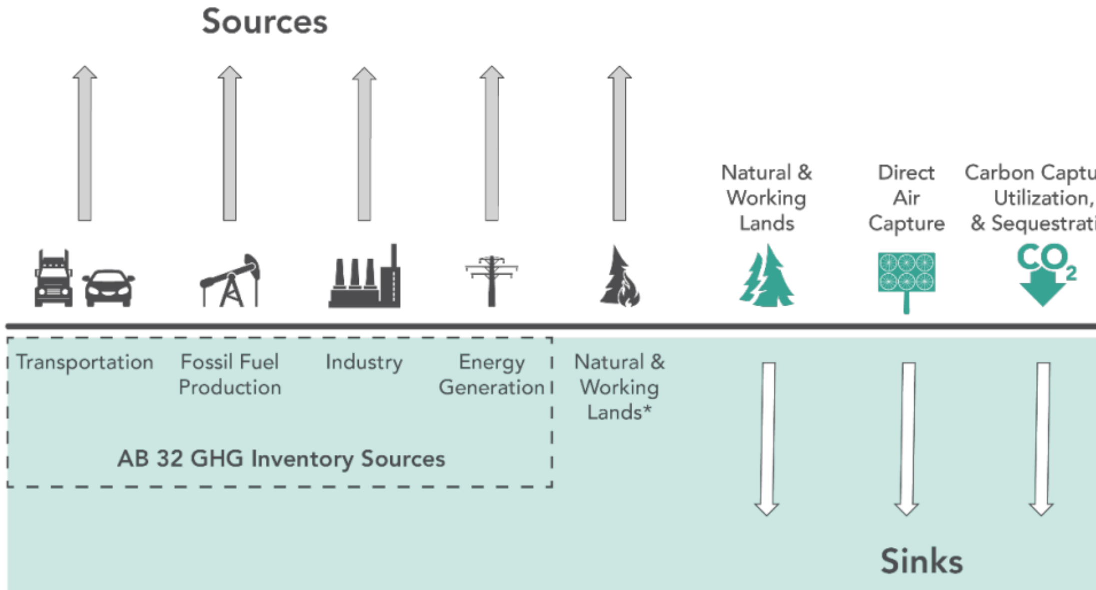
- What types of GHG emissions and emissions reductions projects should be included to determine net-zero emissions associated with cement used in California?
- What types of carbon capture, use, sequestration or removal projects should be included in the accounting under SB 596? Should there be different considerations for projects that meet the requirements of SB 905?
- How should CARB define cement and supplementary cementitious materials (SCMs)?
- How should CARB calculate the baseline GHG emissions intensity and interim intensity target in 2035?

SB 596 requires the state's cement sector to achieve net-zero emissions of GHG associated with cement used within the state "as soon as possible, but no later than December 31, 2045." To determine how the sector can achieve net-zero emissions, it is first necessary to define "net-zero GHG emissions." AB 1279 defines it as "emissions of GHGs to the atmosphere that are balanced by removals of GHG emissions over a period of time, as determined by CARB." The 2022 Scoping Plan Update identified GHG emissions and sinks that need to be considered to quantify net-zero emissions as shown in Figure 11.

[20] Ibid.

[21] A facility that emits 10,000 $MTCO_2e$ per year or greater is subject to GHG reporting requirements under the Mandatory GHG Reporting Regulation.

Figure 11: State-wide Concept of GHG Emission Sources and Sinks[22]



On the sources side, California's cement sector has potential to reduce direct emissions from cement plants. In doing so, CARB is evaluating accounting for direct on-site emissions associated with manufacturing materials used to make cement. Upstream or transportation-related emissions are not under consideration to limit the burden and complexity for quantification and because the vast majority of emissions are associated with cement plant process emissions. On the sinks side, it's possible for cement plants to capture the emissions that couldn't be reduced, which can be either mineralized and used as part of cement or concrete or sequestered. It is also possible for carbon removal projects to fix ambient carbon in concrete or cement production-related minerals. However, per SB 596, every cement GHG reduction project must be related to the cement production/use, as the bill specifies that "CARB shall not include GHG emissions reductions attributable to activities or offsets that are unrelated to the raw materials, fuels or other energy sources, processes, or transportation involved in making or using cement or its inputs." CARB has programs to quantify direct GHG emissions and incentivize emissions reductions at cement plants but does not yet have accounting frameworks for potential carbon sink projects related to the cement sector. Such protocols for CCUS are expected to be developed through the SB 905 implementation process. An overview of potential quantification methodologies for CCUS projects is discussed in the "Carbon Capture, Use, and Sequestration" section.

Potential Approach to Establishing Interim GHG Intensity Targets

SB 596 requires CARB to "establish interim targets for reductions in the GHG intensity of cement used within the state relative to the average GHG intensity of cement used within

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[22] California Air Resources Board. 2022. *2022 Scoping Plan for Achieving Carbon Neutrality.*

the state during the 2019 calendar year, with the goal of reducing the GHG intensity of cement used within the state to 40 percent below the 2019 average levels by December 31, 2035." This section discusses initial concepts on the approach, methodology, and data sources that could be used to calculate the baseline and interim targets.

GHG intensity is typically expressed as the total amount of GHG emissions associated with the production process per unit of production ($MTCO_2e$ per MT of product). To establish an interim target:

1) product definitions related to cement that reflect the SB 596 requirements are needed;
2) GHG emissions associated with the use of each relevant material need to be identified and quantified; and
3) a baseline GHG emissions intensity for 2019 needs to be established.

Defining cement and cement-related products

As the majority of GHG emissions associated with cement used within the state are due to clinker production, displacement of conventional limestone-based clinker by alternative low-carbon materials can reduce GHG emissions associated with cement use. There are two types of materials that can potentially displace clinker to make cement: supplementary cementitious materials (SCMs) and alternative cementitious materials (ACMs). An SCM does not have cementitious properties but can react with some mineral constituents in cement to enhance cementitious properties. An ACM is cementitious and can therefore completely replace clinker. Different materials can be mixed at different ratios, but each cement type needs to satisfy material standards to ensure quality and strength. In the U.S., cement typically must conform to American Society for Testing and Materials (ASTM) standards, which specify technical standards and testing procedures for materials.[23] The American Association of State Highway and Transportation Officials (AASHTO), which represents highway and transportation departments in all 50 states, the District of Columbia, and Puerto Rico, also sets standards for cement that are widely referenced. For the purposes of this Draft SB 596 Cement Strategy, ASTM standards were used, each of which has corresponding AASHTO standards.

There are three major ASTM standards related to cement:[24]

- ASTM C150 for Portland cement: Cement that conforms to C150 is the most widely used cement in the U.S. It prescribes how much non-clinker material can be added to

[23] Another major standard for cement and concrete is set by the American Association of State Highway and Transportation Officials (AASHTO).
[24] For more details about material standards, see Alternative Materials to Reduce Clinker Intensity of Cement and Concrete section.

make Portland cement. Typical C150 cement contains about 90% clinker, 5% gypsum, and 5% limestone.

- ASTM C595 for blended hydraulic cements: Relative to C150, C595 allows increased use of limestone and certain SCMs, such as fly ash, slag, and natural pozzolans. For example, cement that meets the C595 IL standard (Portland limestone cement or PLC) can include up to 15% limestone.
- ASTM C1157 standard performance specification for hydraulic cement: C1157 has no material requirements, only a requirement to perform and provide function equivalent to Portland or blended cement. Cement that does not meet C150 or C595 because of a higher amount of non-clinker materials may still meet C1157.

It is possible that emerging cement types may not meet any of the current ASTM standards, in which case they will need to undergo appropriate testing and demonstration to meet the requisite strength and performance requirements.

Many definitions of cement, including those used in CARB's MRR and Cap-and-Trade Regulation,[25] assume that cement is made using limestone-based clinker and are not specific about alternative materials added to clinker to make cement. For SB 596, CARB is considering broadening the definition of cement to support use of alternative low-carbon materials provided the resulting product satisfies performance requirements and provides comparable functionality to Portland cement. A similar initial concept for the Cap-and-Trade and Mandatory Reporting Regulations was shared in a workshop in Spring 2024.[26]

> "Cement" means a manufactured material that meets the specification standards for Portland cement (such as ASTM C150) or hydraulic blended cements (such as ASTM C595), or that meets performance-based standards for functional equivalents of Portland or hydraulic blended cements (such as ASTM C1157). Cement is used to make concrete, masonry cement, plastic (stucco) cement, and mortar cement.

This definition allows ACMs that were produced using non-limestone minerals or alternate processes to be considered as part of "cement," if they demonstrate functional equivalence to conventional cement. CARB is also considering defining supplementary cementitious materials to provide clarity and certainty for this key term.

> "Supplementary Cementitious Materials" or "SCMs" are materials that are added to and contribute to the properties of a cementitious mixture through hydraulic or

[25] The definition used by CARB's MRR and Cap-and-Trade Program is: "Cement means a building material that is produced by heating mixtures of limestone and other minerals or additives at high temperatures in a rotary kiln to form clinker, followed by cooling and grinding with blended additives. Finished cement is a powder used with water, sand, and gravel to make concrete and mortar."

[26] CARB. Cap-and-Trade Workshop, May 31, 2024. *See Slide 25-30 for overall industrial allocation approach and cement-specific approach.*

pozzolanic activity, or both, such as fly ash, ground granulated blast furnace slag, silica fume, natural pozzolan, calcined clay, and glass pozzolan.

Further, SCMs can be divided into two categories to distinguish the types of GHG emissions associated with their production.

- "Primary supplementary cementitious materials" are supplementary cementitious materials that are produced as a primary product. The production of primary supplementary cementitious materials is associated with some direct GHG emissions. Primary SCMs include natural pozzolan and calcined clay.

- "Byproduct supplementary cementitious materials" are SCMs generated as a byproduct by an industrial process that is designed to produce a product other than the SCM. The generation of byproduct supplementary cementitious materials is not associated with direct GHG emissions, as the emissions are attributable to the primary products. Byproduct supplementary cementitious materials include fly ash, ground granulated blast-furnace slag (GGBF), and materials generated from alternative cement manufacturing processes.

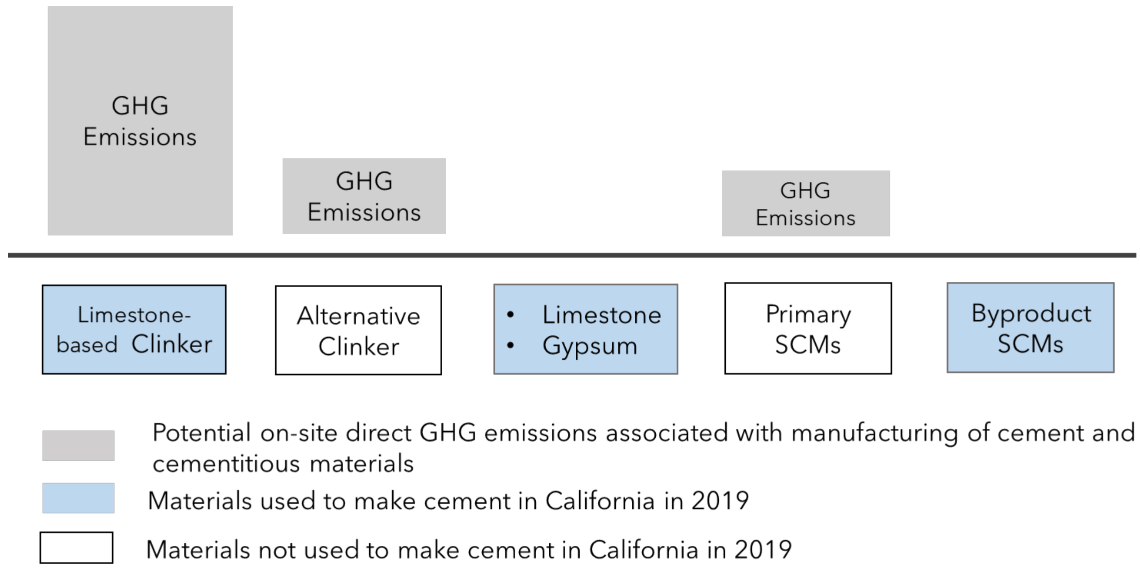
For accounting under SB 596, CARB recommends that GHG emissions associated with in-state production of primary SCMs be included and that GHG emissions associated with the production of out-of-state primary SCMs and all byproduct SCMs be excluded. This is because the out-of-state and byproduct SCMs are associated with processes upstream cement emissions. However, it is important to recognize that common byproduct SCMs, such as fly ash and GGBF, may be created through emissions-intensive industrial processes, such as coal-fired power generation or primary steel production.

Identifying GHG emissions associated with cement

After clarifying the definition of "cement," the next step to establishing a GHG emissions intensity for cement used in California is to identify GHG emissions associated with each material that is mixed to make cement. As shown in Figure 12, clinker and primary SCMs are associated with on-site manufacturing emissions (direct emissions), which are Scope 1 emissions.[27] Limestone, gypsum, and byproduct SCMs are not associated with Scope 1 emissions since they are processed elsewhere and brought into cement plants. However, fly ash and GGBFS, the byproduct SCMs that are most used today, are associated with high levels of upstream GHG emissions: fly ash is a byproduct of coal-fired industrial processes, and GGBFS is a byproduct of primary steel production. The availability of fly ash and GGBFS is also limited worldwide and decreasing.

[27] Scope 1 emissions are direct GHG emissions that occur from sources that are controlled or owned by an entity.

Figure 12: Conceptual Diagram of Direct GHG emissions of Materials Used to Make Cement



In 2019, only clinker, limestone, gypsum, baghouse dust, and ground aids were used to make cement at California cement plants. Of those materials, only limestone-based clinker was associated with on-site direct GHG emissions.

Determining baseline GHG emissions intensity

SB 596 defines the baseline GHG emissions intensity (expressed as the total amount of GHG emissions associated with production of all cement used divided by the amount of cement used) as the average GHG emissions intensity for cement used within the state during the 2019 calendar year. It is understood that GHG intensity for "cement used within the state" includes the GHG emissions associated with domestic production and imports. CARB currently has different levels of data for each.

- Domestic production: CARB maintains high-quality verified data on GHG emissions and production reported by cement plants in California pursuant to MRR.
- Imports: Currently there is no mandatory reporting system to track the amount and GHG emissions intensity for cement imported through California ports. However, the Global Cement and Concrete Association (GCCA) operates a voluntary GHG emissions reporting program for cement plants across the globe. Public GCCA data can be used to estimate the GHG emissions intensity associated with cement imported into California ports in 2019. CARB is not aware of any data available to track cement brought into California from other U.S. states.
- Exports: There are small amounts of cement exported from California ports. It is also understood that some amount of cement is shipped from California plants to other U.S. states, but there are no publicly available data sources that track intra-state goods movement.

To establish the 2019 baseline GHG emissions intensity, CARB recommends including imports from other countries and accounting for the associated emissions but excluding both imports from other U.S. states and exports from California to other U.S. states and countries for following reasons:

- It is unlikely that the GHG intensity associated with cement produced and consumed in-state differed significantly from the GHG intensity associated with cement produced in-state and exported.
- There is no public data source that tracks the amount of cement imported from or exported to other U.S. states.
- The amount of cement exported from California to other countries is insignificant.

The initial recommendation is to calculate the 2019 GHG intensity baseline as follows:

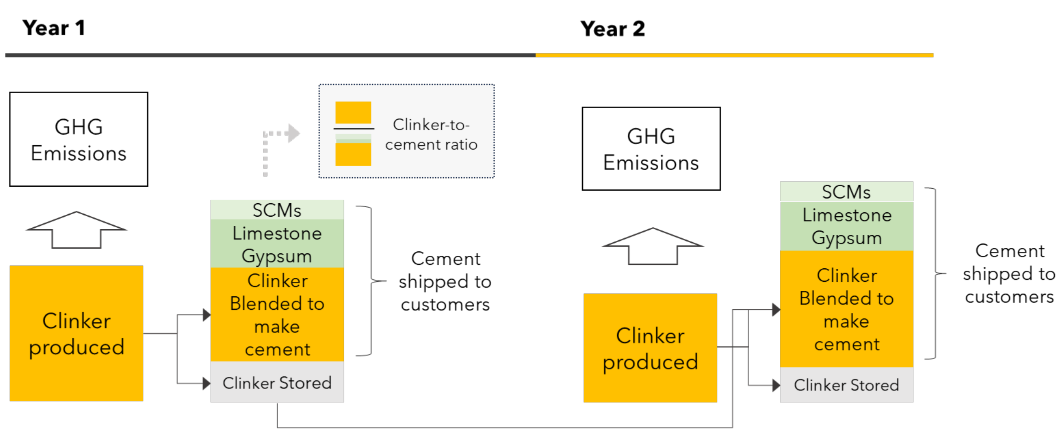
(2019 emissions from California cement plants + 2019 emissions associated with imported cement) / (amount of cement produced by California cement plants in 2019 + amount of cement imported in 2019)

The following data sources are available for each quantity.

1. Cement production in California:

   Annual facility-specific cement production information has been collected by CARB each year since 2008 under MRR. MRR requires the reporting and verification of the amount of clinker produced, and the amounts of clinker, gypsum, and limestone blended to make cement for shipment. MRR requires reporting of the amount of SCMs blended to make cement, but that information is not currently verified. As Figure 13 shows, produced clinker can be stored to be blended for shipping later. Thus, GHG emissions associated with cement production occur at a different time from when the cement is used, and potentially over different years.

Figure 13: Hypothetical Timing of Clinker Production and Blending of Cement



To address potential timing discrepancies, the amount of cement produced in 2019 can be based on the amount of "clinker produced" in 2019. First, the 2019 clinker-to-cement ratio is calculated as the ratio of "clinker blended to make cement" to all clinker and mineral additives blended to make cement for shipment. As shown in Table 5, the amount of cement produced in 2019 can then be calculated as the clinker produced in 2019 adjusted by the clinker-to-cement ratio. When calculated in this manner, the cement produced in California in 2019 was 10,417,622 metric tons.

Table 5: Total Cement Production by California Cement Plants in 2019[28]

Clinker Produced (MT)	Clinker Blended (MT)	Limestone Blended (MT)	Gypsum Blended (MT)	SCMs Blended (MT)	Cement Production (MT)
9,453,091	9,451,877	333,001	609,853	21,556	10,417,622

2. GHG emissions associated with cement production in California:

   As shown in Table 6, annual GHG emissions and purchased electricity information is also reported to CARB by each California cement plant pursuant to MRR.

Table 6: Total GHG Emissions Associated with Cement Production in California in 2019

GHG Emissions ($MTCO_2e$)	Purchased Electricity (MWh)	Average Statewide Electricity Emission Factor ($MTCO_2e/MWh$)[29]	Purchased Electricity GHG Emissions ($MTCO_2e$)	Total GHG Emissions ($MTCO_2e$)
7,767,670	1,399,400	0.207	290,153	8,057,824

3. The amount of imported cement:

   The U.S. International Trade Commission (ITC) tracks the annual quantity of imported commodities by North American Industry Classification System (NAICS) code or Harmonized Tariff Schedule (HTS). The ITC data includes annual import data for NAICS code 327310 (Cement Manufacturing), and data for 2019 is presented in Table 7. The data in Table 7 were used as an estimate of the amount of cement

[28] California Air Resources Board. *Mandatory Greenhouse Gas Emissions Reporting*.

[29] Emissions data were obtained from the CARB GHG Inventory, last updated September 2024 for data year 2022. Available at: *https://ww2.arb.ca.gov/sites/default/files/2024-09/nc-ghg_inventory_scopingplan_all_00-22.xlsx* and generation data were obtained from the CEC Energy Almanac, California Electrical Energy Generation, last updated September 2024 for data year 2023. Available at: *https://www.energy.ca.gov/data-reports/energy-almanac/california-electricity-data/california-electrical-energy-generation*

imported into California ports in 2019. The blending ratio of clinker, gypsum, limestone, and SCMs in the imported cement is not known for this data.

Table 7: Cement Imported to California in 2019 by Country-of-Origin[30]

Country of Origin	Quantity (MT)
China	849,772
Mexico	349,145
Vietnam	122,343
Egypt	49,903
Turkey	45,300
Thailand	17,243
Other regions	595
Total	1,434,301

4. GHG Emissions associated with imported cement:

   GCCA's "Getting the Numbers Right" project[31] collects voluntary data from cement plants across the globe using a GHG quantification methodology that is reasonably comparable to MRR for Scope 1 direct emissions and Scope 2 indirect emissions (associated with electricity consumption). GCCA aggregates and publishes GHG emissions-intensity at a regional level. However, the GCCA emissions-intensity metric does not match CARB's recommended approach to determining cement production described above and provided in Table 5 and Table 6.[32] In order to determine a GHG emissions intensity that is comparable to CARB's approach, a region-specific clinker-to-cement ratio was applied to convert the GCCA region-specific GHG emissions-intensity data for clinker to GHG emissions-intensity for cement.[33] That emissions-intensity of cement value can be multiplied by the quantity of imports in Table 7 to estimate the GHG emissions associated with imports. Results of that calculation for 2019 are provided in Table 8.

[30] U.S. International Trade Commission. *UTC Dataweb.*

[31] Global Cement and Concrete Association. *GNR 2.0 – GCCA in Numbers*.

[32] GCCA uses either clinker, cement (equivalent), or cementitious products as a denominator depending on the specific circumstance. Clinker is gray and white clinker used for the production of gray and white cement. Cement (equivalent) is a cement production value, which is determined from clinker produced on-site applying the plant-specific clinker-to-cement ratio. Cementitious products consist of all clinker produced by the reporting company for cement-making or direct clinker sale, plus gypsum, limestone, clinker kiln dust, all clinker substitutes consumed for blending, and all cement substitutes. The Global Cement and Concrete Association. *"CO_2 and Energy Accounting and Reporting Standard for the Cement Industry, May 2011."*

[33] In "Getting the Numbers Right," the products include gray and white cement except for clinker. California manufacturers only produce gray cement. CARB recommends using the data for gray cement.

Table 8: Estimated Direct GHG Emissions Associated with Cement Imported to California in 2019[34]

Country of origin	GCCA Region	Cement Quantity (MT)	Clinker Emissions Intensity ($MTCO_2$/MT clinker)	Clinker-to-Cement ratio	Cement Emissions Intensity ($MTCO_2$/MT cement)	GHG Emissions ($MTCO_2e$)
China	Asia	849,772	0.849	78%	0.697	592,329
Mexico	Central America	349,145	0.876	72%	0.682	238,103
Vietnam	Asia	122,343	0.849	78%	0.697	85,278
Egypt	Egypt	49,903	0.879	84%	0.758	37,815
Turkey	Middle East	45,300	0.843	85%	0.731	33,135
Thailand	Thailand	17,243	0.843	83%	0.722	12,450
Other		595	Not included	Not included	Not included	
Total						**999,110**

To calculate GHG emissions associated with electricity used to make imported cement, it is possible to: (1) estimate region-specific electricity GHG emissions-intensity in $MTCO_2e$ per MT of cement, and (2) multiply the appropriate region-specific electricity GHG emissions-intensity value by the amount of imported cement originating from each region. To estimate region-specific GHG emissions intensity, GCCA's region-specific electricity intensity (weighted average in MWh per MT of cement produced)[35] can be converted to $MTCO_2e$ of GHG emission per MT of cement by multiplying by the country-specific electricity emissions-intensity factors ($MTCO_2$/MWh) compiled by Ember.[36] Estimated GHG emissions associated with electricity use for cement imported to California in 2019 are provided in Table 9.

[34] Global Cement and Concrete Association. *GNR 2.0 – GCCA in Numbers*.

[35] Unlike direct GHG emissions, gray clinker-specific data aren't available for electricity purchases.

[36] Ember is a European think thank that publishes datasets related to global electricity generation. Embar. *Electricity Data Explorer* . Ember data only account for CO_2 whereas CARB's data includes CH_4 and N_2O in addition to CO_2. However, in 2019 the GHG emissions from CH_4 and N_2O in California was 0.3%.

Table 9: Estimated Indirect Electricity GHG Emissions Associated with Imported Cement in 2019[37]

Country of origin	GCCA Region	Cement Quantity (MT)	Electricity consumption (MWh / MT cement)	Country-specific Grid GHG Intensity ($MTCO_2e$/MWh)	Electricity GHG Intensity ($MTCO_2e$/ MT cement)	GHG Emissions ($MTCO_2$)
China	Asia	849,772	0.094	0.560	0.052	44,499
Mexico	Central America	349,145	0.108	0.442	0.048	16,639
Vietnam	Asia	122,343	0.094	0.504	0.047	5,771
Egypt	Egypt	49,903	0.115	0.467	0.054	2,675
Turkey	Middle East	45,300	0.110	0.412	0.045	2,052
Thailand	Thailand	17,243	0.104	0.501	0.052	894
Other		595	Not included	Not included		Not included
Total						**72,530**

By adding direct GHG emissions from Table 8 and indirect electricity GHG emissions from Table 9, total GHG emissions associated with imported cement in 2019 is estimated to be 1,071,640 $MTCO_2e$.

5. Potential GHG intensity 2019 baseline and 2035 interim target

SB 596 established the 2035 GHG intensity target to be 40 percent below the 2019 baseline GHG intensity. Using the data above, Table 10 shows the 2019 baseline GHG intensity for cement used in California to be 0.770 $MTCO_2e$/MT cement used, and the potential 2035 interim GHG intensity target to be 0.462 $MTCO_2e$/MT of cement used.

Table 10: Potential Baseline GHG Intensity and 2035 Interim GHG Intensity Target for Cement Used in California

Type of Cement	GHG Emissions ($MTCO_2e$)	Quantity of cement (MT)	2019 Baseline ($MTCO_2e$ / MT cement used)	2035 Interim Target ($MTCO_2e$ / MT cement used)
Cement produced in CA	8,057,824	10,417,622		
Cement imported into CA	1,071,640	1,434,301		
Total	9,129,464	11,851,923	0.770	0.462

[37] Global Cement and Concrete Association. *GNR 2.0 - GCCA in Numbers*. Country-specific Grid GHG Intensity Values are by Ember. *Electricity Data Explorer*.

Overview of Decarbonization Levers and Technology Options

This section provides an overview of cement decarbonization levers and technology options, as well as the approach to identify market, statutory, and regulatory concerns and barriers associated with them.

Key questions for feedback

- Are there additional decarbonization levers that should be considered beyond the three following levers that are discussed in this section?
  - Energy-related GHG reduction options at cement plants, including fuel-switching, increased use of low- or zero-carbon electricity, and electrification
  - Carbon capture, use, and sequestration
  - Increased use of low-carbon cement and concrete
- For each lever, CARB is assessing feasibility by considering demand-side, supply-side, and non-economic factors, including permitting issues and whether robust GHG accounting methods exist. Should CARB consider additional factors for evaluation?

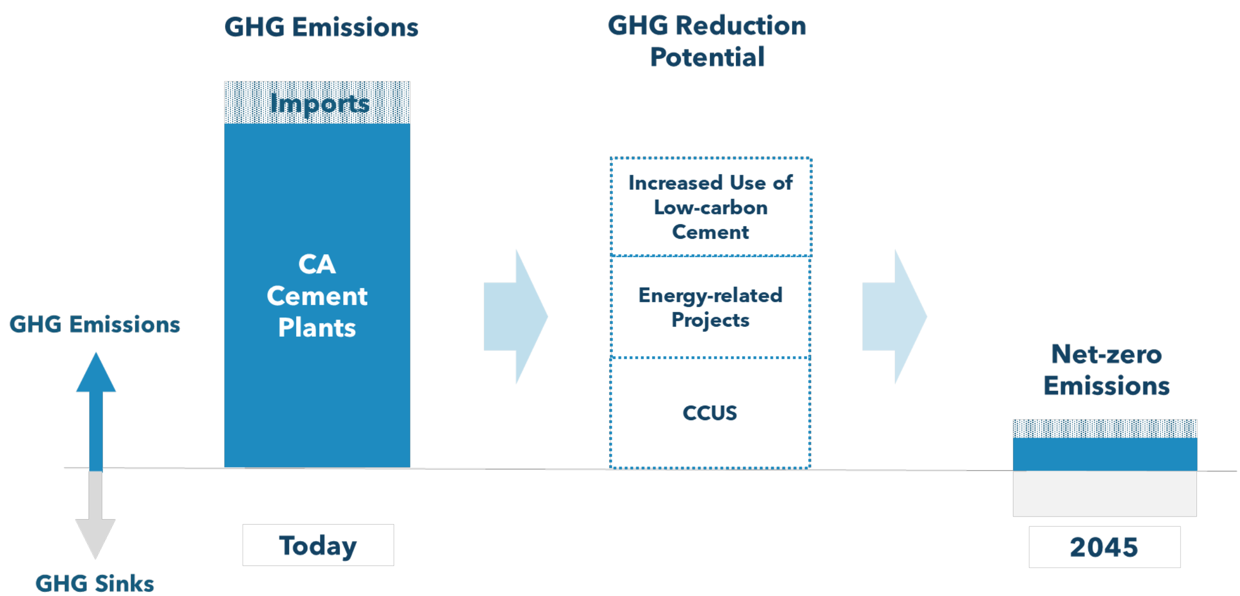
To help identify potential cement decarbonization levers and associated technology options, a variety of technical reports by industry, academia, public agencies, non-government organizations (NGOs), and other organizations were reviewed, including the 15 decarbonization roadmaps identified in Table 11.

Table 11: List of Cement Decarbonization Roadmaps

Roadmap Title	Author	Year Released
Cement Industry		
Achieving Carbon Neutrality in the California Cement Industry Key Barriers & Policy Solutions, Second Edition	California Nevada Cement Association	2023
Concrete Future: The GCCA 2050 Cement and Concrete Industry Roadmap for Net Zero Concrete	Global Cement and Concrete Association	2021
Roadmap to Carbon Neutrality: A More Sustainable World is Shaped by Concrete	Portland Cement Association	2021
Cementing the European Green Deal: Reaching Climate Neutrality Along the Cement and Concrete Value Chain By 2050	The European Cement Association	2020
Concrete Industry		
Achieving Net Zero Concrete in California: Pathways, Opportunities, & Barriers	California Construction and Industrial Materials Association	2023
UK Concrete and Cement Industry Roadmap to Beyond Net Zero	Mineral Products Association / The Concrete Centre (U.K.)	2020
Public Agencies		
Pathways to Commercial Liftoff: Low-Carbon Cement	U.S. DOE	2023
Roadmap to Net-Zero Carbon Concrete by 2050	Government of Canada	2022
Technology Roadmap for "Transition Finance" in Cement Sector	Government of Japan	2022
Enabling Industrial Decarbonization: A Policy Guidebook for U.S. States	United States Climate Alliance	2022
Industrial Decarbonization Roadmap	U.S. DOE	2022
Deep Decarbonisation of Industry: The Cement Sector	European Commission	2020
Technology Roadmap: Low-Carbon Transition in the Cement Industry	International Energy Agency	2018
Non-Government Organizations		
Making Net-Zero Concrete and Cement Possible: An industry-backed, 1.5 °C-aligned transition Strategy	Mission Possible Partnership	2023
Decarbonizing Concrete: Deep Decarbonization pathways for the Cement and Concrete Cycle in the United States, India, and China	Global Efficiency Intelligence/ Climate Works	2021

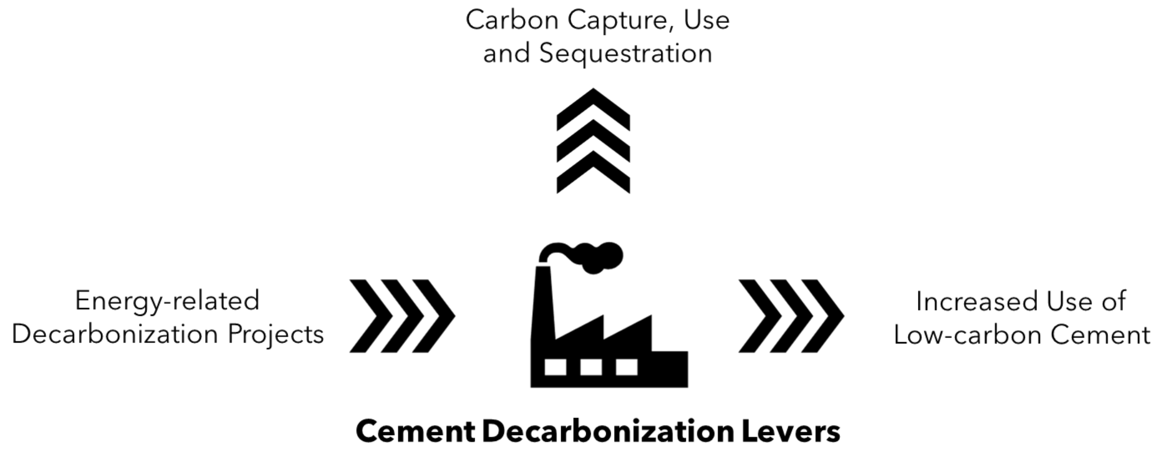
In general, roadmaps and other literature identify a suite of options as decarbonization levers, including carbon capture, use and sequestration, fuel-switching, and the increased use of alternative materials to displace limestone-based clinker. These reports project that 30%~50% of GHG emissions reductions could come from CCUS, as the high level of process emissions associated with cement production increases the carbon dioxide concentration in the flue gas compared to sectors where such process emissions are not present. The reports suggest that another 20%~30% of GHG emissions reductions can be achieved by energy-related projects, which are a combination of fuel-switching, increased use of renewable or zero-carbon electricity, and energy efficiency, such as on-site waste heat recovery. The reports also suggest that about 20%~30% of GHG emissions reductions could be achieved by the use of alternative materials and that if the technology matures fast enough, then the reductions could be much higher because these materials can eliminate the reliance on carbon-intensive limestone. Figure 14 illustrates potential GHG emissions reduction levers toward net-zero emissions based on the projections in existing roadmaps.

Figure 14: Potential GHG Emissions Reductions Levers to Achieve Cement Net-zero Emissions



Based on the literature review and input from interested parties, three general levers for decarbonizing the cement sector were identified. A variety of technological options exist for each lever, some of which are new or emerging technologies. Many of these technologies, including carbon capture, energy-related options, and increased use of low carbon cement, can be implemented at existing cement and concrete plants, but there are economic, practical, permit and other constraints that may limit how extensively an existing facility could be retrofitted to implement them. Some options may be more feasible to implement at new facilities.

Figure 15: Cement Decarbonization Levers

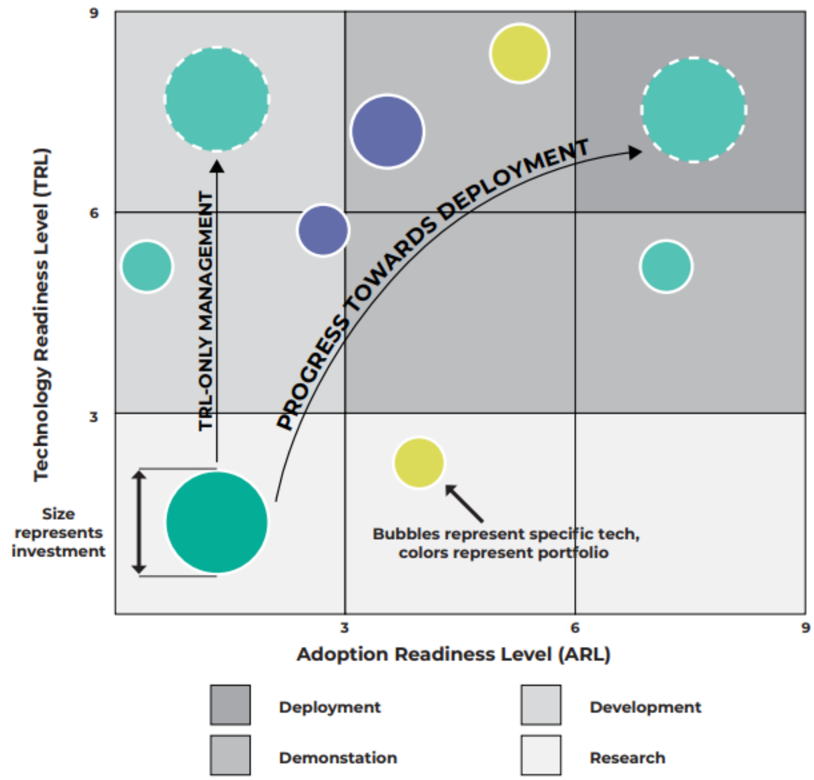


The following sections discuss: (1) potential technologies or project types available for California cement sector for each lever, and (2) market, statutory, and regulatory concerns and barriers for each technology options. In identifying potential cement decarbonization technologies and barriers associated with them, it is important to recognize that currently cement manufacturing is GHG emission intensive. This means that to achieve net-zero the manufacturing process will need innovative and transformational changes, which can require substantial time and financial investment. Multiple cement decarbonization technologies are emerging around the world today, but they are still largely in research, development, and demonstration phase. For these technologies to realize commercialization, they need to overcome multiple technical, financial, market, regulatory and social barriers.

Historically, the U.S. Department of Energy (U.S. DOE) has been using the technology readiness level (TRL) framework to assess the maturity of a technology across lab, pilot, demonstration, and commercial phases. To gauge challenges beyond the technical readiness captured by the TRL, the U.S. DOE recently developed the Adoption Readiness Level (ARL) framework. The ARL assesses factors associated with value proposition, market acceptance, resource maturity, and license to operate. As Figure 16 indicates, both TRL and ARL need to be at high degrees of readiness for an innovation to reach full commercialization. CARB adopted the ARL framework to support the evaluation of barriers for the Draft SB 596 Cement Strategy.[38]

[38] U.S. Department of Energy. 2023. *Commercial Adoption Readiness Assessment Tool (CARAT).*

Figure 16: Assessing Innovation Progress Toward Commercialization Using TRL and ARL Developed by U.S. DOE[39]



The ARL provides a framework to assess the progress of an innovation to achieve commercialization. CARB adapted the ARL to help identify "market, statutory, and regulatory barriers" for each technology lever as required by SB 596. This framework can help identify areas where focused support and actions may be needed to achieve commercial-scale deployment of cement decarbonization technologies and is described in Table 12.[40]

[39] U.S. Department of Energy. 2023. *Commercial Adoption Readiness Assessment Tool (CARAT).*

[40] Notably the "value proposition" category was excluded when adapting this information, as CARB is not positioned to assess value proposition of each technology option. "GHG emissions reduction quantification," was added as some existing/potential emission reductions or CCUS projects do not yet have robust quantification methodologies.

Table 12: Adaptation of the U.S. DOE's Adoption Readiness Level Framework[41]

Factors	Description
Demand-side factors Based on DOE's Market Acceptance risks, refers to the challenges in capturing the target market(s) demand characteristics	• Technology faces demand uncertainty and market barriers to entry • Technology is limited to small markets or relies on a market that does not exist yet • The path to deliver product from a producer to a customer along the value chain is not established
Supply-side factors Based on DOE's Resource Maturity risks, refers to the challenges in producing/providing the product and services at a commercial scale	• Significant capital investment is needed to achieve production on a commercial scale • Deployment of technology requires additional development, integration, and management • Additional infrastructure is needed to enable the technology. • Limited availability of workforce to commercialize the technology
Permitting and other non-economic factors Based on DOE's License to Operate risks, refers to the national, state, and local non-economic risks that can affect the deployment of a technology	• Local, state, and federal regulations or other requirements/ standards must be met to deploy the technology • The process to secure approvals to site and build equipment and infrastructure associated with the technology deployment is complex • Concerns for hazardous side effects or adverse events inherent to production, transport, or use of the technology or product in the absence of sufficient controls • Negative perception by local communities of the technology and its risks or impact, whether founded or unfounded
Quantification of GHG reductions and removals	• Overarching framework to quantify, report, and verify GHG emissions reductions and removal projects in a consistent manner throughout the cement-concrete-construction value chain

Overview of Energy-related GHG Reduction Lever

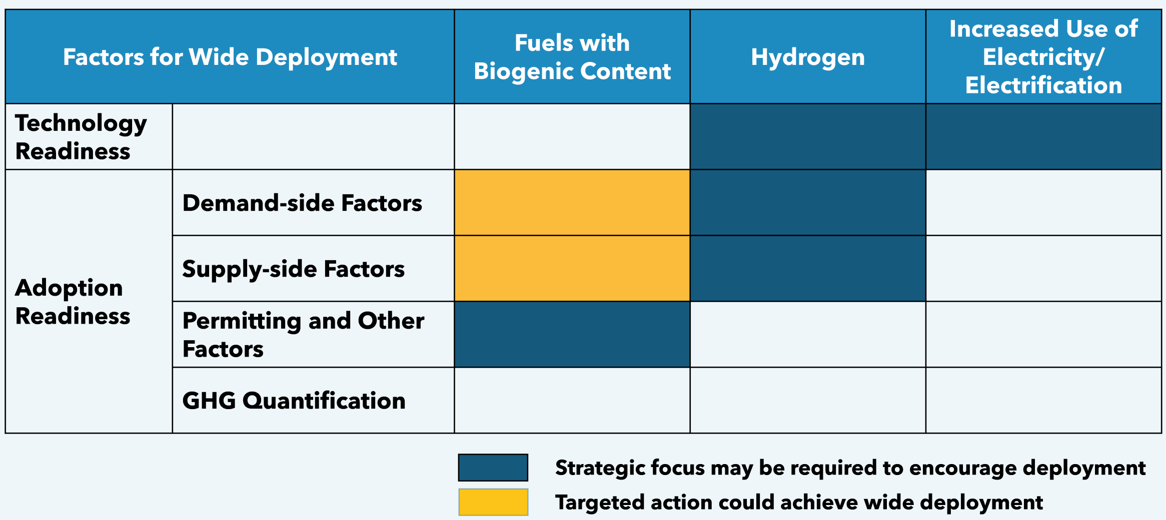
This section provides an overview of the current energy consumption by incumbent cement plants in California, potential alternative fuels, potential to increase the use of low- or zero-

[41] U.S. DOE. 2023. *Commercial Adoption Readiness Assessment Tool (CARAT)*

carbon electricity, and potential concerns and barriers associated with these options, including air quality concerns.

Key questions for feedback

- CARB identified increased use of fuels with biogenic content, introduction of clean hydrogen, increased use of electricity, and electrification as potential options to reduce GHG emissions related to energy use. Are there other energy-related GHG reduction options that should be considered?
- CARB developed an initial list of factors to help achieve wide deployment for each technology category (see "Feasibility Assessment" sections). Each category is associated with different focus areas, which are visually summarized in the figure below.
- Is the overall evaluation appropriate for each option? Should CARB consider additional factors?



Overview of energy consumption by California cement plants

Fuel combustion to produce clinker through limestone calcination accounts for about 3 MMT (about 35%) of GHG emissions associated with cement manufacturing. Clinker production is one of the most energy-intensive of all industrial processes, as cement kilns (long dry kilns), which are at least 14 feet in diameter and can be over 400 feet in length, need to be constantly heated to 1,450 °C. Cement plants in California have historically used coal and petroleum coke as primary fuels for heating kilns because these fuels cost-effectively provide high heat. Table 13 shows the U.S. EPA default CO_2 emission factors and high heat values for fuels used by California cement plants to calculate cement plant GHG emissions pursuant to MRR. Coal and coke have high heat value but are associated with high levels of GHG emissions.

Table 13: U.S. EPA Default Emission Factors and High Heat Values for Fuels Used by California Cement Plants[42]

Fuel Group	Fuel Name	Default High Heat Value	Default CO_2 Emission Factor
Coal and Coke		**MMBtu/short ton**	**kg CO_2/MMBtu**
	Bituminous Coal	24.93	93.40
	Coke	24.80	102.04
Natural Gas		**MMBtu/scf**	**kg CO_2 /MMBtu**
	Natural Gas (Weighted U.S. Average)	1.028×10^{-3}	53.02
Other fuels (solid)		**MMBtu/short ton**	**kg CO_2 /MMBtu**
	Municipal Solid Waste	9.951	90.7
	Tires	26.87	85.97
	Petroleum Coke	30.00	102.41
Solid Biomass		**MMBtu/short ton**	**kg CO_2 /MMBtu**
	Wood and Wood Residuals	15.38	93.80
	Agricultural Byproducts	8.25	118.17
Gaseous Biomass		**MMBtu/scf**	**kg CO_2 /MMBtu**
	Biogas (Captured Methane)	0.841×10^{-3}	52.07

In 2019, California cement plants consumed about 34 million MMBtu of energy and 1.4 terawatt hours of electricity to produce about 9.5 MMT of clinker. As shown in Figure 17, about 58% of the total thermal energy demand was met by coal. Natural gas and petroleum coke each provided about 16% of total thermal energy, followed by waste tires (6%) and biomass-derived waste (4%).

Combustion of coal and petroleum coke has negative air quality and human health impacts. Beyond GHGs, the major pollutants of concern from coal combustion are particulate matter, sulfur oxides, and nitrogen oxides. Some undesirable combustion products, including carbon monoxide (CO) and numerous organic compounds, are generally emitted even under proper boiler operating conditions.[43] Petroleum coke has a similar, but not identical, emissions profile as coal. Due to the refining process, there is often vanadium and nickel present in the PM emissions from combusting petroleum coke. Additionally, though sulfur oxide emissions are low, they are not absent.[44] Existing federal, state, and local air permit requirements govern the criteria air pollutant emissions from the use of these fuels. When

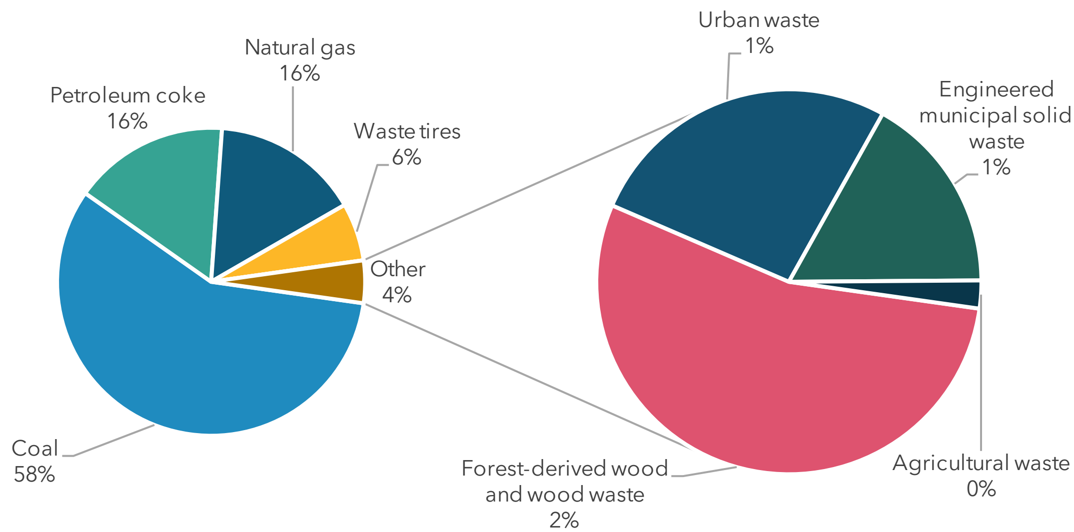
[42] *Final Rule on Mandatory Reporting of Greenhouse Gases* promulgated by the United States Environmental Protection Agency (U.S. EPA) in its Final Rule on Mandatory Reporting of Greenhouse Gases. (40 C.F.R. § 98)

[43] U.S. EPA. AP-42: Compilation of Air Emissions Factors from Stationary Sources. *Bituminous and Subbituminous Coal Combustion.*

[44] Congressional Research Service. Petroleum Coke: Industry and Environmental Issues. October 29, 2013.

replacing fossil fuels with alternatives to reduce GHG emissions, SB 596 requires CARB to identify actions that both reduce GHG emissions and reduce adverse air quality impacts. In order to do so, it is necessary to understand the potential air quality impacts of various alternative fuels. The primary authority to regulate toxic air contaminants and criteria air pollutants at stationary source emissions lies with the local air districts and U.S. EPA.[45] These requirements are discussed in greater detail in the Air Quality Impacts section.

Figure 17: California Cement Plant Energy Consumption by Fuel Type in 2019[46]



Alternative fuels can be used to displace fossil fuels to reduce GHG emissions associated with cement energy use. As potential availability of feedstock to produce low- or zero-carbon fuels can be different from region to region, the 2022 Scoping Plan Update was relied on to identify alternative fuels potentially available to California cement plants, including fuels with biogenic content, low- or zero-carbon hydrogen, low- or zero-carbon electricity, and waste heat recovery.

There is also the potential that decarbonization projects increase thermal energy demand. For example, the European Cement Research Academy estimated that monoethanolamine (MEA)-based carbon capture, the most mature technology for capture carbon, could require about 3,500 mega joules (3.3 MMBtu) of thermal energy and about 80 to 129 kWh of electricity to capture the CO_2 associated with producing one metric ton of clinker.[47] It will be

[45] California Air Resources Board. *Response to Comments on the Draft Environmental Analysis on Proposed Amendments to Cap-and-Trade Regulation*. Page 2-15. 2017.

[46] California Air Resources Board. *Mandatory Greenhouse Gas Emissions Reporting*.

[47] The European Cement Research Academy. 2022. *The ECRA Technology Papers 2022*.

critical to monitor the availability of low- and zero-carbon energy and to take steps to increase supply of these energy sources to power potential decarbonization projects.

Fuels with Biogenic Content

Fuel-switching to fuels with biogenic content presents a near-term option for cement plants to achieve GHG emissions reductions, as the carbon in biogenic CO_2 combustion emissions is part of the existing natural atmospheric carbon cycle and not newly present in the atmosphere as is the case for fossil fuel-derived carbon. Tires and waste-derived fuels are partially biogenic, and in fact over 50% of the GHG emissions associated with burning these fuels can be anthropogenic.[48] As shown in Figure 17 above, about 4% of the thermal demand of California's cement kilns in 2019 was met by the combustion of low-moisture biomass.[49]

Fuels with biogenic content have multiple potential benefits. For example, SB 1383 (Lara, Chapter 395, Statutes of 2016) establishes the State's intent to phase out disposal of organic waste and requires a 40% reduction in statewide methane emissions by 2030. If cement plants use biomethane, it can help support the demand and infrastructure needed to advance the goals of SB 1383 and support methane reduction goals. In addition, combustion of low-moisture biogenic fuels that meet SB 1383 requirements could potentially contribute to diverting organic waste from being landfilled. However, combustion of municipal solid waste is considered solid waste disposal and is outside the scope of landfill diversion.

Woody biomass, including forest-derived wood or wood waste, urban waste, and agricultural waste provided about 3% of the total thermal energy used by cement plants in 2019. These waste-derived fuels are 100% biogenic and therefore can contribute to reductions in anthropogenic GHG emissions when displacing fossil fuel use. However, combustion of any solid fuel, including both fossil fuels and biogenic fuels, can result in local air pollutant emissions, such as particulate matter emissions, and it's important that any cement plant relying on fuel combustion remain in compliance with their air permits, regardless of solid fuel source.

[48] California Air Resources Board. 2016. *California's 2000-2014 Greenhouse Gas Emission Inventory Technical Support Document.* Under the GHG Inventory methane and N_2O emissions resulting from biomass combustion are counted for California's GHG inventory total.

[49] *The California Cap-and-Trade Regulation* defines biomass as "non-fossilized and biodegradable organic material originating from plants, animals, and microorganisms, including products, by-products, residues, and waste from agriculture, forestry, and related industries as well as the non-fossilized and biodegradable organic fractions of industrial and municipal wastes, including gases and liquids recovered from the decomposition of non-fossilized and biodegradable organic material."

Some California cement plants use engineered municipal solid waste (EMSW) and/or waste tires as fuels, which are associated with partial biogenic content. About 1% of the thermal energy needs for California cement plants were met using EMSW in 2019. EMSW is municipal solid waste (MSW[50]) that has been mechanically processed to remove some of the chlorinated plastic and non-combustible materials. EMSW must contain less than 25% moisture and less than 25% non-combustible materials, and it must maximize the calorific value and burn rate of the waste.[51] EMSW does not have a nationwide estimated biogenic content percentage, but U.S. EPA estimates the average biogenic portion of MSW to be 60%.

In 2019, about 6% of thermal demand by California cement plants was met by waste tires,[52] for which U.S. EPA determined the default biogenic fraction to be 20%. Waste tires are subject to the California Tire Recycling Act,[53] and facilities that combust them must get relevant permits from local, state, and federal agencies under the Clean Air Act.[54] Although waste tires have a relatively large high heat value (26.87 MMBtu/short ton compared to 24.93 MMBtu/short ton for bituminous coke), the majority of GHG emissions associated with tires (~80%) are non-biogenic. The use of alternate fuels with high levels of anthropogenic GHG emissions provide limited value to achieving the aggressive goals of SB 596 in decarbonization the cement sector.

EMSW

There is currently a lack of data on criteria and air toxic pollutant emissions associated with combustion of EMSW because facilities in the state use EMSW as only a small fraction of their total fuel. To complete analysis of the potential air quality impacts of each alternative fuel type, more information is needed about the criteria and toxic air pollutants that can be attributed to burning specific fuel types. For example, with EMSW, some, but not all, chlorinated plastics are required to be removed, and combustion of the remaining plastic could produce volatile organic compounds and hazardous air pollutants, such as dioxins. There is ongoing analysis of the potential GHG emissions reductions and air pollutant

[50] CARB's Mandatory GHG Reporting Regulation defines MSW as: "solid phase household, commercial/retail, and/or institutional waste." For a more detailed description, see *Regulation for the Mandatory Reporting of Greenhouse Gas Emission.*

[51] The process and requirements to convert municipal solid waste into engineered municipal solid waste is specified in Ca. Pub. Res. Code § 40131.2" Cal. Pub. Resources Code §40131.2.

[52] The California Tire Recycling Act defines waste tire as "tire that is no longer mounted on a vehicle and is no longer suitable for use as a vehicle tire due to wear, damage, or deviation from the manufacturer's original specifications. A waste tire includes a repairable tire, scrap tire, altered waste tire, and a used tire that is not organized for inspection and resale by size in a rack or a stack, but does not include a tire derived product or crumb rubber. Ca. Pub. Res. Code § 42860

[53] Ibid.

[54] Clean Air Act Title 42 U.S.C. 7401.

impacts of switching to a range of biomass-derived fuels. See the Air Quality Impacts section below for more information.

There is also a lack of clarity over when EMSW can and cannot be used as a fuel. The relevant agencies include local air districts, local municipal waste management agencies, and CalRecycle. One open question is what amounts of chlorinated plastics need to be removed to effectively protect human health.

Tires

Pursuant to section 42889.4 of the California Public Resources Code, CARB is required to publish criteria and toxic air pollutant emissions information from facilities that burn tires as supplemental fuel.[55] The published information does not specify what emissions are directly attributable to combustion of tires; it provides the total quantity of tires combusted at each facility and the total quantity and type of emissions from each facility. This makes it challenging to evaluate the air pollutant emissions directly associated with the combustion of tires. Aligned with the requirements of the Tire Recycling Act (PRC 42873(b)), California Department of Resources Recycling and Recovery (CalRecycle, the state agency responsible for recycling and waste management within the state) does not support incineration of tires. Given the lack of support from CalRecycle, the air quality concerns, and the limited GHG benefits, the use of tire-derived fuels is not a priority for the Draft SB 596 Cement Strategy.

Alternative Pathways to Use Biomass

Currently, solid fuels are directly combusted in cement kilns. However, the 2022 Scoping Plan Update puts forward a long-term statewide plan that will result in a transition away from solid fuel combustion. The move away from combustion will reduce both GHG emissions and local air pollutant emissions to improve air quality and public health for all Californians, especially in priority communities. There is potential to convert solid biomass to energy through either gasification or pyrolysis. Gasification refers to conversion of biomass feedstock in an oxygen- or air-deficient environment to produce fuel gases (e.g., synthesis gas, producer gas), which can then be converted to biomethane via a methanation process.[56,57] Pyrolysis is similar to gasification but is generally optimized to produce liquid fuels or bio-oils. Slow pyrolysis, which has a processing time of several minutes to a few hours, maximizes the production of biochar, which is a fuel with high heat value that is potentially suitable for use in cement kilns. As non-combustion thermal conversion technologies are not widely used to produce alternative fuels today, more information is needed to understand the potential impact on air pollution emissions. Regardless of what any new

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[55] California Air Resources Board. 2021. *Report on Air Emissions from Waste Tire Burning in California*.

[56] Methanation is the conversion of CO_x to methane (CH_4) via hydrogenation.

[57] IEA Bioenergy. *Emerging Gasification Technologies for Waste & Biomass*. 2020.

information may indicate, all emissions are subject to the relevant local, state, and federal permits and emission limits.

Biomethane

Biomethane, sometimes called "renewable natural gas," is a near-pure source of methane.[58] Anaerobic digestion is commonly used to convert biomass with high moisture content to biogas. Solid waste landfills also generate biogas. The resulting biogas can be upgraded to biomethane and injected into common carrier natural gas pipelines as a substitute for natural gas. Biomethane is already commonly injected into common carrier natural gas pipelines for use in commercial applications.

Under the current California policies, most available biomethane is being used in the transportation sector under the Low Carbon Fuel Standard, and some is in the process of being procured to serve residential use under SB 1440.[59] A shift in policies may be needed to support industrial use of biomethane. As indicated above, the use of biomethane by cement plants can also help advance the goals of SB 1383.

Feasibility Assessment of Fuels with Biogenic Content

Technology readiness

Various types of biomass are currently combusted by California cement plants. In addition to direct biomass combustion, biomass can also be converted to biomethane via anaerobic digestion. Biomethane can also be produced from biogas collected from landfills. Biomethane production is already commercialized, but biomethane is not currently used in cement production. Use of biomethane or biomass could increase if the issues discussed below are addressed.

Adoption readiness

Biomass-derived fuels have several focus areas for wide deployment depending on the feedstock/fuel type.

- Demand-side factors
    - Biomethane is already commercially available for the transportation sector, but incentive mechanisms may be needed to grow the market for industrial use.
- Supply-side factors

[58] IEA. 2020. *Outlook for biogas and biomethane: Prospects for organic growth*.

[59] In 2022, the California Public Utilities Commission (CPUC) issued a decision (D.22-02-025) under the Renewable Gas proceeding that adopted biomethane procurement targets for natural gas investor-owned utilities (IOUs) under SB 1440. The short-term procurement target for 2025 is 17.6 billion cubic feet per year and the medium term 2030 target is 72.8 billion cubic feet of biomethane per year.

  - Small amounts of biomass are already combusted by cement plants. However, a robust waste biomass supply market may be necessary to ensure stable supply as overall demand for low-carbon energy sources is projected to increase rapidly.
  - Efficient supply chains need to be developed to collect, transport, and process the different types of waste biomass generated in different regions.
    - The supply of biomass differs regionally in California. Southern California has limited waste woody biomass but has large amounts of MSW, manure, and wastewater. The Central Valley is one of California's major agricultural areas where substantial agricultural waste is generated.[60] Parts of the Central Valley are reasonably close to the area in Southern California where six of the cement plants are located. The cement plant in the northern part of the state (in Redding, CA) has better access to forest and agricultural waste than the cement plants in Southern California.
- Permitting and other non-economic factors
  - Biomass combustion and conversion can be associated with air pollutant emissions and odors.
- Quantification of GHG emissions
  - For fuels with biogenic fractions, more accessible methodologies may be needed to quantify the biogenic portion of GHG emissions.

Potential next steps

To compare the potential local air pollution levels of biomass-derived fuels relative to existing fossil fuel use, small-scale alternative fuels evaluations with detailed emissions monitoring could be undertaken prior to more full-scale biomass use at cement plants. This would allow cement plants to test different fuel mixtures to maximize fuel efficiency, minimize emissions, and gain valuable data on to the chemical composition of their exhaust and potential air quality impacts. This information could then be used by CARB, CalRecycle, and local Air Districts to develop joint agency recommendations on the types of biomass-derived fuels that the cement sector should prioritize. Potential actions could also include cross-sectoral coordination on waste biomass supply and optimal uses of biomethane.

Hydrogen

Low-carbon hydrogen is an important fuel to achieve California's state-wide goal of carbon neutrality by 2045. The 2022 Scoping Plan Update calls for accelerating the transition away

[60] According to the estimation by Breunig et al, major agricultural wastes in California with relatively low moisture content include almond hulls/shells and orchard/vineyard residue (about 5,000 tons biomass solid per year respectively, excluding moisture) and biosolids in dairy manure are estimated to be about 7,000 tons and manure solids are about 3,000-4,000 tons.

from combustion of fossil fuels, in part through low-carbon hydrogen production, including via electrolysis powered by zero-carbon electricity, steam methane reformation (SMR) of biomethane, and biomass gasification with CCS (bioenergy with CCS, or BECCS). As hydrogen provides very high flame temperatures, at over 2000 ˚C in air, it may be suitable for cement kilns. Hydrogen combustion leads to negligible GHG emissions, and a marked decline in PM emissions. Compared to natural gas, hydrogen combustion might have an increase in NO_x emissions, but California cement plants have emissions control equipment for NO_x and SO_x. Several feasibility studies are underway in different parts of the world to understand how hydrogen can be used as a fuel for cement kilns.[61]

There have been multiple efforts at federal, state, and local levels to support the development of low-carbon hydrogen production and infrastructure. At the federal level, U.S. DOE initiatives and the Inflation Reduction Act 45V Hydrogen Production Tax Credit[62] are major drivers for increased production of hydrogen. At the state level, California's Hydrogen Market Development Strategy[63] is building up California's renewable hydrogen market. ARCHES, California's public-private partnership to establish a hydrogen ecosystem to drive down the cost of renewable hydrogen, received up to 1.2 billion dollars as part of the Infrastructure Investment and Jobs Act of 2021 (IIJA) funding.[64] At the local level, initiatives such as the Angeles Link[65] and Lancaster Hydrogen City[66] are starting to develop local/regional hydrogen infrastructure.

Feasibility Assessment of Hydrogen Fuel

Technology readiness

Industrial hydrogen has been produced widely, but low- or zero-carbon hydrogen production based on electrolysis powered from zero-carbon electricity, SMR of biomethane, BECCS, or other low carbon feedstocks are still in the process of achieving cost-effective production or being scaled.

Adoption readiness

- Demand-side factors
  - Some purchase cost reduction programs are likely needed to create a market for industrial use, such as incentivizes or easier access to low-carbon hydrogen.

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[61] See, for example, Global Cement. "*Update on hydrogen injection in cement plants*."

[62] *The Clean Hydrogen Production Tax Credit* creates a new 10-year incentive for clean hydrogen production tax credit with up to $3.00/kilogram.

[63] The Governor's Office of Business and Economic Development. *California's Hydrogen Market Development Strategy.*

[64] "*California wins up to $1.2 billion from feds for hydrogen.*" ARCHES.

[65] SoCalGas. *Angeles Link.*

[66] The City of Lancaster. *The First Hydrogen City.*

- Supply-side factors
  - Low- and zero-carbon hydrogen production costs are currently high.
  - Additional generation capacity for renewable electricity and/or biomass conversion will be needed to support low-carbon hydrogen production.
  - New/additional pipelines may be needed to transport hydrogen, unless it is produced onsite.
- Permitting and other non-economic factors
  - There are concerns about potentially increased NOx emissions resulting from combustion of hydrogen.[67]
  - There are operational and safety concerns related to injecting hydrogen into existing natural gas pipelines.

Current status and potential next steps

In 2022, the Legislature passed Senate Bill (SB) 1075, which calls for CARB, in collaboration with the California Energy Commission and California Public Utilities Commission, to produce a comprehensive report on hydrogen. This report will cover the development, deployment, and use of hydrogen across all sectors as a key part of achieving the State's climate, air quality, and energy goals. The SB 1075 implementation process will help inform the availability of hydrogen for cement plants.

Electrification and Increased Use of Low- or Zero-carbon Electricity

In 2019, California cement plants collectively purchased 1,399,400 MWh of electricity, which was about five percent of the total cement plant energy use. There are two California cement plants with on-site wind generation capacity that totals about 30 MW. While current cement plant electricity consumption is a small portion of overall energy use, electricity has potential to support decarbonization of the cement sector, as (1) electricity is a non-combustion method that can significantly reduce local air pollutant emissions at cement plants, and (2) state policies, including the Cap-and-Trade Program and California Renewables Portfolio Standard Program,[68] continue to drive down electricity sector GHG emissions intensity. There are multiple ways cement plants can leverage low- or zero-carbon electricity.

- Kiln/precalciner electrification: As cement kilns require substantial energy, kiln electrification was not historically considered feasible. However, in recent years there

[67] U.S. DOE's Hydrogen and Fuel Cell Technologies Office has been evaluating how to address potential NOx emissions from gas turbines fueled with hydrogen. U.S. DOE. 2022. *Low NOx Targets and State-of-the-Art Technology for Hydrogen Fueled Gas Turbines.*

[68] SB 100, which was amended by SB 1020 (Laird, Chapter 361, Statues of 2022) in 2022, sets a state-wide goal of 100% of all retail sales from eligible renewable energy resources and zero-carbon resources by December 31, 2045.

have been demonstration projects aimed at achieving needed temperatures by electric heating combined with the convective transfer of heat by process gases.[69]

- Concentrated solar heat: Concentrated solar heat uses arrays of mirrors to direct solar radiation to a receiver, which then transfers heat to needed process. A pilot of this technology has been demonstrated to achieve temperatures needed for clinkering reactions (in excess of 1,500 °C) at the IMDEA solar tower in Spain.[70]
- Conversion of electricity to thermal energy: There are efforts to turn resistive heat generated by electricity into thermal energy exceeding 1,000 °C using mediums such as refractory brick. If these technologies can continuously provide temperatures at about 1,500 °C, they can potentially be used for cement kilns.[71]
- Energy efficiency (waste heat recovery): As cement kilns operate up to 1,450 °C, relatively high temperature waste heat from the kiln can potentially be recovered and used to generate electricity to meet on-site electricity demand. Many industrial facilities, including cement plants, internationally and nationally already employ this technology. The cement industry in California has been exploring waste heat recovery (WHR),[72] as current electricity prices and new federal incentives for onsite electricity generation have created incentives for these investments.

Feasibility Assessment of Electrification and Increased Use of Low- or Zero-carbon Electricity

<u>Technology readiness</u>

Kiln electrification is still in the early stage of demonstration, but precalciner electrification is considered less technically challenging because it requires lower temperatures.[73] There are multiple demonstration projects for concentrated solar heat, but this technology may take longer than five years to reach commercialization. Thermal energy using electricity is in the early stage of commercialization, especially for the high temperatures needed in cement manufacturing. Use of recovered waste heat for electricity generation can be deployed if adoption readiness issues are addressed.

<u>Adoption readiness</u>

Electricity is an established energy source with minimal adoption readiness issues, but the cement industry has raised concerns about high electricity prices and barriers to electrification stemming from electricity rates structures.

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[69] See, for example, European Cement Research Academy. 2022. *The ECRA Technology Papers 2022*.

[70] Global Cement and Concrete Association. *CEMEX – Solar Clinker*.

[71] RONDO. *The Rondo Heat Battery*.

[72] California Nevada Cement Association. 2023. *Achieving Carbon Neutrality in the California Cement Industry Second Edition*.

[73] U.S. DOE. 2023. *Pathways to Commercial Liftoff: Low-Carbon Cement.*

Current status and potential next steps

AB 2109 (Carrillo), Electricity surcharge exemption, was passed and enacted in September 2024 to exempt large industrial customers from paying certain surcharges on their reductions in electricity if that reduction is achieved through an industrial process heat recovery technology with specified requirement. Depending on the implementation of AB 2109, additional support may be needed to increase the use of zero and low carbon electricity at cement plants.

Overview of Carbon Capture, Use, and Sequestration Lever

This section provides: 1) an overview of SB 905, 2) an overview of carbon capture technologies, 3) an overview of carbon use and sequestration technologies, 3) an overview

Key questions for feedback

- For carbon capture, there are diverse technology options of differing readiness and maturity for application in the cement sector. What technology options are viewed as most promising for application in the cement sector? Are there additional technologies that should be considered?
- Are there additional CO_2 use or sequestration methods that should be considered?
- What quantification and verification methodologies are available for CO_2 capture and use in the cement sector that could be incorporated into a SB 905 program?
- Should CO_2 use and removal technologies, like recarbonation be included? If so, under what circumstances and what kinds of quantification, verification and permanence methods should be required? CARB developed an initial list of factors for wide deployment. A discussion section for each technology category is provided, which is found in the following "Feasibility Assessment" sections. What if any additional factors should be considered?

Factors for Wide Deployment		CCS	CCU
Technology Readiness			
Adoption Readiness	**Demand-side Factors**		
	Supply-side Factors		
	Permitting and Other Factors		
	GHG Quantification		

Strategic focus may be required to encourage deployment

Targeted action could achieve wide deployment

of carbon removal technologies, and 4) feasibility assessment of carbon capture, use, sequestration and removals.

In 2019, California cement plants collectively emitted about 4.9 MMT of process emissions (about 63% of total GHG emissions from cement plants) as a result of the limestone calcination process (calcium carbonate ($CaCO_3$) + heat energy = Calcium oxide (CaO) + CO_2). Because of the high level of hard-to-abate inherent process emissions, CCUS is considered an important potential decarbonization option for the cement industry. Carbon Capture, Use, and Sequestration is a three-pronged approach to CO_2 emissions reduction; 'capturing' is the essential first step for 'use' or 'utilization' of captured CO_2, or 'sequestration' which is the removal and storage of carbon from the atmosphere in GHG sinks or GHG reservoirs through physical or biological processes. The use of captured CO_2 for different applications both within and outside the cement and concrete industry are rapidly developing. Overall, CCUS technologies have evolved significantly over the last several years. More recently, the Inflation Reduction Act of 2022 (IRA) and the Infrastructure Investment and Jobs Act of 2021 (IIJA) are providing a significant amount of funding to CCUS projects across several sectors, which will further advance the technology. See "Tools, Rules and Potential Measures to Help Achieve Net-zero Emissions Goals" for current federal/state funding opportunities for CCUS.

SB 905: Carbon Capture, Removal, Utilization, and Storage Program

All carbon capture, use, and removal projects must be quantifiable, verifiable, permanent, and consistent with the requirements of SB 905. Protocols for CCUS and CDR project-types will need to be developed to support broader adoption of CCUS and CDR and the cement sector.

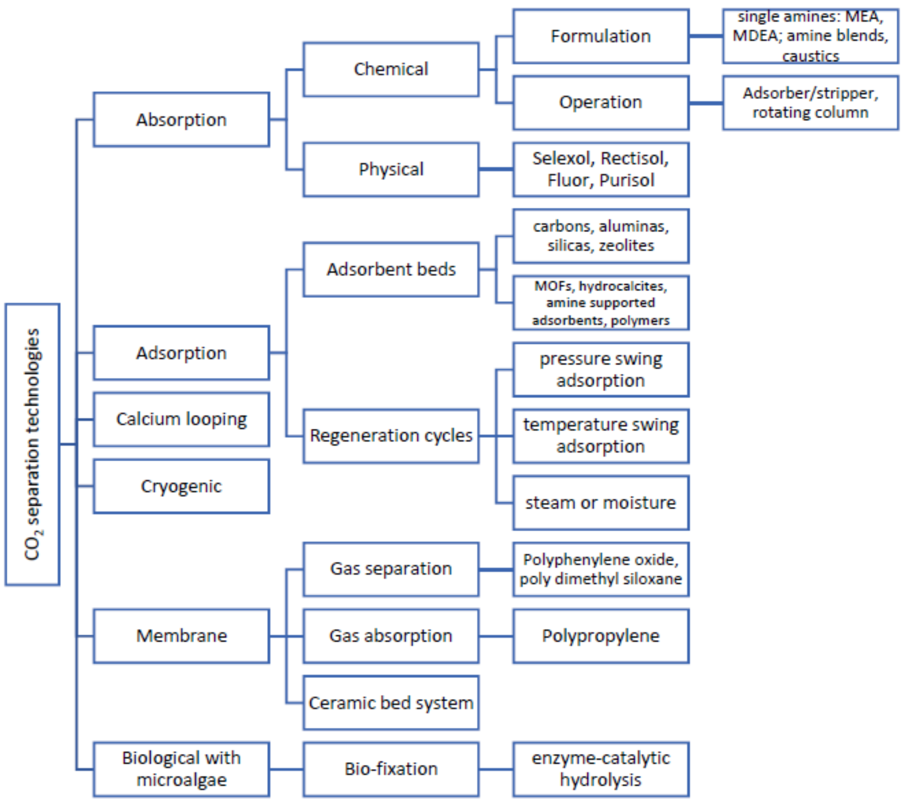
SB 905 was signed into law in 2022 and requires CARB to establish a Carbon Capture, Removal, Utilization, and Storage Program to evaluate the efficacy, safety, and viability of CCUS and CDR technologies, to develop protocols for CCUS and CDR technologies, and to develop monitoring and reporting schedules to state regulatory agencies.

Prior to the passage of SB 905, CARB adopted a CCS protocol in 2018 as part of amendments to the Low Carbon Fuel Standard. This initial CCS protocol is focused on the quantification, monitoring, and reporting of CO2 captured from industrial sources and stored underground in a geologic formation. This initial protocol does not cover the diversity of capture, utilization, sequestration, or removal approaches that could be implemented by the cement sector. As part of implementing SB 905, CARB expects to update and develop new protocols for additional CCUS and CDR approaches, including those that are discussed in this report and that could be utilized by the cement sector to reduce their emissions pursuant to SB 596.

Carbon Capture Technologies

There has been extensive research and development into different methods of capturing CO_2 in recent years. Monoethanolamine (MEA)-based chemical absorption, sorbent-based capture, cryogenic, oxy-fuel combustion capture, indirect calcination, and calcium looping, among other technologies, have been deployed or tested related to cement manufacturing. Ultimately, any CCUS will have to be evaluated and included in the SB 905 Carbon sequestration: Carbon Capture, Removal, Utilization, and Storage Program.

Figure 18: Examples of CO_2 Separation Technologies[74]



- MEA-based chemical absorption, which captures carbon contained in post-combustion flue gas using liquid amine scrubber.[75] It has been used in other sectors, such as petroleum refining and coal-fired electricity generation, over the last couple of decades. However, MEA-based capture requires substantial amounts of energy, water, and space to operate.
- A variety of solid sorbents have been evaluated for carbon capture applications. Relative to liquid solvents like MEA, solid sorbents can potentially have lower

[74] Font-Palma et al. 2021. Department of Engineering, University of Hull. *Review of Cryogenic Carbon Capture Innovations and Their Potential Applications.*

[75] See, for example, Global Cement and Concrete Association. *Amine-based post-combustion capture*.

regeneration energy, lower corrosion concerns, and lower associated emissions (from both manufacturing and required energy for use). Calcium looping uses calcium oxide as a CO_2 sorbent, and alternates calcination and reabsorption processes ($CaO \leftrightharpoons CaCO_3$) to first absorb CO_2 from the exhaust stream using CaO, and then to heat the $CaCO_3$ to release concentrated CO_2 for capture and repeat the cycle. Captured CO_2 is then compressed, transported, and sequestered.

- Cryogenic carbon capture could capture carbon with fewer chemical requirements than sorbents. It separates CO_2 from the exhaust gases by cooling to initiate a phase change from gas to liquid or solid.[76]
- In-oxy-fuel combustion with carbon capture, the fuel combustion happens in pure oxygen or oxygen-enriched air, instead of ambient air, so that the CO_2 concentration of the exhaust gas is higher (because there is less nitrogen present) and the CO_2 capture process is more efficient. However, additional energy is needed to reduce the amount of nitrogen in the combustion environment that produces oxygen.

In addition, there are emerging technologies that isolate the process CO_2 emissions that result from limestone calcination.

- Indirect calcination yields an exhaust gas with a high CO_2 concentration because calcination of limestone occurs before the materials are mixed with combustion flue gas. Capturing the process CO_2 emissions from the high concentration exhaust gas enables more efficient and cost-effective CO_2 capture.

Use and Sequestration of Captured Carbon

In addition to geologically sequestering captured CO_2, it can be used for productive purposes. Broadly, captured CO_2 can have many different uses both within the cement and concrete industries and outside of it. Per the goals of this SB 596 Cement Strategy, the following use and sequestration techniques are focused on applications in the cement sector, but it is recognized that this is not an exhaustive list.

Fuel Production

Captured CO_2 can be used to produce methanol by hydrogenation. Methanol has many uses, but when combined hydrogen it can be used as a liquid fuel for the transportation and shipping industries. The CO_2 is usually captured via direct air capture, or MEA- based chemical absorption from an industrial process, such as cement manufacturing.[77]

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[76] Font-Palma et al. 2021. Department of Engineering, University of Hull. *Review of Cryogenic Carbon Capture Innovations and Their Potential Applications.*

[77] Energy Conversion and Management. 2023. Yang et al. *A strategy for CO_2 capture and utilization towards methanol production at industrial scale: An integrated highly efficient process based on multi-criteria assessment*.

Carbon Mineralization

Carbon mineralization is the process by which carbon dioxide becomes a solid mineral, such as a carbonate.[78] There are several mineralization technologies that fix CO_2 into minerals, such as calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$). These minerals can be used as commercial products within the cement and concrete supply chain, such as in aggregates or supplementary cementitious materials. Additionally, calcium-rich minerals in concrete can absorb CO_2, which means that CO_2 can be sequestered into concrete during its blending and production stage. There are companies that are commercializing the process of injecting CO_2 during the concrete production process.[79]

Both calcium carbonate and magnesium carbonate are stable and can be considered as potentially permanent carbon sinks. Unlike a CCS framework, mineralized CO_2 may be difficult to monitor, due to the challenge of tracking its distribution to buyers and location of ultimate use. Once the product is incorporated into its end products, like concrete, periodic measurement could damage the structure it was used in, or it could be inaccessible. Provided robust quantification, reporting, and verification methods can be developed, CCU could play a role in cement decarbonization, particularly if geological sequestration projects require longer time for implementation.

Geologic Sequestration

Geologic sequestration is the process of injecting CO2 captured from an emissions source into deep subsurface rock formations for permanent storage. Geologic sequestration of CO_2 is an established and well-understood method for long-term storage of CO_2 and presents an opportunity for cement decarbonization in addition to utilization approaches. CO_2 transport, from the cement production site to the injection site, is one of the challenges that the cement sector may experience in implementing carbon capture with geologic sequestration to reduce emissions.

Carbon Removal Technologies

There are also new and emerging technologies that can be used to absorb carbon dioxide from the atmosphere that do not neatly fit into the 'use' or 'sequestration' categories. These technologies are listed below to solicit input on whether and under what circumstances they could be considered for SB 596 and if included how carbon removal technologies would be quantified to the same standards as any other sequestration or use method.

[78] USGS. 2019. *Making Rocks- How Growing Rocks Can Help Reduce Carbon Emissions*.
[79] See, for example, *Carboncure*.

Direct Air Capture (DAC)

Direct Air Capture is the broad term for a suite of technologies that remove CO_2 directly from ambient air. Currently there is at least one direct air capture (DAC) process that could align with the cement-concrete supply chain. It uses calcium oxide as a sorbent to mineralize ambient CO_2 into calcium carbonate. The calcium carbonate with captured CO_2, or any mineral generated by incorporating CO_2 through a DAC process, could potentially be used as concrete aggregate.

Recarbonation

At final use, cement is mixed with aggregate, admixtures, and water to create concrete. Concrete is the most common building material in the world and theoretically can be a carbon sink and a source of permanent sequestration. As hydrated compounds in cement are exposed to atmospheric CO_2, the calcium hydroxide ($Ca(OH)_2$) bonds with CO_2 to return to calcium carbonate ($CaCO_3$), yielding H_2O as a biproduct.[80] This process of concrete absorbing CO_2 from ambient air to create calcium carbonate is known as recarbonation. This is notably different from the previously discussed methods of use and sequestration, because it does not absorb a pure CO_2 stream generated from either process or energy emissions. Theoretically, the calcium hydroxide present in cement can reabsorb 100% of the CO_2 that was emitted during the original calcination process.[81] However, the actual amount of CO_2 that gets recarbonated is limited and may vary widely, depending on factors like the surface area of the concrete, concrete porosity, exposure time, and/or presence of other substances that can react with CO_2. Recarbonation occurs over the lifetime of the concrete, which can be centuries.[82] Overall, quantification of the amount of CO_2 captured would need be held to the same standards as any other sequestration technique: it would need to be measurable, quantifiable, verifiable, and permanent, and meeting these standards may be challenging for recarbonation given its variability.

Feasibility Assessment of CCUS projects

CCUS is a rapidly evolving suite of technologies. As of February 2025, there are not yet any commercial-scale applications of CCUS in operation at a cement plant in California. There are, however, several pilot CCUS projects active in California.[83] There are some uncertainties associated with implementation, which are somewhat differ between CCS and CCU.

- Technology readiness

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[80] *CO_2 Uptake Potential due to Concrete Carbonation: A Case Study*. Possan et. al. 2017.

[81] Global Cement and Concrete Association. 2024. *Carbon Uptake.*

[82] Cembureau. 2019. *Cement Recarbonation*.

[83] See for example, *Fortera*, and *Calpine*.

  - Estimates of the technology readiness for CO_2 capture technologies vary, but amine-based chemical absorption is a relatively mature technology. The first commercial MEA-based capture facility at a cement plant is completing construction in Norway, and Heidelberg in Edmonton, Canada is also developing amine-based carbon capture units. Other CO_2 capture technologies are at different levels of the development stage. For example, there are demonstration projects for indirect calcination and solid sorbent absorption, which are slightly more advanced than cryogenic capture and membrane absorption, which are still in research and development phase. Most CO_2 utilization technologies are in the development stage, but there are demonstration projects in California where CO_2 captured from the flue gas of an industrial facility (a power plant and a cement plant) is mineralized to produce aggregates or SCMs.
- Adoption readiness
  - Demand-side factors
    - CCU: Cement and/or concrete products produced using captured CO_2 need to conform to standards, codes, and specifications for cement, concrete, and/or aggregate and be accepted by the concrete-construction industry.
  - Supply-side factors
    - CCUS technology is capital intensive.
    - Infrastructure, including carbon storage facilities, transportation pipelines, and geologic sequestration wells, need to be developed.
    - Standardized frameworks and/or agreements may be needed among stakeholders on the value chain (cement plants, transportation providers, storage, and sequestration project operators) to implement effective and efficient CCUS projects.
  - Permitting and other non-economic factors
    - SB 905 Carbon Capture, Removal, Utilization, and Storage Program is under development.
    - The permitting requirements for transporting and sequestering captured CO_2 are under development by the federal Pipeline and Hazardous Materials Safety Administration.[84]
  - Quantification of GHG emissions
    - CCUS will need GHG quantification protocols to contribute to the goals of SB 596.

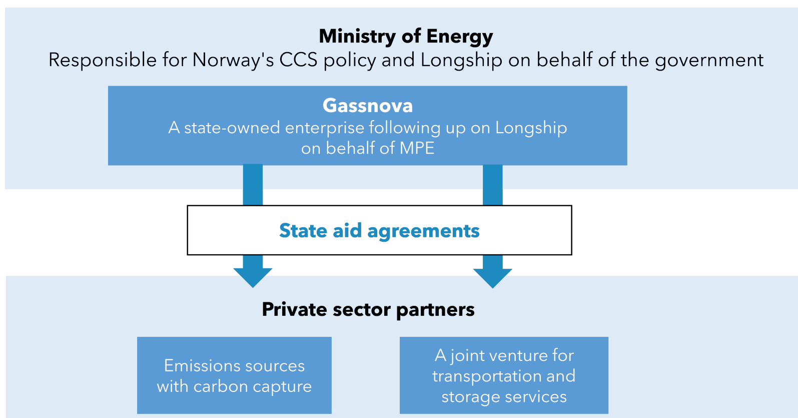
[84] US Department of Transportation. *USDOT Proposed New Rule to Strengthen Safety Requirements for Carbon Dioxide Pipelines*. January 15, 2025.

CCUS technologies are not at scale. It will take coordination to simultaneously develop carbon capture and the needed infrastructure for use or sequestration.

CASE STUDY: Norway Development of the CCS Value Chain

CCS requires infrastructure to safely and sustainably capture, transport and sequester carbon. When a cement plant installs a carbon capture unit, captured carbon needs to be safely transported and permanently stored at a sequestration site. However, it is most likely that each stage is owned, developed and operated by different business entities and will require different levels of investments, planning, permitting and construction. In Norway, the state played a pivotal role to make sure that all three phases become operational at the same time. Acting as the "project integrator," Norway is helping develop an industrial CCS value chain (Longship Project) by providing both financial and technical support to stakeholders carrying out carbon capture, transportation and offshore sequestration.

Figure: The Framework of Longship Project



Under the Longship Project, Heidelberg Materials' cement plant is installing amine-based carbon capture units with plans to capture around 400,000 tons of CO_2 annually. Northern Lights, a joint venture, is responsible for the operation of onshore/offshore facilities to receive CO_2 from the Heidelberg Materials plant, ship it to a receiving terminal, and transporting it via pipeline to a storage site 2,600 meters below the seabed. According to *Gassnova*, as of Fall 2024, Heidelberg CCS project is 76% complete and Northern Lights project is 94% complete.

Because CCS is an emerging technology, this project addressed the lack of commercial incentives for the industrial partners and risks to adopt emerging technologies. To do so, the Norwegian government offered a tailor-made state aid agreements for companies willing to capture carbon and transport/sequester that carbon. These financial aids cover approximately two-thirds of the total costs according to the initial cost estimates.[1] The state-owned enterprise, Gassnova also coordinated on issues that required harmonization such as CO_2 specification, export rates from the capture plants, and use of loading arms between capture export terminal and ship. A committee was also established to address cross-sectoral operation issues including transport schedule. Gassnova is also responsible for project evaluation and tracking the progress of the entire project. The state aid agreements, technical studies, reports on lessons learned among other materials are publicly available as resources for other projects and similar efforts. For more information on Longship Project, visit *https://ccsnorway.com/the-project/*

In California, SB 905 is projected to facilitate the implementation of CCUS projects on multiple fronts. CARB is coordinating efforts to ensure that CCUS issues related to the cement sector will be addressed through both processes. In addition, the potential for installation of on-site CO_2 capture units to reduce local air pollutant emissions depending on the technology deployed is being evaluated.[85]

Overview of Increased Use of Low-carbon Cement and Concrete Lever

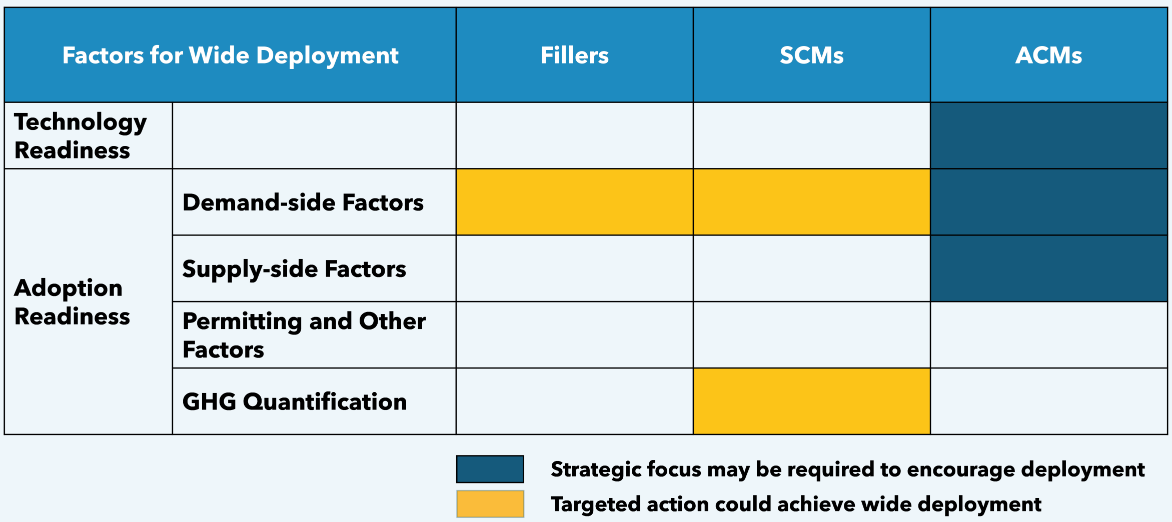
This section provides: 1) an overview of standards, codes and specifications that govern the use of cement, 2) technical descriptions of material to make low-carbon cement (fillers, CMs, and ACMs), and 3) concerns and barriers to promote the use of low-carbon cement and concrete. Alternative raw materials with lower GHG emissions can be added to reduce the amount of clinker in cement. In the U.S., most alternative materials are typically added to cement when making concrete at concrete plants, while some are blended with clinker at cement plants. There are three major categories of low-carbon alternative materials that can be added cement: fillers, supplementary cementitious materials (SCMs), and alternative cementitious materials (ACMs). Some materials are already used by industry, and others may be made available by new manufacturers or suppliers that are not currently part of the cement-concrete-construction value chain. These materials are discussed in the following sections.

[85] Clean Air Task Force. 2023. *Air Pollutant Reductions from Carbon Capture.*

Key questions for stakeholder feedback

Alternative low-carbon materials can be added by cement or concrete producers to displace limestone-based clinker to lower GHG emissions associated with cement.

- CARB staff identified fillers, SCMs and ACMs as potential materials to displace limestone-based clinker. Should other product categories be included?
- An initial list of focus areas for wide deployment for each technology category is found in the “Feasibility Assessment” sections. Each category is associated with different levels of challenges, and potential areas for priority is visually summarized in the figure below. Is the overall evaluation of each material appropriate? Should CARB consider additional barrier factors?



To facilitate stakeholders feedback on this subject, the appendices of the Draft SB 596 Cement Strategy include (1) the status of a new material approval process by California Department of Transportation (Caltrans) (Appendix B), and (2) the results of the California concrete producer survey (Appendix C).

Standards, Codes, and Specifications of Cement and Concrete

Before discussing low-carbon materials, it’s important to understand the standards, codes, and specifications that apply to cement and concrete, which are subject to rigorous rules to ensure the final products’ strength and safety. Every alternative material used to replace clinker in cement needs to conform to relevant requirements.

Material standards

Material standards provide material specifications and testing methods to help industries supply products with standardized, uniform quality. The ASTM and American Association of State Highway and Transportation Officials (AASHTO) are the major standard setting bodies for cement and concrete in the U.S. and in California. As discussed in “Potential Approaches to Establishing SB 596 Targets" section, ASTM C150 (AASHTO M 85) for Portland cement, ASTM C595 (AASHTO M 240) for hydraulic blended cements, and ASTM C1157 for the standard performance specification are the three primary standards used for cement in the United States.

Once cement is shipped to concrete producers, it's mixed with aggregates, chemical admixtures, and water to become concrete products. The standard specification for ready-mixed concrete is ASTM C94 (AASHTO M 157), which governs the mixing and testing of concrete.

Building codes

Depending on the type of construction, concrete is also subject to building codes and specifications that set minimum requirements for how structural systems, plumbing, heating, and other aspects of residential and commercial buildings should be designed and constructed. In the U.S., the American Concrete Institute (ACI) develops reference specifications.[86] After development, an ACI specification is then considered for inclusion in the International Building Code (IBC), which is a model building code developed by the International Code Council (ICC). The California Building Standards Code (Cal. Code Regs., Title 24) adopts the IBC. However, local governments have authorities to adopt, via ordinance, amended building standards with more stringent requirements to accommodate environmental standards or other considerations.

Standard specifications

Based on material standards and building codes, project owners, both public and private, write specifications to ensure that their projects realize their plan while satisfying code requirements. They may either use standard specifications written by organizations such as the ACI or ASTM or write their own. For public infrastructure projects, such as road and bridge construction, state departments of transportation (DOT) write their own specifications. These specifications often incorporate unique requirements for both testing and construction methods based on regional conditions. Because of that, the DOT specifications are typically more restrictive than standard material specifications and are often used as the default minimum requirements in construction market in respective states. In California, California Department of Transportation (Caltrans) specifications have significant influence on specifications used throughout the state. Private project owners may leverage standard or pre-packaged specifications, as it can be time-consuming and resource-intensive to examine a wide range of requirements, including requirements for cement or concrete, to support writing their own specifications.

[86] The ACI 301-20 reference specification governs concrete, and the ACI 318-19 reference specification specifically lists building code requirements for structural concrete, covering placement, consolidation, and curing, among other aspects.

Fillers

Fillers are relatively inert, finely ground particles that can fill voids in cement to improve binding efficiency. Limestone powder is the most used type of filler, which is typically interground with clinker and gypsum at cement plants to ensure that they are evenly mixed. ASTM C150 allows a maximum 5% limestone filler, but the ASTM C595 Type IL standard for Portland limestone cement (PLC), allows up to 15% limestone. By switching cement from ASTM C150 to C595 Type IL, the amount of clinker can be reduced by about 10%. GHG emissions associated with limestone filler are minimal because it is made by finely grinding limestone without a thermal process. Depending on the application, PLC could improve the hydration reaction as it provides nucleation sites, which could also increase concrete strength.

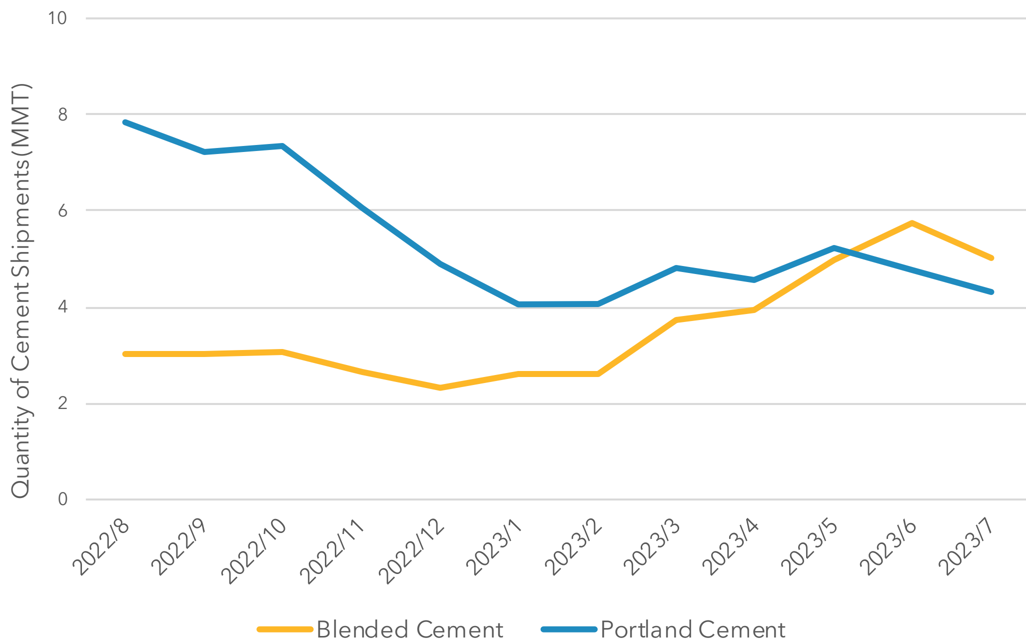
Historically, PLC has been commonly used around the world but has not been widely used in California or in the U.S. However, PLC use in the U.S. is rapidly increasing. The USGS Mineral Commodity Summaries for cement issued in January 2023 observed that: "Following widespread acceptance of Portland-limestone cement (PLC) blended cement by various authorities, several cement plants announced their transition to PLC (Type IL)."[87] Figure 19 shows that shipment of blended cement (of which the majority is PLC)[88] in the U.S. exceeded the shipment of Portland cement in 2023.[89]

[87] U.S. Geological Survey. 2023. *Mineral Commodity Summaries for cement, January, 2023*.

[88] Starting with the January 2023 Minerals Industry Survey, USGS asks the amount of PLC as part of blended cement. July 2023 report estimated that 4.9 Mt (98%) of blended cement shipment in July 2023 was PLC.

[89] U.S. Geological Survey. 2023. *Cement Mineral Industry Surveys*

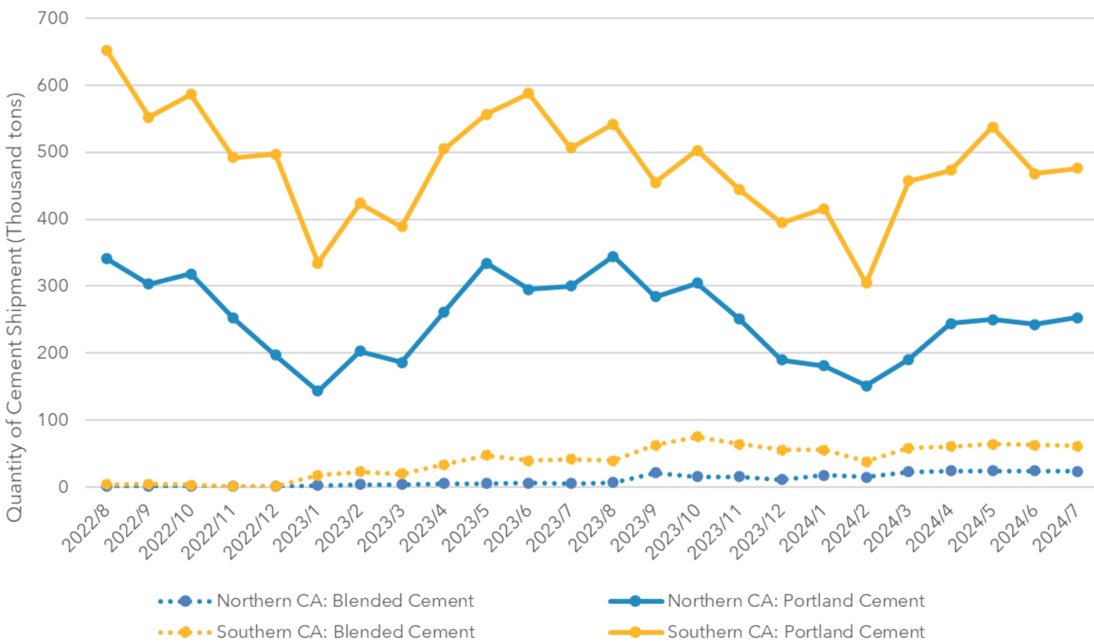
Figure 19: Cement Shipments in the U.S. by Type[90]



In 2022, CalTrans approved the use of PLC for its projects, which is expected to help increase the use of PLC in California. However, the transition to PLC in California has been relatively slow, as shown in Figure 20. In 2023, CARB conducted a survey with concrete producers in California to understand the barriers to increased use of PLC. Details of the survey are in Appendix D.

[90] U.S. Geological Survey. 2023. *Mineral Commodity Summaries for cement, January, 2023*.

Figure 20: Portland Cement and Blended Cement Shipments in California[91]



There are construction project owners that have been prioritizing PLC for multiple reasons. University of California, San Diego has been using PLC for aesthetic benefits in addition to GHG emission reduction benefits.

Beyond PLC, there are emerging technology options to increase the amount of limestone filler above 15%. For example, high-filler, low-water cement can potentially include 50% limestone filler and may still conform to ASTM C1157, even when its limestone content is greater than 15%.[92]

[91] U.S. Geological Survey. 2023. *Mineral Commodity Summaries for cement, January, 2023*.

[92] See, for example, UN Environment Program, *Eco-efficient Cements: Potential Economically Viable Solutions for a Low-CO2 Cement-based Materials Industry.*

CASE STUDY: Leveraging Benefits of Portland Limestone Cement

As part of its commitment to responsible stewardship of resources and to demonstrating leadership in sustainable business practices, The University of California has a Policy on Sustainable Practices. One of the policy goals is green building design. One example of green building design is at UC San Diego where there are currently 63 LEED certified projects on campus for a total of 7,380,300 square feet of green building. UC San Deigo has been using Portland limestone cement (PLC) in its buildings for more than a decade for both aesthetic and sustainability reasons.

Because of the higher amount of limestone, PLC exhibits lighter and brighter colors compared to conventional Portland cement. UC San Diego first introduced PLC for aesthetic benefits. Exposed concrete made of PLC is one of the key design features of some major on-campus buildings.

(Source: UC San Diego Franklin Antonio Hall *https://fah.ucsd.edu/about*)

PLC can reduce cement's embodied carbon by about 10% compared to conventional Portland cement by replacing clinker, the most emissions intensive component of cement. However, as a new material with limited historical data, there were uncertainties in how PLC would perform. To address the concerns, a UC San Diego contractor used mockups to test the performances of different types of concrete mix using PLC such as consistency, workability, set times, and temperatures. This allowed the project owner to approve deviations from the original specifications when they arose. Mock-ups also helped the design and cost optimization because it dictated which design details or finishing methods would result in additional costs. For example, sharp edges or certain seam finishes, which are critical details for exposed concrete design in some cases, added additional work and costs. UC San Diego projects demonstrate how PLC's unique characteristics can be addressed while leveraging its benefits.

Supplementary Cementitious Materials

Cement (calcium silicates) sets and hardens when it reacts with water to form calcium silicate hydrate paste. But some portions of cement forms calcium hydroxide, which does not contribute to hydration. Supplementary cementitious materials can be added to turn calcium hydroxide into calcium silicate hydrate paste to provide additional cementitious properties.[93] SCMs can also control alkali-silica reaction (ASR),[94] sulfate attack,[95] or other reactions that distress concrete. Fly ash (byproduct of coal combustion) has been widely used as an SCM because it can control ASR and sulfate attack cost-effectively, in addition to providing other benefits such as increasing concrete workability. GGBFS (byproduct of primary steel production) is also widely used as an SCM because it increases the strength and durability of concrete. However, supply of fly ash and GGBFS has been steadily decreasing as we transition away from emissions-intensive production methods for electricity and primary steel. Negligible amounts of fly ash and GGBFS are generated in California. There are ongoing projects to recover ash from landfills or to use bottom ash as an SCM. Silica fume is a highly pozzolanic SCM that can enhance the strength and durability of concrete. Silica fume is mostly used as a component in special types of concrete with a need for greater resistance to chloride penetration, such as parking structures, bridges, and bridge decks.

While fly ash, GGBFS, and silica fume are byproducts of other industrial processes, SCMs are also produced from naturally occurring clay, which is not associated with upstream industrial activities. Silica contained in natural pozzolan, when finely ground, can react with calcium hydroxide in cement[96] to form calcium silicate hydroxide and perform similarly to fly ash. Also, natural pozzolans are often treated at a temperature in the range 700-850 °C and used as calcined clay. The reactivity of natural pozzolans or calcined clay is influenced by particle size, material composition and temperature. Different types of natural pozzolans and calcined clay have been tested, and metakaolin, which is made by calcining kaolinite, is considered to exhibit high reactivities.[97] It can be blended at a higher ratio than other SCMs to make limestone calcined clay cement (LC3), which contains about 30% metakaolin, 15% limestone filler, 50% clinker, and 5% gypsum.

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[93] U.S. Department of Transportation Federal Highway Administration. *Use of Supplementary Cementitious Materials (SCMs) in Concrete Mixtures.*

[94] ASR is caused when a chemical reaction between the alkalis in Portland cement and certain types of silica minerals present in some aggregates occurs. The reaction product, which is a hygroscopic gel, can absorb moisture, swell, cause expansion and cracking of the concrete.

[95] Sulfate attack occurs when the sulphates present in saline soils, ground waters or seawater react with calcium hydroxide in concrete. Sulfate ion can ingress and cause deterioration of the concrete cement paste, which results in the concrete losing physical integrity.

[96] National Precast Concrete Association. 2017. *SCMs in Concrete: Natural Pozzolans.*

[97] RMI. 2023. *Scaling Limestone Calcined Clay Cement (LC3): Learnings from the First Movers*

SCMs can also be generated using recycled materials. It is environmentally beneficial to use them if environmental impacts to recycle them are lower than those of producing other SCMs. Glass pozzolan, which is made from recycled glass, is one of such products with potential environmental benefits. ASTM recently developed ASTM C1866 to provide specifications for glass pozzolan used as an SCM.

Caltrans is currently evaluating new types of SCMs to reduce GHG emissions associated with cement and concrete by focusing on locally or regionally available materials. See Appendix B for details about the Caltrans process to approve new alternative materials for use in concrete.

Alternative Cementitious Materials (ACMs)

There are emerging cementitious binding materials that are functionally equivalent to limestone-based clinker that can be produced using lower carbon alternative minerals or processes. Whereas SCMs and fillers can only partially replace limestone-based clinker, alternative materials with cementitious properties can completely replace it. They may be referred to as alternative cement, novel cement, or alternative binding materials, but this report refers to them as alternative cementitious materials (ACMs). There has been a variety of emerging ACMs that are in research, development and deployment phase, and it is more likely that new companies will start producing ACMs rather than incumbent cement manufacturers. If an ACM meets performance requirements equivalent to Portland cement (including ASTM C15), hydraulic blended cements (including ASTM C595), or performance-based standards such as ASTM C1157, it can be considered as cement.

The ACI's definition for alternative cement divides it into three categories: clinkered alternative cements,[98] calcined alternative cements,[99] and nonclinkered alternative cements.[100] Clinkered alternative cements are made by processing non-limestone minerals which can contain no carbon. However, it still requires high temperature clinkerization processes similar to Portland cement. Belite-based cements are less energy intensive than conventional alite-based cement, as it's produced at temperatures lower than 1,300 °C, compared to conventional alite-based cements that are produced at 1,300 °C to 1,450 °C. Belite-cement can be produced from the existing cement manufacturing process. There is

[98] The ACI defines clinkered alternative cements as "produced using technologies similar to Portland cement production, with process changes that preclude production of Portland cement but positively affect the environmental impact of production."

[99] The ACI defines calcined alternative cements as "an alternative cement produced by calcining a raw material only, without further pyroprocessing, to produce additional mineral phases within the material."

[100] The ACI defined nonclinkered alternative cement as "an alternative cement produced using precursors that require no pyroprocessing and set after addition of an activating solution to cause reactions that are not hydration or acid-base."

calcium silicate-based cement production that is in research, development and demonstration stage.[101]

Whereas clinkered alternative cements still require significant amounts of thermal energy, calcined alternative cements are a combination of calcined magnesite and other minerals that are produced at calcining temperatures in the range 700 to 1,000 °C, a lower temperature than needed to for clinkered alternative cements. Magnesium-based cements have been known and produced for decades, however the supply of magnesium oxide suitable for cement production is limited compared to limestone.

The third category, non-clinkered alternative cements, is produced via chemical reactions with no thermal process thereby avoiding both process and combustion emissions. Major non-clinkered alternative cements are alkali-activated materials (AAM), which is based on materials called precursor that include some combination of silica (SiO_2), alumina (Al_2O_3), and calcium oxide (CaO). Most major SCMs, including GGBS, fly ash, or metakaolin, fall under this category. When precursor materials react with an alkali activator, chemical compounds in precursor materials break, reform, and then polymerize to become a binder. Calcium oxide-rich precursors react like hydraulic cement, while precursors rich in silica and alumina go through non-hydraulic geopolymerization reactions (the resulting binder is known as a geopolymer). Non-clinkered alternative cements have potential to drastically reduce GHG emissions associated with cement production. However, as major precursors are also used as SCMs, the supply of these materials may have to be increased significantly to respond to growing demand for SCMs and AAMs.

There is also a pilot project to use an electrochemical reactor to process limestone to produce calcium hydroxide without relying on thermal processes. Carbon contained in limestone is released as pure CO_2 stream at room temperature for easy capture. The resulting calcium hydroxide can be used as cement with the addition of SCMs.[102]

Feasibility Assessment of Increasing the Use of Low-carbon Cement

Technology Readiness

Alternative cementitious materials are at varying stages of commercialization, but in general SCMs are closer to mass production compared to ACMs. Conventional SCMs, such as fly ash and GGBFS, are already commercial throughout the world but the supply has been steadily decreasing. SCMs such as natural pozzolans and calcined clay are also already produced in different parts of the world, and California has known natural pozzolan deposits. On the other hand, most ACMs are still in the early stages of research, development,

[101] CARB. 2022. *Kick-off Workshop for Net-Zero Emissions Strategy for the Cement Sector.*

[102] U.S.DOE. 2024. *Industrial Demonstrations Program Selections for Award Negotiations: Cement and Concrete. First Commercial Electrochemical Cement Manufacturing*.

demonstration, and deployment. In 2024, Industrial Demonstrations Program, funded by the Bipartisan Infrastructure Law and Inflation Reduction Act and administered by the U.S. DOE, selected three SCM/ACM projects for funding. One project aims to achieve wide commercialization of limestone calcined clay cement. A California-based company is targeting to start production of cement that uses calcium silicate rocks and alternative production methods.[103] Another project plans to build a production facility that produces cement using non-thermal electrochemical process to treat calcium silicate-based feedstock.[104] Additionally, some types of ACMs, such as belite-based clinker and alkali-activated clinker, are already produced at a small scale.

In July 2024, the U.S. DOE Industrial Efficiency and Decarbonization Office (IEDO) announced its plan to create a Cement and Concrete Center of Excellence to accelerate the development and adoption of novel low-carbon cement and concrete technologies. The center will support collaboration among various interested parties to develop and validate low-carbon cement and concrete technologies.[105]

<u>Adoption Readiness</u>

Low-carbon alternative materials will need to be produced at a commercial scale, then accepted by the construction industry to achieve wide commercialization. Market acceptance and resource maturity are the major barriers.

- Demand-side factors
    - As construction material used for structures, cement is required to satisfy relevant material standards, building codes and specifications. Because of that, professionals on the concrete-construction value chain tend to rely on conventional cement types with proven track records and avoid low-carbon cement types even if they meet the same performance requirements.
        - As mentioned above, CARB conducted an online survey with California concrete producers to understand the barriers to using PLC. The results demonstrated that there is a group of concrete producers that still see issues accepting PLC, such as the lack of track record, storage space and demand. See Appendix C for the results of the survey. Most of the barriers applicable to PLC also apply to other SCMs and ACMs, as any new materials must conform to applicable standards/codes and then accepted by concrete users.

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[103] U.S.DOE. 2024. *Industrial Demonstrations Program Selections for Award Negotiations: Cement and Concrete. Deeply Decarbonized Cement*.

[104] U.S.DOE. 2024. *Industrial Demonstrations Program Selections for Award Negotiations: Cement and Concrete. Deeply Decarbonized Cement*.

[105] U.S. DOE. 2024. *U.S. Department of Energy Announces Plans To Create Low-Carbon Cement and Concrete Center of Excellence To Reduce Industrial Emissions*

- Recent developments to address demand-side challenges:
    - Standardization bodies including ASTM are reviewing existing requirements for materials used to make cement. In 2024, the American Concrete Institute published ACI Code 323-24 to provide provisions for low-carbon concrete where reduced global warming potential is required in a construction project.[106]
    - In November 2019, Marin County became the first local jurisdiction in California to adopt a low-carbon concrete building code that requires concrete used to construct buildings in the county to meet the GHG intensity thresholds per unit of concrete.[107] In 2024, City of Santa Monica adopted a new ordinance to reduces emissions from concrete poured in new buildings, spas, and swimming pools.[108] In the same year, City of Dublin adopted a low-carbon concrete building code intended to reduce the embodied carbon associated with concrete.[109]
    - At the State level, effective July 1, 2024, the 2022 California Green Building Standards Code (CALGreen) requires large-scale non-residential and school construction projects to lower embodied carbon in concrete and other construction materials.[110]
    - In 2024, the Federal Highway Administration (FHWA) awarded funding for 39 State Departments of Transportation, including Caltrans, under the Low Carbon Transportation Materials Discretionary Grant Program. Funds may be used for work that may be necessary to determine low-carbon cement/concrete eligibility, availability, and appropriateness for use on public projects.[111]

- Supply-side factors
    - Production of ACMs requires new manufacturing facilities which can be capital intensive.
    - As major SCMs are also AAM precursors, supply may have to be increased to address potential demand for low-carbon cement.
    - Concrete producers may need to install additional silos to store additional materials.
    - Workforce training may be needed to test/handle new materials.

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[106] American Concrete Institute. 2024. *ACI CODE-323-24: Low-Carbon Concrete - Code Requirements and Commentary*

[107] County of Marin. *Low-Carbon Concrete Requirements*.

[108] City of Santa Monica. *Low-Carbon Concrete Requirements.*

[109] City of Dublin. *Low-Carbon Concrete Building Code*.

[110] *Supplement Update to the Guide to the 2022 California Green Building Standards Code (CALGreen)-Nonresidential.*

[111] Federal Highway Administration. *Low-Carbon Transportation Materials Grants Program*

- Permitting and other non-economic factors
  - Any new facilities that start producing SCMs or ACMs must go through appropriate permitting process to protect public health, safety and environment.
- GHG emission quantification
  - Barrier description: as cement is an ingredient of concrete, a consistent accounting framework may be needed throughout the cement-concrete-construction value chain.
  - Recent developments to address barriers:

In 2024, U.S. EPA U.S. awarded funding to help develop robust, high-quality environmental product declarations (EPDs) for construction materials including cement and concrete. Awardees included national industry organizations and cement manufacturers.[112]

Potential next steps

Potential next steps can include coordination and collaboration among interested parties to accelerate adoption of new materials including other agencies that have jurisdiction over cement and concrete use, cement producers, alternative material producers, concrete producers, contractors, engineers, architects, public/private project owners, standard/code setting bodies, industry experts, and NGOs.

[112] U.S. Environmental Protection Agency. 2024. *Biden-Harris Administration Announces Nearly $160 Million in Grants to Support Clean U.S. Manufacturing of Steel and Other Construction Materials*

Potential Community Benefits and Opportunities

This section covers SB 596 requirements to identify actions that (1) reduce adverse air quality impacts, and (2) support economic and workforce development in communities neighboring cement plants.

Key questions for feedback

Local air quality is managed by multiple regulations at the local, state and federal level for different types of pollutants and toxics.

- What actions at the local, state, or federal level should be considered to reduce potential adverse air quality or toxics impacts to communities neighboring cement plants?

Two areas for potential job creation related to cement decarbonization have been identified: 1) installation of new carbon capture or power generating units at cement plants, and 2) handling of low-carbon cement in the concrete-construction value chain.

- Are there other job creation opportunities CARB should consider? What kind of frameworks/approaches should CARB consider to promote high quality jobs associated with cement decarbonization?

Air Quality Impacts

SB 596 requires CARB to "identify actions that reduce adverse air quality impacts…in communities neighboring cement plants." Non-GHG emissions, such as criteria pollutants and toxic air contaminants, are governed by multiple regulations implemented by local, state, and federal agencies.

As Table 14 indicates, California's cement plants are in three air districts: Mojave Desert AQMD, Eastern Kern APCD, and Shasta County AQMD.

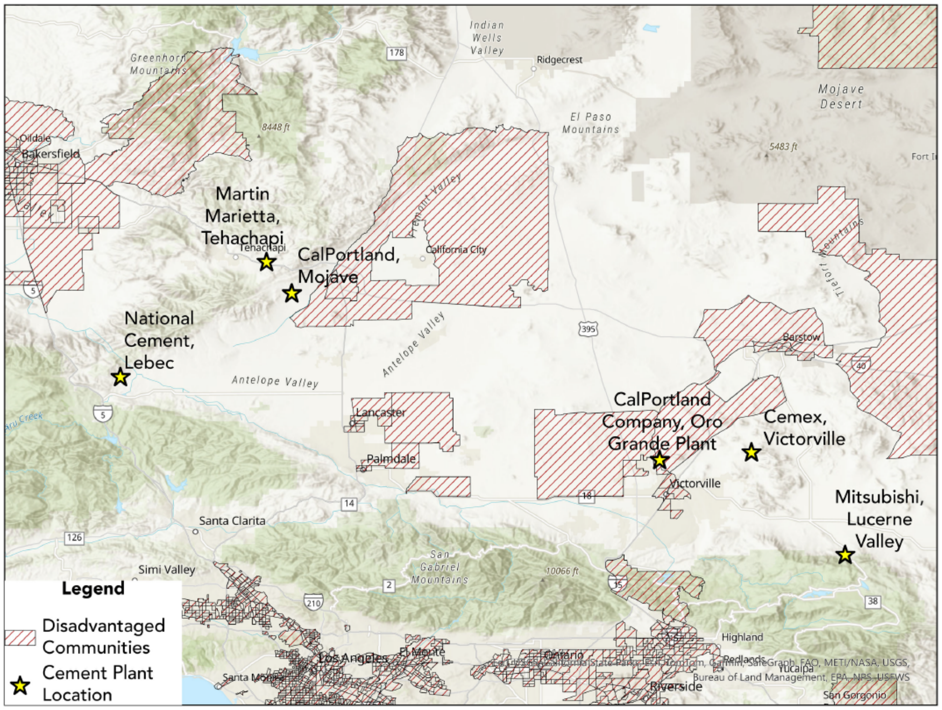
Table 14: California Cement Plant Locations, Air District and Population

Air District	Cement plant	City	Population
Mojave Desert AQMD	Cemex, Victorville	Apple Valley (unincorporated)	75,791
Mojave Desert AQMD	CalPortland, Oro Grande	Oro Grande (unincorporated)	10,357
Mojave Desert AQMD	Mitsubishi Cement, Lucerne Valley	Lucerne Valley	3,562
Eastern Kern APCD	Tehachapi Cement Plant	Tehachapi	8,240
Eastern Kern APCD	CalPortland, Mojave	Mojave	3,394
Eastern Kern APCD	National Cement, Lebec	Lebec (unincorporated)	1,634
Shasta County AQMD	CalPortland, Redding	Redding	85,699

As seen in Table 14 most cities near where cement plants in California are located have small populations (see Figure 10 for population density by county). Some cement plants do not have communities within a five-mile radius. Figure 21 shows the distance of cement plants to disadvantaged communities (represented with crosshatching on the map). Under SB 535, census data and CalEnviroScreen 4.0 scores are combined to determine which communities are designated as disadvantaged in the practical definition of 'Disadvantaged Communities'.[113] One of the seven cement plants is located within a disadvantaged community. CalPortland, Oro Grande is in a subdivision of the unincorporated area of Oro Grande with a population of 1,660, which is a disadvantaged community just outside of the City of Victorville. There are several schools within a mile of the Oro Grande cement plant. There are other large facilities located within a 10-mile radius of this disadvantaged community, including George Air Force Base, High Desert Power plant, and American Organics, a large composting facility. There is also high-density truck traffic associated with a nearby Amazon distribution center and Snapple bottling plant that can impact local air quality. It's also notable that the seven cement plants are in various types of topography, and the terrain can affect how emissions from individual sources contribute to the regional and local air quality.

[113] Senate Bill 535 (De Leon, Statutes of 2012). *Practical Definition* of 'Disadvantaged Communities' Under SB 535.

Figure 21: Locations of Cement Plants in Southern California and Redding Relative to Disadvantaged Communities



As described earlier, California cement plants combust coal, petroleum coke, natural gas, waste tires, biomass, and other types of fuels to process a feedstock that includes minerals and small amounts of metals, and the plants are required to comply with relevant local, state, and federal air quality permitting and environmental rules.

District-wide air quality rules

Criteria pollutants (carbon monoxide (CO), lead (Pb), nitrogen dioxide (NO_2), ozone (O_3), particle pollution ($PM_{2.5}$ and PM_{10}), and sulfur dioxide (SO_2) are the six principal pollutants that can be harmful to public health and the environment. The federal Clean Air Act requires U.S. EPA to set the National Ambient Air Quality Standards for criteria pollutants. CARB is responsible for establishing the State strategy for meeting all its local air quality standards and for adopting regulations and control measures for state-wide sources of pollution. Local air districts are responsible for adopting rules and regulations to attain those standards in their respective districts. Such regulations include control measures on equipment at stationary sources, including cement plants, that emit criteria air pollutants and other pollutants that contribute to the atmospheric formation of criteria pollutants. Generally, regulatory authority over air pollution from specific sectors and sources is split among CARB and the local air districts. Local air districts oversee local air pollutant regulations and permits for stationary facilities, such as cement plants, that are within their jurisdiction. CARB regulates local air pollution from mobile sources in the State, such as cars and trucks.

Areas that do not meet an ambient air quality standard are classified as nonattainment area for the pollutant that does not meet the standard. Mojave Desert AQMD and Eastern Kern APCD are currently nonattainment areas for both ozone and PM_{10}, and Shasta County AQMD is a nonattainment area for ozone. Per Assembly Bill 617 (AB 617, Garcia, Chapter 136, Statute of 2017), air districts with nonattainment status are required to adopt an expedited schedule to implement Best Available Retrofit Technology (BARCT).[114] These requirements apply to all stationary sources within all air districts with nonattainment status. The Expedited BARCT implementation schedules for Mojave Desert AQMD, Eastern Kern APCD, and Shasta County AQMD include control options for the cement plants in their respective districts.[115] However, no district has updated their BARCT requirements for cement because of Expedited BARCT.

AB 617 also established the Community Air Protection Program (CAPP). CAPP's primary focus is to reduce exposure in communities most impacted by air pollution, with a specific focus on local pollutants such as PM and toxics.[116] To date, CARB has selected 19

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[114] CARB. *Expedited BARCT.*

[115] The BARCT Implementation Schedule for each air district is available from the following links: Mojave Desert AQMD. *AB 617 BARCT Implementation Schedule.* Eastern Kern APCD. *AB 617 BARCT Implementation Schedule.* Shasta County AQMD. *AB 617 BARCT Implementation Schedule.*

[116] CARB. 2017. *Community Air Protection Program*.

communities to participate in the CAPP. The intent is to use the lessons learned and pollution reductions strategies in these communities to improve health in burdened communities across the state. There are no cement plants within the communities in the CAPP.

Cement decarbonization projects implemented in California can potentially reduce air pollutant emissions. For example, when high-carbon fuels are replaced by low-carbon fuels, emissions such as NOx and SOx can be reduced, depending on the fuel and process changes. As described in the energy-related GHG reduction section above, there are opportunities for adoption of zero emission technologies, including electrification at cement plants. Where feasible, a transition from on-site fuel combustion to zero emission technologies can reduce or eliminate local emissions associated with combustion. Furthermore, the installation of carbon capture units at cement plants combined with the appropriate control equipment can potentially reduce NOx and SOx concentrations in flue gas, which is the mixture of combustion and process emissions.[117]

Air Toxic Rules

Substances found in fuels or feedstock used by the cement plants, or formed as a result of the manufacturing process, can be released into the air during manufacturing processes and pose health risks. Reducing the impurities in the fuels could limit the amount of air pollutants produced in the flue gas. AB 2588 (Connelly, 1987), the Air Toxics "Hot Spots" Information and Assessment Act, requires local air districts to develop methods to prioritize facilities that release air toxics by considering the potency, toxicity, quantity, and volume of hazardous materials released from the facility, the proximity of the facility to potential receptors, and any other factors that the district determines may indicate that the facility may pose a significant risk. A facility that is ranked as a high priority is required to submit a health risk assessment (HRA) to its local air district. The information related to California cement plants can be accessed using CARB's AB 2588 Air Toxics "Hot Spots" Facility Search Tool.[118] The CalPortland Cement Plant in Shasta County AQMD is classified as 'High Priority' under the 2023 Shasta County AB 2588 Annual Report.[119] The three cement plants located in Eastern Kern APCD are all classified as 'intermediate risk' per the 2022 AB 2588 Report,[120] and two cement plants in the Mojave Desert AQMD are all required to conduct quadrennial public notification to households and businesses that there is the potential of exposure to health risks exceeding the District's public notification level.[121]

[117] Clean Air Task Force. 2023. *Air Pollutant Reductions from Carbon Capture.*

[118] CARB. *AB 2588 "Hot Spot" Facility Tool.*

[119] Shasta County Air Quality Management District. *2023 AB 2588 "Hot Spots" Report*.

[120] Eastern Kern Air Pollution Control District. *2022 Annual AB 2588 Air Toxics Report*.

[121] Mojave Desert Air Quality Management District. *2022 Air Toxics "Hot Spots" Program Annual Report*.

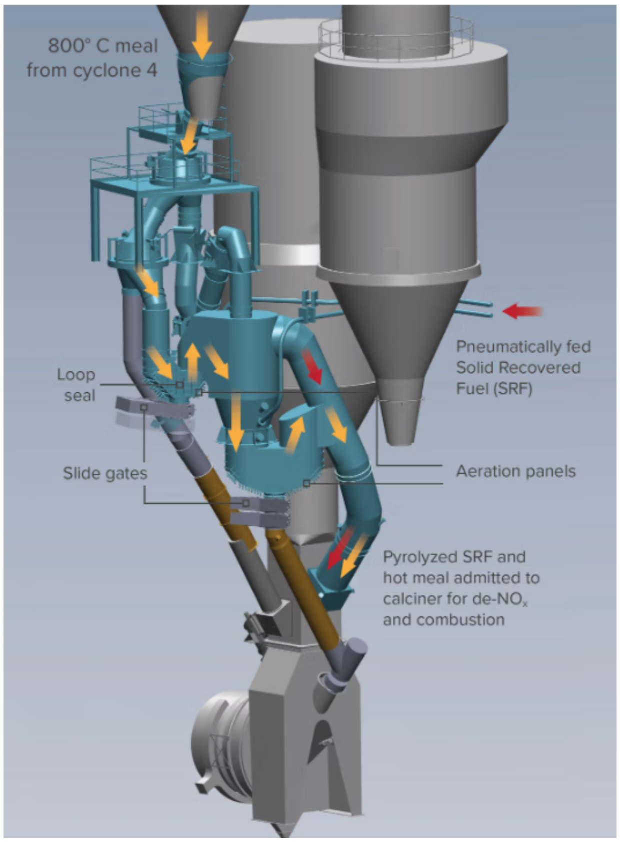
Potential next steps

As detailed above and in the Decarbonization Levers section of the SB 596 Cement Strategy, potential GHG reduction projects can use different types of fuels and substances associated with different potential emission impacts. Stakeholders have expressed concerns over potential increases in local air pollutant emissions or air toxics due to the combustion of waste or fuels with biogenic content, potential increases in VOC emissions from amine-based capture absorbers, and potential increases in NOx emissions due to hydrogen combustion. Potential next steps include CARB's continued coordination with local air districts and as described above in the Feasibility Assessment for Fuels with Biogenic Content there is the potential to use small-scale alternative fuels evaluations with detailed emissions monitoring to better understand test different fuel mixtures gain valuable data on any changes to the chemical composition of their exhaust and potential air quality impacts. It may also be possible to leverage existing regulatory frameworks to ensure pollutant control mechanisms support the improvement of local air quality for a range of potential fuels. Data on potential fuels alone cannot speak to the harmful air pollutant exposure any individual may face. Therefore, understanding the other sources of air pollution that impact a community, or individuals must also be considered when assessing health impacts.

A cement plant in Iowa is switching to primarily alternative fuels and tackling the associated increase in NOx emissions. The case study below is a model for decarbonization via the fuel switching lever while simultaneously reducing adverse air emissions.

CASE STUDY: Alternative Fuel Use and Emissions Reduction Pilot Project

In September 2024, Summit Materials and Green America Recycling's, Davenport, Iowa Cement Plant completed the first pre-commercial installation of the FuelFlex Pyrolyzer system. This 38-million-dollar investment eliminates the need for a complete upgrade of the calciner to handle the switch from fossil fuels to refuse derived fuels and biomass, which have more variability and higher volatility than fossil fuels. High volatile solids include MSW and EMSW, as well as some biomass-based waste streams. The installation also reduces the need for ammonia injection to reach NOx emission compliance. If successful, the pilot project will enable the plant to replace approximately 55% of its fossil fuel use with non-hazardous waste, thereby cutting coal and petcoke consumption by over 50,000 tons annually. The fuel switching is expected to reduce the plant's ghg emissions. This change in fuel and the installation of the pyrolyzer will also reduce NOx emissions and production of waste ammonia water.



FLSmith
FuelFlex Pyrolyzer

How it works:

1. 800 ˚C meal from the lowest preheater cyclones is used as a gasification medium to pyrolyze alternative fuels.
2. Air pulsation fluidizes the hot meal, forming a U-shaped gas lock that prevents pyrolysis gases from flowing backwards.
3. The hot meal stream flows into the pyrolyzer vessel. Refuse derived fuel (RDF) is added and through contact with the hot meal, it is pyrolyzed to form reactive gases and char.
4. The volatile gases and char are separated before being reunited and fed as a very reactive stream into the calciner.
5. The stream of pyrolysis products reacts with rotary kiln NO by so-called "re-burning" reactions, utilizing pyrolysis gases to convert NO into free N2. This project is the first of its kind and in its early stages, more information is expected after its first year in operation.

Workforce Development

SB 596 also requires CARB to identify actions that support economic and workforce development in communities neighboring cement plants. Consistent with the 2022 Scoping Plan Update, such actions could focus on investments and high road job opportunities in communities near cement plants, and especially in low-income communities and communities of color.[122]

At least two areas where SB 596 implementation could support new job opportunities are:

- Installation of carbon capture or power generating units at cement plants, which can result in new construction jobs and new long-term employment opportunities for operation and maintenance.
- Concrete producers, engineers, architects, and construction workers potentially need to acquire new skills to test, specify, and handle low carbon materials blended in cement and concrete. Because cement is consumed throughout the state, new job skills and training opportunities are needed throughout the State for concrete/construction-related workers using lower carbon cement and concrete mixes.

There are already some local initiatives that link workforce development and decarbonization projects. For example, Bakersfield College of the Kern Community College District has a public-private partnership, the Valley Strong Energy Institute,[123] which supports workforce development and growth of regional renewable energy industry. Such platforms/frameworks could potentially be extended or used for workforce development projects related to the cement and concrete industry.

[122] According to the *California Labor and Workforce Development Agency's High Road Training Partnership program*, high road jobs are considered "Quality jobs [that] provide family-sustaining wages, health benefits, a pension, worker advancement opportunities, and collective worker input and are stable, predictable, safe and free of discrimination."

[123] Bakersfield College. *Bakersfield College Valley Strong Energy Institute.*

Action Items to Address Workforce Barriers Identified by the Industry

Workforce education and training has an important role to play in removing barriers for low-carbon cement and concrete acceptance by the construction sector. Below is the list of key action items identified by industry:

- Communicate why low-carbon cement/concrete is needed and provide specific technical training to professionals such as engineers, designers, and tradespeople to equip them with needed skills and knowledge;
- Focus on training tradespeople on concrete mixture optimization techniques, specialized placement procedures for low-carbon construction materials, systems, and other relevant skills required for implementing these new technologies;
- Collaborate with state DOTs, federal agencies, engineering and design firms, trade organizations, industry associations, union halls, and trade schools to ensure the dissemination of technology transfer and skill training resources; and

For the existing workforce:

- Collaborate with organizations and associations serving tradespeople and professionals in the cement and concrete industries to provide training for individuals relevant professionals on cement/concrete decarbonization;
- Train the trainer to deliver continuing education curriculum;
- Focus on training designers, engineers, architects, contractors, and tradespeople initially and offer parallel training directed to owners; collaborate with public/private organizations with technical expertise to deliver training and presentations.

For college-level education:

- Provide applicable reference material and model curricula for faculty to integrate into their courses;
- Develop a cadre of guest lecturers who can visit universities and jump-start programs on cement decarbonization;
- Establish minors or certificate programs and offer scholarships focused on cement decarbonization in construction materials to encourage students to study and specialize in this area; and
- Support summer programs providing intensive study.

Source: Sutter et al. *Overcoming Barriers to Adopting Carbon Reduction in Concrete*. American Concrete Institute.

<u>Potential next steps</u>

Potential next steps can include seeking input from labor unions and experts on workforce development and fostering collaboration among relevant local, state agencies, academic institutions, and other interested parties to identify job opportunities.

Tools, Rules, and Potential Measures to Help Achieve Net-zero Emissions Goals

This section discusses: (1) GHG accounting frameworks to quantify different types of GHG emissions reductions projects, (2) rules that govern cement decarbonization projects and associated permitting requirements, and (3) potential additional measures that can help achieve the goals of SB 596.

Key questions for feedback

- Additional methodologies may be needed to quantify GHG emissions reductions associated with CCUS and as well as the increased use of low-carbon materials to make cement. Should CARB consider specific quantification methodologies or protocols?
- Should EPDs or elements of EPDs have a role in tracking the use of low-carbon cement in concrete?
- The SB 596 Cement Strategy includes an initial list of existing or new programs that can be leveraged to achieve the goals of SB 596. Which programs are simple to administer and/or leverage existing frameworks and programs to facilitate quick implementation in California and elsewhere? Are there additional programs CARB should consider especially at the onset of the implementation?

GHG Accounting Frameworks

To achieve net-zero emissions in the cement sector, a suite of GHG emissions reduction efforts will need to be implemented by incumbent cement manufacturing plants, alternative material manufacturing plants, facilities or sites that use or sequester carbon captured at cement plants, and by cement users throughout the concrete-construction value chain. Because different project types may require different accounting frameworks, it is critical to develop an overarching framework that can appropriately account for GHG emissions throughout the cement-concrete value chain.

<u>On-site GHG emissions reduction projects</u>

As production of conventional limestone-based cement requires substantial amounts of energy and is also associated with process emissions, the goal of SB 596 is to achieve net-zero emissions associated with manufacturing of cement consumed in California. To achieve this goal, incumbent cement manufacturers may implement projects such as fuel-switching or energy efficiency. Seven incumbent cement plants in California are already covered by the Mandatory Reporting Regulation (MRR) and report GHG emissions (both energy-related and process emissions) and production data using rigorous methodologies harmonized with U.S. EPA's GHG emissions reporting program. Reported data are verified by CARB-accredited third-party verifiers. On-site GHG emissions can also be reduced by decreasing the production of limestone-based clinker by replacing ACMs or SCMs with lower GHG emissions intensity. If an ACM and/or SCM were produced in California, the producer will be covered by the MRR if their annual emissions exceed 10,000 $MTCO_2e$.[124] In addition, an initial concept to include cement importers in the MRR and require them to report GHG emissions associated with imported cement was introduced at a workshop in Spring 2024. Such a provision would enable CARB to quantify GHG emissions associated with imported cement used in California.[125]

Carbon capture, use and sequestration (CCUS)

GHGs emitted at cement plants could potentially be captured, transferred to be used or sequestered. Any potential reporting, monitoring, and verification for options under this category will need to be in compliance with regulations developed by CARB to implement SB 905. Once carbon dioxide is captured at cement plants, there are multiple options to contribute to emissions reductions through various types of carbon sequestration. This includes the potential to sequester CO_2 in geological formations or mineralize it in rocks that can be used as either aggregate or SCM products. For these projects to be eligible to contribute to SB 596 decarbonization, emissions reductions will need to meet permanence standards and be quantified using robust and consistent quantification methodologies. This includes: 1) the amount of carbon dioxide captured at cement plants, and 2) the fraction of captured carbon that was used and/or sequestered.

There may be other types of carbon capture and use projects, such as using captured carbon dioxide to make transportation fuels, at the end of which carbon is released into atmosphere.

In addition, there may be potential carbon dioxide absorption projects in which ambient carbon dioxide is absorbed by concrete in use or residual minerals generated from alternative cement manufacturing. These projects could require different accounting frameworks as project scope and methodologies to quantify the amount and permanence of absorbed carbon dioxide developed for geologic sequestration projects may not apply.

As different CCUS project types may be associated with different accounting frameworks, it is important to ensure that they conform to the equivalent level of project and quantification stringency.

Quantification of GHG emissions reductions associated with increased use of low-carbon cement

[124] If their annual emissions were below 10,000 MTCO2e, they could still opt-in to the Cap-and-Trade Program to report GHG emissions through MRR.

[125] CARB. 2024. *Cap-and-Trade Workshop May 31, 2024. Staff Presentation.* Slide 50-52.

Cement and/or alternative materials shipped to concrete producers or other cement users to finalize cement is associated with embodied GHG emissions. Downstream cement users can indirectly contribute to SB 596 goals by increasing the use of low-carbon cement, which will in turn decrease demand to produce emissions-intensive limestone-based clinker.

As discussed above, on-site GHG emissions associated with cement manufacturing, and potential GHG reductions from eligible CCUS or carbon absorption projects must be quantified accurately to be counted toward SB 596 goals. On the other hand, potential GHG emissions reductions from increased use of low-carbon cement will have indirect impact and not be counted towards net-zero emissions goals. However, estimating such reductions is critical to track and evaluate the progress to achieve the goal, as it will inform how fast market demand for low-carbon cement would increase toward 2045. It is critical for the concrete-construction value chain to shift from limestone-based cement to low-carbon cement, and such a shift must be closely monitored and incentivized.

For entities on the concrete-construction value chain, embodied GHG emissions associated with cement are upstream emissions. Environmental product declaration (EPD) is a tool to account for life cycle environmental impacts, including upstream emissions, associated with commonly used products such as cement and concrete. It is defined by ISO 14025 Type III (Environmental labels and declarations — Principles and procedures) based on which product category rules (PCR) are developed to specify how to quantify impacts such as GHG emissions associated with a given product. Conventional cement and concrete both have existing PCRs.

In recent years, environmental product declarations (EPD) are increasingly used as a policy tool to quantify embodied GHG emissions and/or set GHG limits allowed per unit of materials for construction/building materials. For example, the Buy Clean California Act (BCCA) used publicly available EPDs for four materials (structural steel, concrete reinforcing steel, flat glass, and insulation) commonly used in public works to set maximum acceptable limits of embodied GHG emissions. While improvements are needed, EPDs can serve as a benchmark for the data available to quantify embodied carbon for different products in the absence of robust data.

SB 596 could also leverage embodied carbon accounting through EPDs or elements of EPDs to quantify indirect GHG emissions reductions associated with the use of low-carbon cement. In doing so, it is important to acknowledge the difference between direct emissions quantification methods, such as MRR and EPDs. Whereas CARB's verified data collected through MRR uses primary, facility-specific information measured at covered facilities annually, EPDs typically use primary and secondary data, which could be aggregated and averaged by third parties as industry-wide values. This means that cement manufacturing-related GHG emissions for a concrete EPD could be based on secondary data compiled from third-party data sources. Depending on the source, the data used could be from a different set of manufacturing facilities, employ different quantification/estimation methodologies, and used different data years, all of which make apples-to-apples comparisons challenging. Also, embodied carbon data may not be updated annually or may be subject to varying quality assurance and verification requirements. Additionally, if an EPD includes emissions reductions achieved by offsets or CCUS projects, it will need to meet relevant California requirements, including any applicable SB 905 requirements.

There is an increasing number of regulations and programs at federal, state and local level that use or plan to use and improve portions of EPDs as a tool to quantify GHG emissions and/or set GHG emissions intensity associated with building materials, including concrete. Examples include AB 43 (Embodied Carbon Emissions for Construction Materials), Buy Clean California, CalGreen Embodied Carbon Requirements, SB 253 the Climate Corporate Data Accountability Act and local low carbon concrete Requirements.[126] Multiple efforts led by federal/state/local agencies, industry associations, NGOs and businesses are underway to improve the quality of EPDs. In 2024 U.S. EPA provided grants to 38 groups including organizations in the cement/concrete industry to help businesses develop robust, high-quality EPDs.[127] It will be critical for CARB to ensure that GHG emissions associated with materials used to make cement are quantified in a consistent manner across programs.

It is also notable that embodied emissions accounting used by the concrete-construction value chain can contribute to identifying alternative materials that can have the least environmental impacts. For example, conventional byproduct SCMs, such as fly ash and GGBFS, are associated with emissions-intensive upstream industrial activities, such as coal-fired power generation or primary steel manufacturing. EPDs could potentially identify substitutes for them by comparing total environmental impacts among different alternative materials.

Rules that Govern GHG Emissions Reduction Projects and Associated Permitting Processes

The array of available emissions reduction options for the cement sector are subject to different rules administered by different local, state, and federal regulatory agencies, as well as private standard/code setting bodies. As one of the SB 596 requirements is to identify statutory and regulatory barriers that may delay implementation of potential decarbonization projects, we take a holistic view of all relevant rules.

It is expected that existing cement plants will implement on-site emissions reduction projects, such as adding carbon capture equipment or modifications of existing

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[126] CARB. *Embodied Carbon*. Department of General Services. *Buy Clean California Act*. Department of General Services. *California Green Building Standards Code 2022 Title 24, Part 11. Revision Record Supplement.* County of Marin. *Low Carbon Concrete Requirements.*

[127] For details, see "Funding Opportunities" section.

equipment/practices. It is also possible that facilities that manufacture ACMs or SCMs start or expand operations in California. These projects will be subject to permitting requirements that regulate construction of new facilities or modification of existing facilities. First, conditional land use permits are generally needed to start or change operations at a site, and the city or county in which the project is located is typically the authority for this type of permit. Conditional land use permits are generally discretionary approvals that trigger the California Environmental Quality Act (CEQA), which may be applicable to any new project or modification/expansion. CEQA requires a rigorous review process to foster transparency and integrity in public decision-making while ensuring land-use decisions account for the impacts of development on our natural and human environments. Under CEQA, a lead agency, must prepare an environmental impact report for a construction project, which needs to be considered by all relevant state and local agencies during the project's permitting process.

Once a facility transitions to the operation phase, a facility is required to obtain operating permits from its local air district to limit criteria air pollutant emissions pursuant to the federal Clean Air Act. In addition, a local air district may determine that a facility is subject to the requirements of Air Toxics "Hot Spots" Information and Assessment Act for toxic substances it might release.[128]

For GHG emissions, all seven cement plants in California are currently subject to CARB's MRR and Cap-and-Trade Regulation, which require them to report their GHG emissions and participate in a market-based emissions reduction program. A facility that manufactures low-carbon alternative materials in California will also be subject to MRR if its annual GHG emissions are greater than 10,000 $MTCO_2e$, and subject to the Cap-and-Trade Regulation if its annual GHG emissions are greater than 25,000 $MTCO_2e$.

When a cement plant in California uses a municipal solid waste-derived fuel, it must acquire a solid waste facility permit through a process co-regulated by CalRecycle and local enforcement agencies.[129] There may be additional permits a facility needs to obtain depending on the operations or processes, which would require additional administrative process.

Cement plants use substantial amounts of energy which is supplied by relevant utilities. California cement plants currently purchase electricity from investor-owned utilities and electric service providers that are regulated by the California Public Utilities Commission (CPUC). Lower carbon sources of energy such as renewable electricity or renewable natural

[128] California Air Resources Board. Air Toxics "Hot Spots." "Hot Spots." *Prioritization Program*.

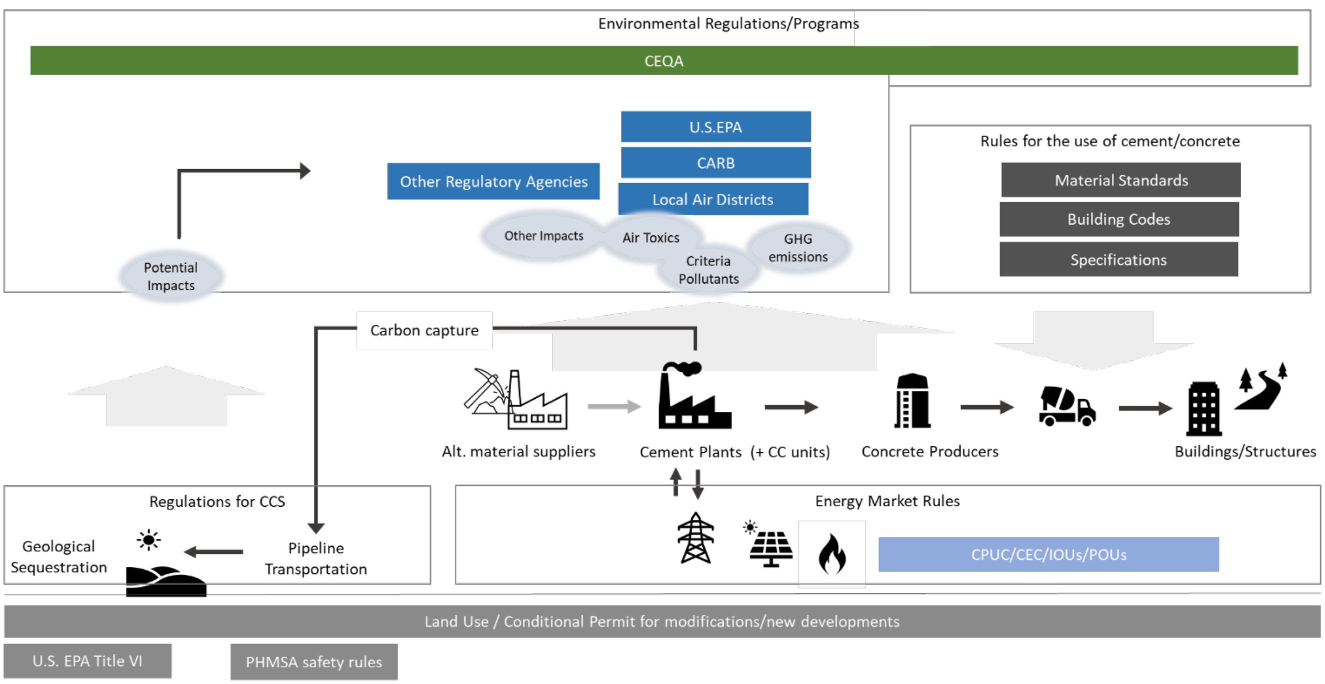
[129] Department of Resources Recycling and Recovery (CalRecycle). *Solid Waste Facilities, Sites, and Operations page*.

gas, as well as any energy-related activities on-site, may be subject to rates and rules set by the CPUC.

Furthermore, the use of cement and concrete are governed by multiple material specifications, building codes, and specifications. Materials used to make cement and concrete must conform to material standards set by national or international organizations, such as ASTM and AASHTO, to ensure performance. Construction of buildings and structures must conform to building codes written by the ACI, which are included in the International Building Code (IBC) and adopted as the California Building Code in California or by local governments. Project owners and contractors write specifications for construction projects. Specifications written by Caltrans are widely referenced by the local construction industry in California.

As shown in Figure 22, a single cement decarbonization project can require multiple permits and must comply with applicable rules, each of which can require time and resources. Each permit process and rule are governed by different authorities with different timelines. SB 596 offers the opportunity to discuss if there are pathways to make the overall permitting framework or other processes more efficient and to share knowledge among permitting agencies about new and emerging technologies.

Figure 22: Illustrative Examples of Rules Governing Cement Decarbonization Projects



Overview of Rules Governing CCS Projects

Permitting carbon capture and sequestration (CCS) projects can be especially complex. As no geologic sequestration project has yet been approved in California, there are uncertainties about the potential lead time and resources needed to obtain permits for that type of operation. To help streamline CCS project applications in California, SB 905 directs CARB to develop a unified permit application process for sequestration projects. All CCUS projects in the state will be subject to the SB 905 framework, which is currently under development.

In addition to complying with applicable CEQA requirements, a geologic CCS project needs to obtain permits from U.S. EPA under the Safe Drinking Water Act's Underground Injection Control (UIC) Class VI well program, which has five phases:

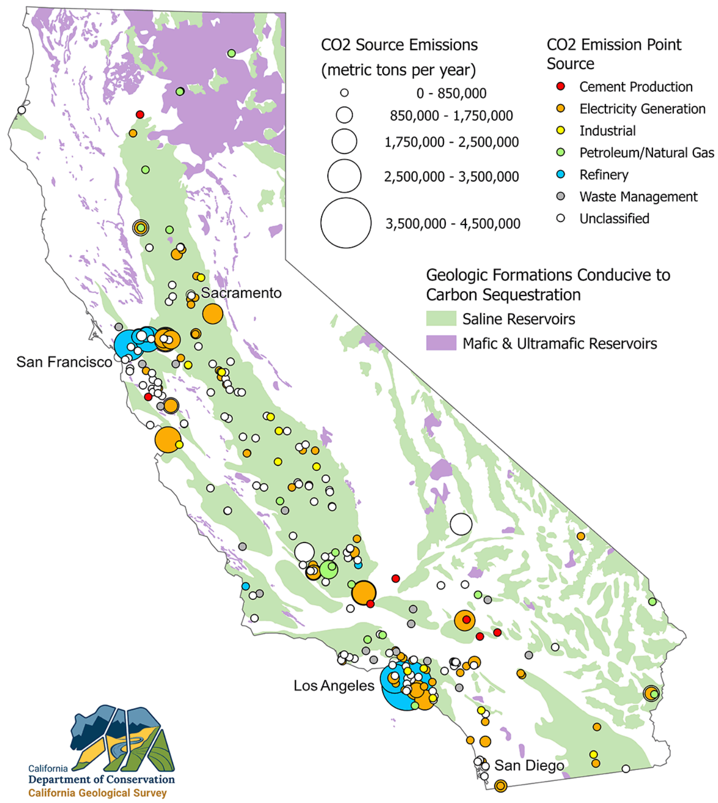
1. Pre-permitting phase: The prospective owner or operator notifies the permitting authority of their intent to prepare a Class VI permit application.
2. Pre-construction phase: The permitting authority will perform a thorough review of every component of the detailed permit application with a minimum 30-day public comment period.
3. Pre-operation phase: If a permit is issued, the Class VI well operator constructs the well, performs pre-operational testing, and submits additional information before they are authorized to inject CO_2.
4. Injection phase: Owners or operators begin operation of the injection well and perform testing and monitoring.
5. Post-injection phase: The Class VI well owner or operator plugs the injection well.

U.S. EPA aims to review complete Class VI applications and issue permits when appropriate within approximately 24 months.[130] The actual time needed for the review process depends on several factors, such as the complexity of the project, technical detail to ensure the proposed project will not endanger underground source of drinking water, and the quality and completeness of the submitted application. Once the technical review determines that the permit application meets the requirements of the Class VI Rule and the proposed project is suitable for CO_2 injection, a draft permit will be prepared with specified conditions under which the well would be able to operate. It is followed by a public comment period before the final permit is prepared with modifications based on feedback received during the Public Comment Period, where appropriate.[131]

In terms of potential geologic sequestration sites near California cement plants, Figure 23 shows a map of California's geologic carbon sequestration potential published by the California Department of Conservation. The map includes the locations of cement plants (red dots). It's likely that CO_2 captured at cement plants will need to be transported to a geologic storage site rather than sequestered on-site.

[130] US Environmental Protection Agency. 2024. *Class VI- Wells used for Geologic Sequestration of Carbon Dioxide*.

Figure 23: California's Geologic Carbon Sequestration Potential[132]



Per the requirements of SB 905, if CO_2 captured at cement plants is transported to injection sites via pipelines, such transportation projects cannot happen in California until the U.S. Pipeline and Hazardous Materials Safety Administration (PHMSA) concludes a rulemaking (RIN 2137-AF60) on safety standards for pipeline transportation of carbon dioxide. This rulemaking process was initiated in 2022. In January 2025, PHMSA announced new and comprehensive proposed requirements for carbon dioxide and hazardous liquid pipelines.[133] The rulemaking is currently open for public comment and will close in March of 2025.

Addressing Emissions Leakage

SB 596 requires CARB to “include provisions to minimize and mitigate potential leakage and account for embedded GHG emissions in imported cement in a similar manner to emissions of GHGs for cement produced in the state, such as through a border carbon adjustment mechanism.” AB 32 passed in 2006 first defined emissions leakage as “a reduction in GHG

[132] California Department of Conservation. *Geologic Carbon Sequestration in California.*

[133] US Department of Transportation. *USDOT Proposes New Rule to Strengthen Safety Requirements for Carbon Dioxide Pipelines*. January 2025.

emissions within the state that is offset by an increase in GHG emissions outside the state." In 2017, AB 398 (Garcia, Chapter 135, Statute of 2017) was passed to extend the Cap-and-Trade Program, an AB 32 program. It also required CARB to report to the Legislature, by December 31, 2025, on the program progress and recommend necessary statutory changes to the program to reduce emissions leakage, including the potential for a border carbon adjustment.

In California, the cement sector is covered by the Cap-and-Trade Program, which requires covered entities to acquire and surrender compliance instruments (allowances or a limited quantity of offset credits) that match their covered GHG emissions. Compliance instruments are either directly allocated to covered entities or purchased by covered entities, which means that there can be costs associated with complying with the Cap-and-Trade Program. Generally, there is a risk for emissions leakage if production from California cement plants shifts outside of California due to regulatory compliance costs and the production is replaced by imported cement. Currently, the Cap-and-Trade Program provides direct allowance allocation to minimize the risk of emissions leakage in covered industrial sectors. A border carbon adjustment (BCA) is an alternative to direct allowance allocation that could be used to minimize leakage. In principle, a BCA imposes an obligation on the importer of a product based on the GHG emissions associated with producing the product. In May 2024, CARB put forward an initial concept to have cement importers report GHG emissions as one step in evaluation of a potential BCA as required by SB 596.[134]

The European Union (EU) puts a price on GHG emissions from industrial facilities via the EU Emissions Trading System, and the EU is the first jurisdiction to implement a carbon border adjustment (CBAM).[135] The CBAM took effect in October 2023 to cover emissions associated with on-site direct emissions and emissions associated with the use of electricity for cement, iron and steel, aluminum, fertilizers, electricity, and hydrogen. The first two years of CBAM is a transitional period during which importers of covered products must (1) register with national authorities, and (2) report the amount of production and GHG emissions associated with imported goods. There is no mandatory verification of reported data nor compliance obligations associated with imported products during this period.

[134] California Air Resources Board. *California Public Workshop: Potential Amendments to the Cap-and-Trade Regulation*. May 2024.

[135] The European Parliament. *Carbon leakage: preventing firms from avoiding emissions rules*. Final CBAM regulation can be accessed at the *Official Journal of the European Union*.

Existing and New Potential Policy Mechanisms

Previous sections identified barriers and current policy frameworks that govern each cement decarbonization lever and technology option. This section identifies a range of potential programs, voluntary actions, funding opportunities, and collaborations to address identified barriers of market acceptance, resource maturity, license to operate and lack of GHG quantification methods. The list includes options identified by CARB, as well as suggestions from interested parties. The evaluation of these options will be completed based on public input. As SB 596 is a long-term project, it's possible that new types of programs may be considered in the future.

Key questions for feedback

- Are there additional policies or programs that should be considered?
- Which potential programs should be prioritized and why?
- In addition to program effectiveness, administrative simplicity and implementation considerations, what other factors should CARB consider in identifying potential policies or programs that should to be prioritized?

Among potential programs, some existing programs can be leveraged as is, while others may require modifications or legislative action. CARB implements the majority of state-wide climate programs based on legislative mandates, regulations and policy direction in the most recent Scoping Plan. Some of these policies and requirements directly regulate or indirectly affect the cement manufacturers in California. At the same time, federal, state, and local agencies implement a variety of programs that regulate local air pollutants, cement and concrete used for construction projects and aspects of permitting and oversight of CCUS projects.

As discussed above, the SB 596 Cement Strategy aims to prioritize programs that are administratively simple and easy to implement, given the urgency to act quickly and create frameworks that can be used and implemented by other sectors or jurisdictions. To that end, different programs and voluntary actions face different degrees of time and resource requirements for implementation. For example, both CARB and other agencies can potentially implement regulatory programs, each of which will require an independent rulemaking process by the lead agency. During the public rulemaking process, the lead agency must address a variety of questions including the efficiency and effectiveness of the potential program implementation, potential economic impact on regulated communities and the state economy, and environmental impacts on local and/or disproportionally affected communities. Some identified programs may require additional legislative action. On the other hand, voluntary actions and collaborations do not require rulemaking processes and can generally be undertaken sooner but may not be sufficient to support the commitment and transparent actions needed to decarbonize the sector.

Some interested parties recommend implementing annual or bi-annual carbon intensity targets for cement produced in-state and imported into California from 2026 to 2035 to ensure that the SB 596 interim target is achieved. This approach may be infeasible as it presumes annual steady declines are achievable, where past experience shows incremental progress in the industrial sector emissions reductions are possible and that large reductions in GHG emissions generally occurs in stages with the implementation of decarbonization technologies.

Potential programs to address demand-side factors

Demand-side focus factors include demand uncertainty, market barriers to entry, limited or non-existent market for low-carbon products, and the lack of a path to deliver product from a producer to a customer along the value chain.

Energy-related decarbonization

New policy/supporting frameworks may be needed to facilitate industrial customers to access emerging fuels with limited supply or increased amount of electricity.

- Targeted support or policies may be needed to direct biomethane use to the industrial sector from its current use in the transportation and residential sectors.
- Targeted support or policies may be needed to support hydrogen use. SB 1075 Hydrogen Development, Deployment and Use (CARB): SB 1075 requires CARB to prepare an evaluation that includes policy recommendations regarding the use of hydrogen and a description of strategies supporting hydrogen infrastructure. The evaluation report will cover the development, deployment, and use of hydrogen across all sectors in California, which may inform how hydrogen can become available for the cement industry.
- Electricity rate structure may need to be changed to incentivize industrial customers to promote electrification.[136]

Increased use of low-carbon cement and concrete

As more than 75% of cement manufactured in California is used to make concrete, concrete/construction market must quickly adopt low-carbon cement.

- Demonstration projects to validate the performance of emerging low-carbon cement and concrete will increase market confidence to accelerate adoption.
- Caltrans has an existing process to write specifications and evaluate and approve new materials for use in Caltrans projects. It is possible that Caltrans could expedite the process to transition to performance-based standard and evaluate

[136] See page 53, AB 2109 exempts large industrial customers from paying certain surcharges on their reductions in electricity use if that reduction was achieved through an industrial process heat recovery technology with specified requirements.

low-carbon materials for approval. See Appendix B for details. It is also possible for Caltrans to carry out demonstration projects for emerging low-carbon cement/concrete.

- Global Warming Potential (GWP) limits for concrete could be tightened in CALGreen Embodied Carbon Requirements to achieve GHG reductions in eligible projects.
- Under the BCCA, DGS sets the maximum acceptable GWP limit for eligible products. Concrete could be added as an eligible product.
- Local authorities could adopt a low-carbon concrete building code similar to the ones adopted by Marin County, City of Santa Monica and City of Dublin.
- Construction material bidding requirements can include provisions to provide incentives for low-carbon cement/concrete per unit of volume purchased.

CASE STUDY: Minnesota DOT Demonstration Project

Demonstration projects can remove market acceptance barriers by testing how low-carbon materials perform in a real-world environment. However, they also require significant collaboration and investment. Two such collaborations are highlighted below.

MnROAD, owned and operated by the Minnesota Department of Transportation (MnDOT), is a 3.5-mile-long pavement-research test track made of various materials and pavements that receives high-volume interstate highway traffic. It is used as a demonstration space to test materials to improve road life, perform better, cost less to ... nment.

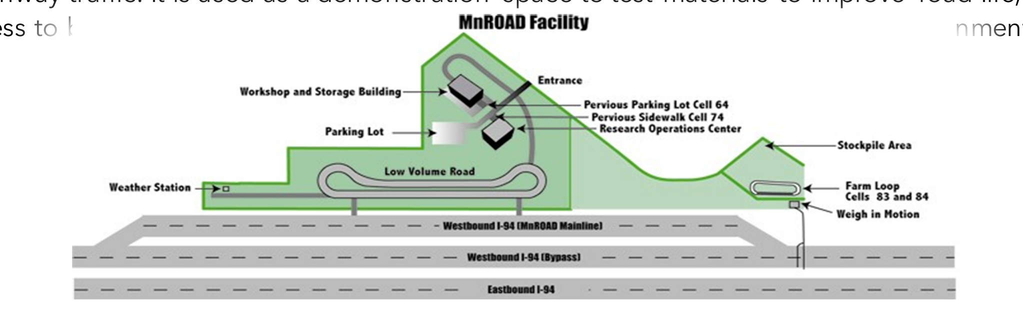


Figure 1: MnROAD Facility Layout

The project started in the 1980's as a task force that included MnDOT, Federal Highway Administration (FHWA) and Strategic Highway Research Program administrators, industry representatives and university experts. The first test sections were constructed in early 1990's funded by state and federal sources. A partnership between MnDOT and the Minnesota Local Road Research Board (MRRB) provided most of the operations funding for the first ten years. Over time the MnROAD facilities and data have been used by researchers from around the nation and the world. In 2022, MnROAD started testing alternative low-carbon concrete-making materials. Tested materials included blended cement using calcined clay or natural pozzolan, Portland limestone cement with higher limestone content, and cement with carbon mineralization technology. It is expected that the project will produce multi-year results on how alternative cements behave in real field conditions in the next few years.

The funding for this phase of the research, test cell construction, and improvements in the data systems, cost about $11 million dollars and came from eleven different contributors including in-kind contributions from industry partners, other states, the LRRB, FHWA and MnDOT.

One lesson learned is that it is critical to establish a well-balanced partnership/funding structure to construct testing tracks and operate them for an extended period to obtain reliable test results.

CASE STUDY: UC Pavement Research Center Demonstration

In California, University of California Pavement Research Center (UCPRC) launched the Sustainable Concrete Lab2Slab initiative in 2024 with support from industry, the American Concrete Institute Foundation (ACI Foundation), California Department of Transportation (Caltrans), and Department of Energy (DOE). The goal of the initiative is to accelerate the adoption of more sustainable and higher performing solutions in infrastructure projects from decades to a few years by advancing the evaluation of novel low-carbon materials and technologies for concrete, beginning with at the laboratory scale and progressing to constructing test beds as the technology scales up.

The next step focuses on transitioning these technologies from test beds to pilot scale, during which phase low-carbon materials will be tested in real-world street or highway sections to validate the performance. The resulting data will be published to help involved agencies to develop or revise specifications, as well as transitioning pilots into standard practice.

Potential programs to address supply-side factors

Supply-side focus factors include the need for significant capital investments to achieve production on a commercial scale and lack of adequate infrastructure. Funding can play a pivotal role to provide needed resources for emerging decarbonization technologies. See the following section for funding opportunities.

Increase supply of low- or zero-carbon fuels and electricity

Additional generation capacity for renewable electricity and/or biomass conversion will be needed to increase supply of low-carbon fuels and hydrogen production.

Increase the use of low-carbon cement

Currently, most alternative cementitious materials (ACMs) are still in the research, development, and demonstration phase. Product prices for these materials during the initial production stages are expected to be substantially higher than conventional cement, reflecting high costs for development. Higher product prices generally limit demand, which is a barrier to achieving wide commercialization. As ACMs have never been produced on a commercial scale, some interested parties recommended potential programs to accelerate their commercialization. For example, several environmental groups have suggested new types of credit trading programs under which cement manufacturers are required to purchase credits based on GHG emissions intensity performance standard. The revenue would be used to accelerate low-carbon cement production in California. Establishing a market-based program requires significant resources to establish, develop technical infrastructure, and continuously implement, and thus is a more effective option for a large market with many participants. There are currently less than five companies operating the seven in-state cement plants, making a establishing a resource-intensive trading program less cost-effective and infeasible due to small market size. Requiring participation in a market-based program by small entities, like concrete batch plants, is likely infeasible due to the administrative resources needed to participate in such a program. In addition, the seven in-state cement plants are already covered by a market-based program, the California Cap-and-Trade Program. In recognition of the requirement in SB 596 to reduce the costs of implementing GHG reduction technologies and the overall benefits that can be gained in leveraging existing programs, the SB 596 Cement Strategy highlights actions that the Cap-and-Trade Program can take to support the goals of SB 596. A simpler approach to design and implement a GHG reduction strategy also makes it more exportable to other regions where staffing resources may be limited. With these objectives and limitations in mind, below are two approaches suggested by interested parties.

- Zero Emissions Cement (ZEC) Standard: The objective of a ZEC standard is to trigger investment and construction of a first-of-kind near-zero emissions cement production facility in the near-term, such as in the 2025-2030 timeframe. A ZEC Standard is a market-based program based on crediting relative to a very stringent (near-zero) GHG emissions intensity performance standard for cement. A plant that meets the near-zero emissions performance standard generates ZEC credits for each ton of near-zero cement produced. Producers/sellers of conventional limestone-based cement are required to hold a fixed amount of ZEC credits for every ton of limestone-based cement they sell. As credits are tradable near-zero emissions cement producers could sell ZEC credits to conventional cement plants to generate revenue. The number of ZEC credits conventional cement producers/sellers are required to hold can start at a low percentage (~10%) of the amount of limestone-based cement sold and can gradually increase to ensure that there is a market for alternative cement until they reach full commercialization.
- Low-carbon Cement Standard: A low-carbon cement standard is a market-based program based on crediting relative to a GHG emissions intensity performance standard for cement. The standard can increase in stringency over time. Companies that make cement with an emissions intensity below the benchmark generate credits, whereas companies that produce cement with an emissions intensity above the benchmark must acquire and surrender credits.

Alternatively, funding can directly come from future buyers of ACMs. Advanced market commitments and/or offtake agreement can create long-term demand for nascent ACMs to provide steady financial support to realize commercialization. For programs that involve public purchasers of cement or concrete, leading authorities may be local/state agencies responsible for public procurement. Private companies can also enter into agreements.

- Advanced Market Commitments (AMC): An AMC is aimed at accelerating the development and market entry of emerging products, typically ones that are close to commercialization. It takes the form of a legal contract that guarantees purchase if the product is successfully developed, delivered, and satisfied agreed-upon requirements. If used for concrete, an AMC can send a signal that there will be a market for low-carbon alternatives rather than conventional limestone-based cement. AMCs could potentially be adopted in both the private and public sectors. Commitments by public agencies are also called advance procurement commitments (APC).

- Offtake agreements: An offtake agreement is an agreement between a producer and a buyer to purchase some of a producer's goods that haven't yet been made. As it may be negotiated before the construction of manufacturing facilities and before production begins, it can provide financial certainties for companies that are transitioning from RD&D phase to full-scale production. It can also guarantee buyers the supply of a product in anticipation of future demand.

Mechanisms that provide financial incentives can help accelerate commercialization of different decarbonization technologies. It may be possible to leverage funding from businesses outside the cement value chain to achieve the economies of scale necessary for cement decarbonization technologies through emerging approaches that enable businesses to purchase emissions reductions achieved by low-carbon cement production. This approach may not be applicable in California because cement sector emissions are under the cap and therefore cement sector emissions reductions achieved in California could potentially be double counted in other jurisdictions.

- Book-and-claim allows low-carbon product producers to "book" the emissions savings of a good they've produced in one place, and customers to "claim" the emissions benefit from these goods for climate disclosures in a different place. Any such scheme will need guardrails to ensure there is no double counting of emissions toward the state's climate targets.

Potential programs to address permitting and other non-economic factors

License to operate barriers include the complexity and resource requirements to fulfill local, state, and federal regulations or other requirements/standards, concerns for hazardous side effects or adverse events inherent to the production, transport, or use of the technology solution or product in the absence of sufficient controls, and concerns from local communities.

CCUS

- SB 905 Carbon Capture, Removal, Utilization, and Storage Program: SB 905 requires CARB to evaluate, demonstrate, and regulate CCUS. It is expected that GHG quantification protocols for CCUS projects will be developed in alignment with the requirements of SB 905, which can be applicable to cement-related projects. SB 905 also requires CARB to establish a unified permit application process for the construction and operation of CCUS projects.

Potential air pollutant emissions reductions from decarbonization projects

CCUS and fuel switching

- Updates to plants could trigger BACT/BARCT, which could require plants to upgrade and update their emission control systems across the plant, not only systems related to new CCUS infrastructure.
- New fuels may trigger AB 2588 new source review, which could result in updated emission limits and permits.
- Alternative fuel use could require Title V permit updates from the local air districts, which could lead to changes in emissions limits for criteria and hazardous air pollutants.

Permitting

- In addition to developments under SB 905, potential CARB-developed information repository on cement decarbonization as a resource for interested parties, including permitting authorities.

Potential programs for GHG quantification

GHG quantification frameworks and requirements may be needed when there is the lack of an overarching framework to quantify, report, and verify GHG emissions reductions and removal projects in a consistent manner throughout the cement-concrete-construction value chain.

- Quantification protocols for CCUS are expected to be developed as part of the SB 905 implementation process.
- AB 43/AB 2446 will have a role in determining how to quantify embodied carbon in construction materials including concrete.

Potential programs to minimize risks of emissions leakage

The Mandatory Reporting Regulation and Cap-and-Trade Program directly regulate reporting and GHG emissions from California cement plants.

- MRR: The regulation requires stationary sources that emit a minimum of 10,000 $MTCO_2e$ per year to report their annual GHG emissions to CARB. California’s cement plants have been reporting their emissions and production data to CARB since 2009.

- California Cap-and-Trade Program: A market-based GHG emissions trading system that covers large stationary emission sources emitting a minimum of 25,000 $MTCO_2e$ per year and puts a price on GHG emissions by requiring covered facilities to acquire and surrender tradable compliance instruments to cover their GHG emissions. The carbon price imparted by the Cap-and-Trade Program is California's primary policy tool to incentivize decarbonization of in-state industrial facilities. However, the carbon price imparted by the Program may also increase the risk of emissions leakage, defined by AB 32 as a decrease in GHG emissions in-state that is offset by an increase in out-of-state GHG emissions. Cement plants in California have been covered by the Program since 2013. To fulfill legislative requirements to minimize emissions leakage, the Cap-and-Trade provides free allowances to specific covered industrial facilities including cement plants.

- CARB proposed the following initial concepts for potential changes to the Cap-and-Trade and MRR regulations in Spring 2024 that are applicable to SB 596:
  - MRR: Potential inclusion of reporting by cement importers of amount of cement and associated GHG emissions.
  - Cap-and-Trade Regulation: Modification of the product definition for the cement sector eligible for direct allocation to include alternative cementitious materials (ACMs) and supplementary cementitious materials (SCMs) used to finish cement. This would provide an equivalent level of emissions leakage protection and incentives for low-carbon materials produced in California and used to make cement.

Funding opportunities

Funding programs provide critical support for emerging decarbonization technologies that are at research, development, demonstration and pilot phase to address resource maturity barriers especially for CCUS and alternative low-carbon materials. Table 15 identifies recent funding opportunities and selected/awarded projects relevant to CCUS and cement decarbonization. CARB is closely monitoring the awarded projects to understand how decarbonization technologies are developing and achieving commercialization.

There is a need for additional funding for California facilities and projects to achieve the needed economies of scale to help achieve zero-emissions goal in a timely manner. To align future California funding with the requirements of SB 596, such funding could include requirements to address adverse air impacts and workforce development.

Table 15: List of Federal/State Funding Opportunities Related to Industrial Decarbonization

Funding Opportunity	Agency/ Statute	Deadline	Available Funding ($million)
Industrial decarbonization / Federal			
Industrial Demonstrations Program to fund energy-intensive industrial subsectors decarbonization through transformational, commercial-scale demonstration projects.	DOE / IIJA, IRA	8/11/23	6,000
Selected/awarded projects • *Calcined Clay Production for Limestone Calcined Clay Cement* Roanoke Cement Company, LLC (Up to $61.7 million - Troutville, Virginia) • *Mitchell Cement Plant Decarbonization Project* Heidelberg Materials US, Inc. (Up to $500 million - Mitchell, Indiana) • *Deeply Decarbonized Cement* | Brimstone Energy, Inc. (d/b/a Brimstone) (Up to $189 million - TBD) • *First Commercial Electrochemical Cement Manufacturing* Sublime Systems, Inc (Up to $86.9 million - Holyoke, Massachusetts) • *Lebec Net Zero Cement Plant Project* National Cement Company of California, Inc. (Up to $500 million - Lebec, California) (see Case Study below) • *Low-Carbon Calcined Clay Cement Demonstration* Summit Materials, Inc (Up to $215.6 million - Port Deposit, Maryland; McIntyre, Georgia; Elmendorf, Texas; Sulphur Springs, Texas)			
Reducing Embodied Greenhouse Gas Emissions for Construction Materials and Products to support organizations including businesses that manufacture construction materials and products to develop and verify Environmental Product Declarations.	EPA / IRA	1/8/24	100
Selected/awarded projects[137] • Heidelberg Materials US, Inc. (Selected Funding Amount: $5,000,000): proposes to create a robust, web-based tool that can help ready-mixed concrete, cement and aggregate facilities produce EPDs • Holcim US, Inc. (Selected Funding Amount: $1,371,814): For cement, asphalt and ultra-high-performance concrete, the project supports the development, enhanced standardization and transparency, and reporting criteria for EPDs. • International Code Council (Selected Funding Amount: $3,500,000): through the Pacific Northwest EPD Partnership, the project focuses on developing facility-specific EPDs for materials including concrete. • National Ready-Mixed Concrete Association (Selected Funding Amount: $9,632,293): increase the quantity and robustness of ready-mixed concrete EPDs by providing grants to producers to create EPDs from an additional 3,000 plants (up from 1,500 currently). • Portland Cement Association (Selected Funding Amount: $2,457,063): (1) provide technical assistance to help cement/SCM manufacturers develop facility-specific EPDs; (2) improve cement/slag cement industry average EPDs and create new ones for coal ash/natural pozzolans; (3) develop a single cementitious materials PCR and (4) support an LCA and benchmarking tool for concrete mix design. • Prestressed Concrete Institute (Selected Funding Amount: $9,975,000): update the precast concrete PCR and producing product-specific EPDs across multiple trade associations.			

137 U.S. EPA. 2024. *Summaries of the FY 23-24 IRA 60112 Grant Selections: Reducing Embodied Greenhouse Gas Emissions for Construction Materials and Products*

Funding Opportunity	Agency/ Statute	Deadline	Available Funding ($million)
Low-Carbon Transportation Materials Grants Program to fund low carbon materials that create less pollution by reducing the levels of embodied GHG emissions, including concrete (and cement), glass, asphalt mix, and steel.	DOT/ FHWA	6/10/24	2,000
In November 2024, the Federal Highway Administration (FHWA) announced the award of $1.2 billion to 39 State DOTs including Caltrans. The grant will be used for activities including identifying eligible low-carbon materials, preparing acceptance and verification procedures for collecting material Environmental Product Declarations, coordinating with industry stakeholders, conducting training on new procedures, benchmarking the global warming potential of relevant sets of materials, identifying thresholds that define LCTM, testing and evaluating LCTM to ensure performance is satisfactory and adequate for use on Federal-aid construction projects. Specifications for materials and construction may be updated to accommodate new LCTMs and processes on construction projects. States will identify eligible construction projects to implement LCTM and set up monitoring a process after construction is complete.			
Clean Construction Projects and Large-scale Contract Opportunities make federal buildings more sustainable, higher performing, and more cost-efficient through next generation technologies and low embodied carbon materials.	GSA	N/A	2,150 (low embodied carbon projects)
Awarded projects in California • NASA Ames Research Center, Sunnyvale • San Francisco Appraisers Building facade repairs, San Francisco • Otay Mesa Land Port of Entry Main Building and Primary Inspection sidewalk paving, San Diego • Leo J. Ryan Federal Records Center pavement, San Bruno • 801 I Street Federal Building parking lot repaving, Sacramento • Calexico LPOE modernization, Calexico • Calexico West Land Port of Entry Historic Custom House pavement, Calexico			
Cement and Concrete Center of Excellence to accelerate the development and adoption of novel low-carbon cement and concrete technologies. U.S. national laboratories can receive up to $9 million through an upcoming competitive lab call to develop and lead the center.	DOE	TBD	9
Hydrogen / Federal			
Regional Clean Hydrogen Hubs to support investment in the development of H2Hubs that demonstrate the production, processing, delivery, storage, and end-use of clean hydrogen.	DOE / IIJA	4/7/2023	7,000
Selected/awarded projects • California Hydrogen Hub (ARCHES) is a network of clean hydrogen production with the goal of decarbonizing public transportation, heavy duty trucking, and port operations. $30 million of the total federal cost share of up to $1.2 billion. • Pacific Northwest Hydrogen Hub (PNWH2) to build a clean hydrogen ecosystem across Washington, Oregon, and Montana. $27.5 million of the total federal cost share of up to $1 billion. • Appalachian Hydrogen Hub (ARCH2) is a network of projects that leverages the region's vast resources for diverse clean hydrogen production, storage, delivery, and end-use applications across			

Funding Opportunity	Agency/ Statute	Deadline	Available Funding ($million)
West Virginia, Ohio, and Pennsylvania. $30 million of the total federal cost share of up to $925 million			
Clean Hydrogen Production Tax Credit (45V) for a 10-year $0.60/kg clean H2 credit (inflation adjusted); reward increases with lower lifecycle GHG emissions, up to a 100% multiplier for H2 produced with <0.45kg/CO_2e footprint (well to gate).	Treasury / IRA	12/31/32	-
Carbon capture, use, and sequestration / Federal			
Carbon Storage Validation and Testing to test, mature, and validate CCUS technologies at commercial scale.	DOE / IIJA	11/30/22	2,250
In November 2023, Round 2 selected 16 projects ($444 million) focused on economic/technical feasibility of reservoirs including the following: • Colorado School of Mines (Golden, CO) aims to conduct a feasibility study to advance a carbon storage reservoir in the Sacramento Delta at the Carbon Terra Vault III project site. (DOE Funding: $8,915,350) • Electric Power Research Institute (Palo Alto, California) intends to confirm the commercial storage capacity and demonstrate the techno-economic feasibility of safely transporting CO2 and storing it at the onshore basalt storage complex on the Modoc Plateau in northeastern California. (DOE Funding: $9,000,000) In October 2024, Round 3 selected 23 projects ($518 million) to support the development of new and expanded commercial large-scale carbon storage projects including the following: • California State University Bakersfield (Bakersfield, California) plans to accelerate the development of transport and storage in multiple depleted oil and natural gas reservoirs that will be repurposed for UIC Class VI storage at the Elk Hills Oil Field in Kern County, California. (DOE Funding: $26,984,027) • Pelican Renewables LLC (Stockton, California) intends to develop a regional CO2 storage hub at the island of Rindge Tract in the eastern portion of the Sacramento-San Joaquin Delta in California ("Delta") that is accessible by barge and rail. (DOE Funding: $45,221,386)			
Carbon Capture Demonstration Projects to fund integrated CCS projects that demonstrate substantial improvements in efficiency, effectiveness, cost, and environmental performance.	DOE / IIJA	5/23/23	1,700
Selected/awarded projects • Baytown Carbon Capture and Storage Project: Baytown, Texas to capture CO2 from a natural gas combined-cycle power plant. The CO2 will be transported using new and existing pipelines and sequestered in storage sites on the Gulf Coast. • Project Tundra: Center, North Dakota is a carbon capture system for a coal-fired power plant. The captured CO2 will be safely and permanently stored in saline geologic formations beneath and surrounding the power plant. • Sutter Decarbonization Project: Yuba City, California will demonstrate and deploy a commercial-scale carbon capture system at a natural gas combined-cycle power plant. The project will then transport the CO2 and sequester it permanently and safely more than a half a mile underground in saline geologic formations.			

Funding Opportunity	Agency/ Statute	Deadline	Available Funding ($million)
Carbon Dioxide Transportation Infrastructure Finance and Innovation Program to finance companies building CO_2 transport infrastructure projects that cost more than $100 million.	DOE / IIJA	-	-
Carbon Capture Large-Scale Pilot Projects provide the support needed to test novel technologies at intermediate scale and under relevant conditions in both the power and industrial sector.	DOE / IIJA	6/21/23	820
Selected/awarded projects • Carbon Capture Pilot at Cane Run Generating Station: Louisville, Kentucky to deploy a carbon capture system at a natural gas combined-cycle power plant. • Carbon Capture Pilot at Vicksburg Containerboard Mill to build a carbon capture system at a pulp and paper mill. • Carbon Capture Pilot at Big Spring Refinery: Big Spring, Texas to deploy an innovative post-combustion carbon capture process at a refinery's fluidized catalytic cracking Unit. • Carbon Capture Pilot at Dry Fork Power Station: Gillette, Wyoming – to deploy a carbon capture system a coal-fired power plant.			
Carbon Utilization Procurement Grants FOA to support procurement and use of products developed through the conversion of captured CO_2 and CO emissions.	DOE / IIJA	4/30/25	100
Underground Injection Control Grants to support the development of UIC Class VI programs.	EPA / IIJA	3/20/23	50
Available funds have been allocated evenly among the 25 interested states and Tribes (Alabama, Alaska, Arizona, Colorado, Delaware, Georgia, Kansas, Kentucky, Louisiana, MHA Nation, Michigan, Mississippi, Montana, Navajo Nation, Nebraska, New Mexico, North Dakota, Ohio, Oklahoma, Oregon, Pennsylvania, Texas, Utah, West Virginia, and Wyoming) with an allotment of $1,930,000 for each program.			
Credit for Carbon Oxide Sequestration (45Q) applies to any projects that commence construction before 2033, expands credit value from $50/MT to $85/MT sequestered ($180/MT for direct air capture), and awards $60/MT for utilization ($130/MT for direct air capture).	Treasury / IRA	12/31/32	-
Funding Opportunities by the California Energy Commission			
The Industrial Grid Support and Decarbonization Program (INDIGO) supports industries that can benefit the electrical grid, reduce GHGs, achieve the state's clean energy goals, and reduce air pollution in under-resourced communities.	22-23 Budget/ AB 209	TBD	90

CASE STUDY: Lebec Net-Zero Cement Plant Project

The Department of Energy's Office of Clean Energy Demonstrations has awarded up to $500 million to the Lebec Net-Zero Cement Plant Project in California. This project aims to demonstrate how a combination of decarbonization levers can drive emissions associated with existing U.S. cement production facilities to net-zero.

https://www.nationalcement.com/news-main/national-cement-of-california

A Three-Pronged Approach to Achieve Net-Zero Cement

1. Replace fossil fuel with use locally sourced biomass from agricultural byproducts such as pistachio shells
   - The project aims to use 70% alternative fuels by its completion.
2. Replace clinker with a less carbon intensive alternative (calcined clay) to produce limestone calcined clay cement (LC3)
   - The Lebec cement plant manufactures Portland limestone cement (PLC), which uses up to 15%limestone.
   - The transition to solely producing the lower carbon LC3 cement needs additional market support and regulatory acceptance for its use across the state and country.
3. Capture and sequester the plant's remaining approximately 950,000 metric tons of carbon dioxide each year
   - The CCS portion of the project expects to capture and clean the flue gas from the cement manufacturing process and transport it to an offsite geologic sequestration site in Kern County. This portion of the project will require a range of permit approvals and emerging regulatory frameworks including implementation of state and federal regulation of pipeline transport of CO_2 for sequestration and inclusions of CCS in the Cap-and-Trade Program.

Public Engagement Process

SB 596 requires CARB to coordinate and consult with local communities surrounding cement plants in the development of the Strategy. To date, CARB hosted two public workshops (October 20, 2022, and May 31, 2023) and one community meeting (October 18, 2023) and received 28 total written public comments.[138] A variety of interested parties have come forward to provide input and to express interest in working with CARB, and staff have also worked to engage with local communities. To identify community organizations and community members who might be interested in the Strategy, staff reached out to county supervisor offices, local air districts, and chambers of commerce in areas near cement plants, as well as the Environmental Justice Advisory Committee and representatives from cement plants and cement industry groups. Internet searches were conducted to identify potentially interested community groups and members. Table 16 is a complete list of all organizations contacted as part of this process.

Table 16: List of Organizations CARB Contacted in Alphabetical Order

Adventist Health Tehachapi Valley	Kern County Supervisor District 2	San Bernardino County Supervisor District 1
California Communities Against Toxics	Lucerne Valley Chamber of Commerce	San Bernardino County Supervisor District 3
Center for Community Action and Environmental	Lucerne Valley Economic Development Association	Shasta County Air Quality Management District
Cummings Valley Protective Association	Mojave Chamber of Commerce	Shasta County Public Information Office
Eastern Kern Air Pollution Control District	Mojave Desert Air Quality Management District	Shasta County Supervisor District 4
Friends of Sand Canyon	Mountain Communities Chamber of Commerce	Tehachapi Mountain Democrat Club
Greater High Desert Chamber of Commerce	North State Climate Action	Tehachapi Rotary Club
Greater Tehachapi Chamber of Commerce	Redding Chamber of Commerce	Victorville Planning Department
Kern County Public Information Office	San Bernardino County Public Information Office	

[138] Public comments can be accessed from CARB's website:
Public comments for the first workshop. *Public comments for the second workshop. Public comments for the Community meeting.*

In addition, CARB's Tribal liaison contacted all tribes and tribal members near, or with ancestral lands near, California cement plants to ensure that tribes were aware of the Strategy and the associated process. Table 17 is the list of tribes contacted:

Table 17: List of Tribes in Alphabetical Order

Berry Creek Rancheria of Maidu Indians of California	Hoopa Valley Tribe	Quartz Valley Indian Reservation
Cachil DeHe Band of Wintun	Karuk Tribe	Redding Rancheria
Chemehuevi Indian Tribe	Kletsel Dehe Wintun Nation of the Cortina Rancheria	San Manuel Band of Mission Indians
Colorado River Indian Tribes	Mechoopda Indian Tribe of Chico Rancheria	Southern California Tribal Chairpersons Association
Enterprise Rancheria	Mooretown Rancheria of Maidu Indians of California	Susanville Indian Rancheria
Fort Mojave Indian Tribe	Paskenta Bank of Nomlaki Indians	Tejon Indian Tribe of California
Greenville Rancheria	Pit River Tribe	

CARB received one written response from a representative of the San Manuel Band of Mission Indians that expressed concerns about criteria pollutant emissions, the potential for increases of cement plant footprint into their ancestral territory, and possible impacts to Tribe health, well-being, and cultural resources. The San Manuel Band of Mission Indians did not wish to engage in formal consultation at that time, but they indicated a desire to be informed about public activities pertaining to the Strategy.

Interested parties are encouraged to provide additional suggestions for organizations, groups, or individuals CARB can contact to identify communities interested in the SB 596 process.

Appendix A: USGS Glossary of Terms

Additive: Material intermixed with hydraulic cement to form a different finished cement product.

Admixture: Ingredient (other than cement, water, and aggregates) added to a concrete mix.

Aggregates: Particulate materials such as sand, gravel, crushed stone, and crushed slag, used in construction.

Alite: A cement mineral, generally equated to C3S but usually somewhat impure.

ASR: Alkali-silica reactions or reactivity. Undesirable reactions in concrete between disordered silica in some aggregates and alkali hydroxides in the cement.

ASTM: American Society for Testing and Materials; organization has now been renamed ASTM International. Sets standards for testing and performance of construction and other materials.

AASHTO: American Association of State Highway Transportation Officials. An alternative to ASTM for setting of standards; however, many cement- related AASHTO standards are similar or even identical to those of ASTM.

Belite: A cement or clinker mineral, generally equated to C2S but usually somewhat impure.

Blended cement: A hydraulic cement made of a mixture of Portland cement (or clinker plus gypsum) plus pozzolans or other SCM.

Calcination: (1) The heat-induced removal, or loss, of chemically-bound volatiles, usually other than water. (2) In cement and lime manufacture, it involves the thermal decomposition of calcite and other carbonate minerals to a metallic oxide (mainly CaO) plus carbon dioxide.

Carbonation: The re-formation of carbonate minerals through the absorption of carbon dioxide by metallic oxides (e.g., carbonation of lime yields calcite).

Cement: (1) A binding agent. In construction, this agent is a powder to which water is added and which develops binding properties either through hydration of the component minerals in the cement (hydraulic cement) or through carbonation (e.g., lime mortars). (2) informal term for cement paste.

Clinker: An intermediate product of hydraulic cement manufacture. Clinker is produced in a kiln and consists of semifused nodules that contain a controlled and intimate mix of clinker (or cement) minerals. Portland cement clinker consists, chiefly, of the four minerals C3S, C2S, C3A, and C4AF. Clinker is finely ground to make finished cement; in the case of portland cement, the clinker is interground with a small amount of gypsum and/or anhydrite.

Clinkering: The thermochemical formation of the actual clinker minerals, especially to those reactions occurring above about 1300 °C; also the zone in the kiln where this occurs. A.k.a. sintering or burning.

Concrete: A proportioned mix of hydraulic cement, water, fine and coarse aggregates, and sometimes additives, that hardens to a tough, rocklike material used for construction.

Curing: The process of maintaining the moisture content of concrete to allow full hydration of the component hydraulic cement minerals and hence the development of full strength.

Final customer: A term of convenience used in the cement industry to denote a purchaser of cement other than a rival cement company or a sister plant or terminal owned by the selling company. As a practical reporting matter, most final customers are concrete companies, construction contractors, or building material suppliers, and are not individual citizens or companies owning the location where the concrete or mortar was actually put into place. Blending plants independent of the originating or rival cement companies are included as final customers. In the case of swaps, the final customer is that which paid the originating company for the cement.

Flux: (1) A material that reduces the temperature and/or energy input requirements of a chemical reaction or physical change (such as melting). (2) In clinker manufacture, a material that lowers the temperature and energy requirements of the clinker-forming (especially the sintering) reactions by promotion of the development of a liquid phase. Casually synonymous with mineralizer.

Fly ash: Fine grained glassy silicate particles released through the burning of coal in power plants and recovered by scrubbers. Some varieties of fly ash are useful as pozzolans or SCM and others can be used as raw material for clinker manufacture and as fine-grained construction aggregates.

Granulated slag: A form of blast furnace slag that quenched through a water stream so as to form sand-sized grains of silicate glass. When very finely ground (GGBFS), this material is an SCM. Can also be used as a grinding aid in the finish mill.

Gray cement: Cement other than white or colored varieties. Generally synonymous with gray Portland cement, but would include other, similar use cements (e.g., blended cements). It may or may not include gray masonry cement.

Ground granulated blast furnace slag (GGBFS): A form of blast furnace slag produced by quenching molten slag in a water stream to form sand-sized grains of glass. When finely ground, this material is a latent cement, although it is generally included as a pozzolan or SCM. Increasingly, GGBFS is being sold under the imprecise term slag cement. See also pelletized slag.

Gypsum: Calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$ or in shorthand $C\bar{S}H_2$); it is a mineral component of portland cement, and its function is to control setting time.

Hydration: Chemical combination of water with another compound. Hydration of cement minerals (to form new minerals called hydrates) is the key reaction in the hardening and development of strength in concrete. 2) absorption of structural water into a crystal lattice.

Hydraulic: Refers to a cement's ability to set and harden under, or with excess, water (cement) through the hydration of the cement's constituent chemical compounds or minerals.

Kiln: The heating apparatus in a cement plant in which clinker is manufactured. Unless otherwise specified, may be assumed to refer to a rotary kiln.

Limestone: (1) A sedimentary rock composed primarily of calcium carbonate (generally as the mineral calcite). Limestone is generally the main raw material for cement manufacture. (2) locally, any rock (e.g., limestone, cement rock, marble) composed primarily of calcium carbonate and used by the plant as its primary raw material in cement manufacture.

Masonry: (1) Refers to construction using natural or manufactured blocks (e.g., bricks, dimension stone, cinderblock), either shaped or unshaped; (2) see masonry cement.

Masonry cement: A general term for cement used as the binder in mortars. Commonly consists of a mix of Portland cement plus plasticizing agents such as lime or ground limestone. Loosely, the term includes true masonry cements, portland-lime cements, plastic cements, and cements for stucco.

Mortar: (1) The binder in masonry construction. Generally, a proportioned mix of masonry (or similar) cement, water, and fine aggregates. (2) In the oldest historical literature, sometimes used synonymously with cement.

PCA: Portland Cement Association. The principal U.S. private organization representing the cement industry.

Portland cement: The most common hydraulic cement. A proportioned and finely interground mixture of Portland cement clinker and a small amount of calcium sulfate (generally as gypsum). In practice, minor amounts of other additives may also be incorporated. Strictly, the term in the United States is limited to the Types I through V varieties (and their air-entrained variants) as defined in ASTM C-150; these types are also collectively called straight Portland cement. Apart from the straight varieties, "Portland cement" when used loosely (a common industry practice) can also include a number of similar hydraulic cements,

including blended cements, that are based on Portland cement clinker plus gypsum.

Pozzolan(ic): (1) A natural or synthetic silicate material that develops hydraulic cementitious properties when interacted with hydrated lime. Pozzolans and similar materials are commonly lumped under the term SCM. (2) Used loosely, the term is synonymous with SCM.

Precalciner: A kiln line apparatus, usually combined with a preheater, in which partial to almost complete calcination of carbonate minerals is achieved ahead of the kiln itself, and which makes use of a separate heat source. A precalciner reduces fuel consumption in the kiln, and allows the kiln to be shorter, as the kiln no longer has to perform the full calcination function.

Preheater: An apparatus used to heat the raw mix before it reaches the dry kiln itself. In modern dry kilns, the preheater is commonly combined with a precalciner. Preheaters make use of hot exit gases from the kiln as their heat source.

Pyroprocessing: Chemical transformation using intense heat from a flame. In cement, it refers to the manufacture of clinker, which is achieved in a kiln utilizing the flame from an internal burner tube. The pyroprocessing circuit or line is also called the kiln line of a cement plant.

Ready-mix(ed): Also spelled as one word (readymix). Common type of concrete in which all the ingredients, including water, are pre-proportioned at the concrete plant and placed into the rotatable drum of a mixing truck. The concrete is then thoroughly mixed via drum rotation while the truck is in transit from the concrete plant to the jobsite. Data on ready-mixed concrete generally includes similar concrete made at semimobile batch plants positioned near the jobsite. Batch plants are used where the jobsite is too far from the main concrete plant to allow convenient delivery of ready-mixed concrete by truck.

Rotary kiln: A kiln consisting of a gently inclined, rotating steel tube lined with refractory brick. The kiln is fed with raw materials at its upper end and heated by flame from, mainly, the lower end, which is also the exit end for the product (clinker), c.f., vertical shaft kiln.

Set or setting: Hydration-induced stiffening of cement paste or concrete. Initial set is the loss of fluidity and plasticity of the material; final set is the development of a certain degree of hardness. Concrete is difficult to work once setting has commenced.

Silica: (1) Silicon dioxide, SiO_2; denoted S in cement chemistry shorthand. (2) Pertaining to the silicon dioxide content of a material.

Silica fume: Ultrafine particles of disordered silica formed as a byproduct of the manufacture of silicon metal, silicon carbide, and silicon alloys (e.g., ferrosilicon). It is used as a pozzolan or SCM.

Slag: A silicate melt produced during metal smelting and which essentially is the residuum of the fluxing agents used and the impurities from the metal ores and fuels or reductants. The term also applies to the silicate material after it has cooled to a solid. In the general context of cement and concrete, slag (unmodified) refers to iron or steel (furnace) slag. More specifically, as a cementitious component of finished cement or concrete admixture, slag refers to the granulated variety used either unground as a grinding aid in the finish mill or ground (GGBFS) as an SCM. As a raw material for clinker manufacture, slag generally refers to steel furnace slag. As an aggregate in concrete, slag generally refers to air-cooled blast furnace slag.

Slag cement: (1) Properly, an ASTM C-595 blended cement (Type S), defined as having ≥70% GGBFS; (2) Increasingly on the U.S. market, the term slag cement is used for a 100% GGBFS product that is sold as an SCM.

Sulfate attack: Deleterious expansion of concrete caused by reaction of certain hydrated monosulfate phases in the cement with sulfate-bearing groundwater or soils. The reaction re-forms ettringite (a higher-volume phase).

Supplementary cementitious material (SCM): Materials that can be incorporated within blended cements or in concrete mixes as partial substitutes for portland cement. Common examples are GGBFS, fly ash, silica fume, and pozzolana. Casually synonymous with pozzolan.

White cement: A cement made from white clinker and is based upon raw materials having very low contents of iron (oxides) or other transition elements to avoid the coloring effects of these elements. Unless otherwise specified (e.g., white masonry cement), white cement generally is confined to white Portland cement. White cement is used to make white concrete and mortar, and serves as a base for colored cements, and is generally much more expensive than equivalent-performance gray cement varieties.

Reference:

van Oss, H.G., 2005, Background facts and issues concerning cement and cement data: U.S. Geological Survey Open-File Report 2005-1152, 88p (Accessed July 1, 2023, at https://pubs.usgs.gov/of/2005-1152-2005-1152.pdf.)

Appendix B: Caltrans New Material Approval Process

Standards, building codes and specifications play a critical role for new low-carbon materials to be accepted by project owners, architects, engineers, and concrete producers. Specifications written by state DOTs are especially important as they set local standards in respective states. In California, Caltrans' specifications are widely referenced and used in construction projects including those by local agencies. Caltrans oversees much of California's extensive transportation infrastructure. It manages more than 50,000 miles of highway and freeway lanes, provides inter-city rail services, permits more than 400 public-use airports and special-use hospital heliports[139] Caltrans is in the process of reviewing and approving a variety of alternative materials that could potentially lower GHG intensity of cement and concrete. This section discusses Caltrans' progress to date to approve low-carbon materials.

Portland Limestone Cement

PLC that conforms to ASTM C595 Type IL and AASHTO M240 can contain up to 15% uncalcined limestone powder. Caltrans approved the use of PLC in January 2022, paving the way for its wider use in California. The approval of PLC sent a strong signal to the state's concrete market that a strategic shift to lower-carbon cement was needed to meet the State's climate targets, provided they satisfied requirements for strength, durability and safety.

The review process for PLC started in 2016 and went through multiple committees and task groups comprised of Caltrans staff, industry representatives, engineers, national and regional experts. As Caltrans is responsible for the extensive portion of California's transportation system, the process considered a wide range of performance characteristics as shown in Table 18. It is notable that California has complex geology and topography (e.g. extensive coastal lines and mountain ranges covered with ice and snow) that can add extra stresses to concrete structure and local material availability, among other factors.

Table 18: List of Performance Characteristics Reviewed by Caltrans

1	Constituent material characterization	8	Corrosion of reinforcing steel
2	Alkali-silica reactivity	9	Air entrainment
3	Shrinkage and restrained shrinkage	10	External sulfate attack
4	Mechanical properties	11	Construction schedule
5	Transport properties	12	Environmental impact
6	Chloride binding	13	Thermodynamic simulations
7	Resistance to chloride ingression	14	Corrosion of reinforcing steel

[139] Caltrans. About Caltrans. https://dot.ca.gov/about-caltrans

The approval process also involved a three-year study by the Oregon State University, who contracted with Caltrans and tasked with determining if PLC could replace Portland cement without the loss of mechanical and durability performance of concrete materials and mixtures specific to California. The results demonstrated that PLC was equally suitable for Caltrans' construction projects as ordinary cement. PLC was adopted into its Standard Specifications in October 2021 before it was officially approved in early 2022. The list of PLC products authorized by Caltrans is on its "Authorized Material List - Cementitious Materials for use in Concrete".[140] Based on the experiences to approve PLC, Caltrans is in the process of reviewing other alternative SCMs such as harvested coal ash and the requirements related to low-carbon cement. The development of the Authorized Material List process for those approvals is expected to take 1-2 years. In the meantime, Caltrans is allowing project specific review and approval of harvested coal ashes that meet the AASHTO M 240 Class F requirements, Caltrans Section 90 Alkali-Silica Reactivity (ASR) expansion limits and are using innocuous aggregates. Once the Alternative Material List (AML) is developed the suppliers will submit their products through that program to be included on the list.

Supplementary Cementitious Materials (SCMs)

Blended SCMs

The 2024 Caltrans Standard Specifications[141] have been updated to allow blended SCMs if they meet the state's criteria. This effort was led in partnership with industry through the Pavement Materials and Partnering Committee (PMPC). Some of the additional controls included in Section 90 for blended SCMs:

- Required to be on the AML
- Additional test data consistency criteria and test method requirements
- Additional Loss of Ignition (LOI) criteria
- Additional ASR expansion limitations
- Updates to the Certificate of Compliance language to require the suppliers clearly state the percentages of SCM, by weight, in the blend.
- Silo storage requirements with clarification that blended SCMs with differing targeted manufacturer masses are considered different cementitious materials. Caltrans requires silos to be emptied before using the silo for a different cementitious material.

[140] *Authorized Material Lists* are specified in Caltrans specifications and are primarily a proactive measure used in conjunction with other acceptance activities as outlined in Department standards and guidance documents. The materials included on these lists are authorized for use on Caltrans construction projects.

[141] California Department of Transportation. *2024 Standard Plans, Standard Specifications, and Contract Item Codes*

- Caltrans AML is open for blended SCMs and testing of new products is underway. Caltrans anticipates that this will help mitigate the fly ash supply issues that have come up in recent years as coal fire power plants are shut down.

Alternative SCMs

Caltrans, in partnership with UC Davis Pavement Research Center, is currently evaluating new types of SCMs and other additives as shown in Table 19 to reduce GHG emissions associated with cement and concrete and replace fly ash that is facing decreasing supply, by focusing on locally or regionally available materials. The findings from this research are expected to be published in 2025.

Table 19: List of Materials Reviewed by Caltrans

Material type	Evaluated Materials
SCMs	Harvested fly ash
	Class C fly ash
	Silica fumes
	Natural pozzolan
	Calcined clay
	Ashes from biomass
	(Rice hull ash)
	Ashes from MSW
	Glass pozzolan
Fillers	Seafood waste
	Carpet backing
Nanomaterials	Cellulose nanomaterials
	Chitin nanomaterials
Fillers/SCMs	Construction demolition waste powder
	Asphalt plant baghouse fines
	Dust from lightweight aggregate production
	Returned plastic concrete

Caltrans is conducting a research project with Oregon State University focusing on reclaimed coal ash, coal ash class C, and glass powder. This project aims to investigate the feasibility of using alternative SCMs in Caltrans applications. The alternative SCMs may include, but are not limited to:

- Harvested coal ash
- Class C coal ash
- Recycled glass powder
- Ashes from the combustion of biomass for electricity production
- Waste products of forest management, etc.

The outcomes of this research will shed light on the accessibility of such resources, along with required treatments, and impacts on concrete properties in fresh and hardened states.

It will provide Caltrans with data to make informed decisions on the potential availability, use, testing, and specification of alternative SCM materials. When incorporated, these SCMs can result in a 20 to 40% CO_2 reduction in concrete depending on the volume of cement replaced and the SCM used. The research is complete, and the final report is under review. Specification updates will follow.

Implementation of Advanced Sustainability and Performance-Based Practices for Concrete Infrastructure

This research seeks to enhance the sustainability of California's transportation infrastructure by conducting a risk-benefit analysis and performance evaluation of innovative advanced alternative materials in concrete. The innovative materials/technologies evaluated in this study includes:

- CO2 sequestration technologies used in concrete materials;
- Alkali activated concrete;
- Cement produced using sustainable or clean energy.

It involves selecting best practices, reviewing Caltrans' Standard Specifications, and developing performance criteria aligned with current and future infrastructure needs. The project also assesses computational platforms for integrating material properties into Life Cycle Assessments (LCAs) and recommends or develops a tool as needed.

This research will provide the readiness level of the existing new technologies for Caltrans and suggest an evaluation protocol for accepting novel materials. This project started in 2024 and is expected to take 3-4 years.

- Another research project is in partnership with UC Davis: Developing A Framework for the Assessment and Implementation of Innovative Concrete Construction Materials – UCD fiscal year 24/25.
- Performance-based Specification Update:
  This is a long-term goal and will take years to implement. This is a major change to how Caltrans accepts concrete mixes and there are many stakeholders and specification updates required. Caltrans has approved the Concrete Sustainability and Performance Roadmap in the summer of 2024 in conjunction with the PMPC. The goal is to provide a performance-based specification option to start and eventually remove the outdated prescriptive specifications. Key points:
  - Allows the suppliers to develop mixes and prove they meet design and environmental criteria.
  - Performance testing data is submitted for review as part of the acceptance.

Moving to a performance-based specification is supported by ACI and outlined in ACI’s Report on Performance Based Requirements for Concrete. Caltrans plans to align the requirements with this report.

Caltrans Low-carbon Transportation Materials (LCTM) Grant Update

- From the Inflation Reduction Act, the FHWA has $2 Billion in grant funding for the use of construction materials and products determined to have "Substantially lower levels of embodied greenhouse gas emissions."
- June 2024 – Materials Engineering and Testing Services (METS) submitted application
- November 2024 – METS awarded $31,933,577
- Currently - Working with FHWA to obligate funds awaiting on final determination from the executive order.
- February 2025 – Caltrans Specification requires submittal of Concrete and Asphalt EPDs for projects with bid opening date after February 1, 2025.

Irrespective of federal funding Caltrans is continuing the commitments already made in line with Caltrans strategic goal of "lead climate action".

- Environmental Product Declarations (EPDs)
- Concrete performance-based specifications
- Research to accelerate new product evaluations
- Balanced Mix Design (BMD) for hot mix asphalt

EPD Update

- Through the Climate Challenge,[142] FHWA is providing funding and technical assistance to quantify GHG emissions from materials and practices for the design, construction, and maintenance of pavements.
- Caltrans was awarded $312,000 to incentivize the development of EPDs and funds expire April 1, 2026.
- Caltrans has received some increased interest after increasing reimbursement amount, but EPD collection is slow and will not suffice to establish CA benchmarks and thresholds.
  To accelerate EPD collection, Caltrans and industry, through the Pavement and Materials Partnering Committee (PMPC), implemented a new specification to be inserted into applicable projects starting February 1st, 2025. The new specification change only applies to large projects with quantities over a set limit for Asphalt and Concrete EPDs. There are financial penalties for not providing the EPDs. Based on collected data, Caltrans will eventually perform regional benchmarking that helps support improve plant efficiencies while promoting local businesses.

[142] Federal Highway administration. *FHWA Climate Challenge - Quantifying Emissions of Sustainable Pavements*

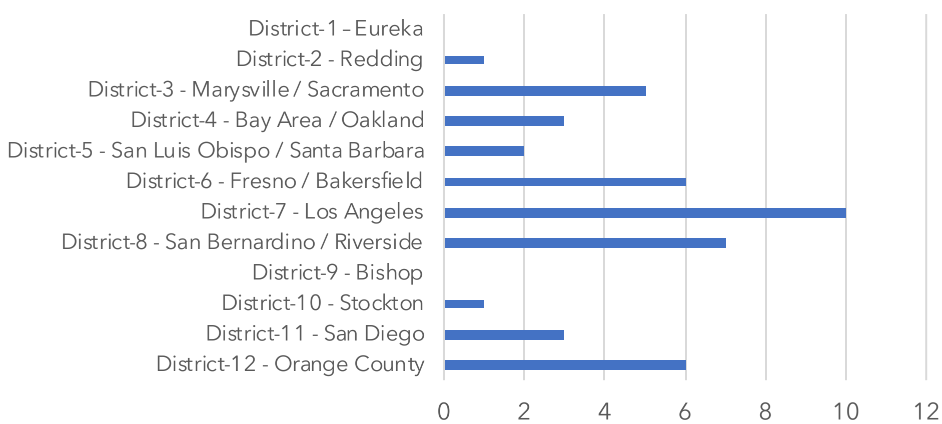
Appendix C: Results of Online Concrete Producers Survey

To promote the use of low-carbon cement including Portland limestone cement (PLC), it is critical to ensure that the users of cement - concrete producers, constructors, architects, engineers and project owners - are ready to accept it. To understand the status of market acceptance after Caltrans approval of PLC in 2021, CARB conducted an online survey of California ready-mixed concrete plant owners that are members of CalCIMA from May to November 2023. The survey was sent to 33 CalCIMA member companies that own about 325 ready-mixed concrete plants out of the approximately 375 total plants in California. Of 33 companies, 19 are vertically integrated or owned by other businesses. They operate about 300 concrete plants. The rest are owned by 14 small/independent companies, showing that concrete industry is diverse in sizes and types of ownership. The survey received 22 responses for a 63% response rate. The average time to respond to the online survey was 25 minutes, and many respondents provided thoughtful written responses.

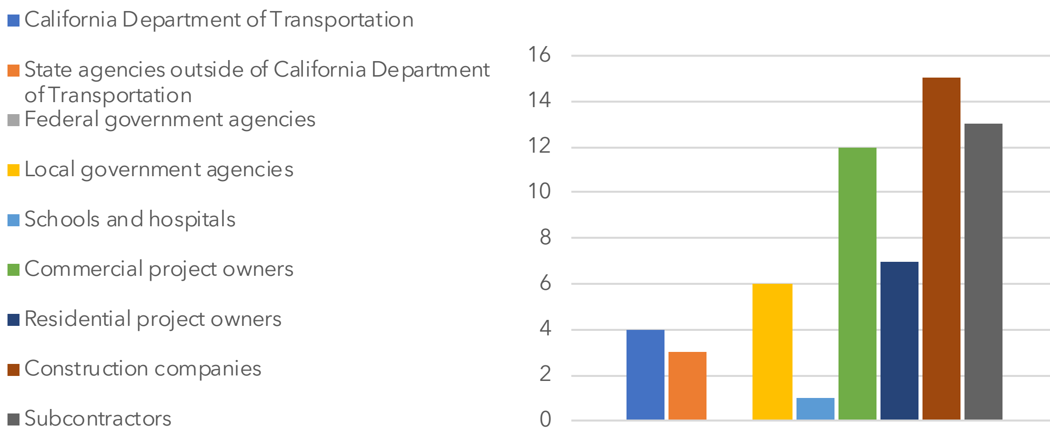
1. Describe your company.

Vertically integrated cement/aggregate/concrete producer	1
Integrated cement manufacturer	3
Concrete batch plant	12
Concrete batch plant and cement toll blender	1
Integrated aggregate producer	2
Integrated aggregate producer/concrete batch plants	1
Precast concrete manufacturer	2
Total	22

2. What market area(s) do you operate in? Choose up to three areas, which are organized by Caltrans district.



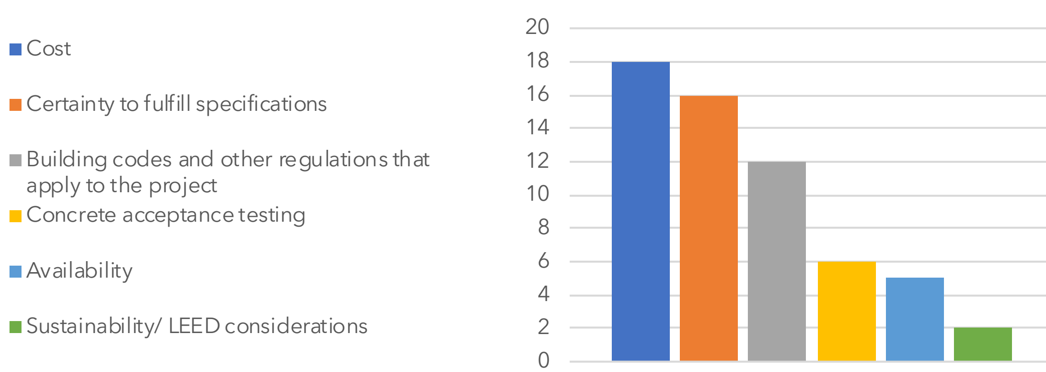
3. Who are your main customers? Please select at most 3 options.



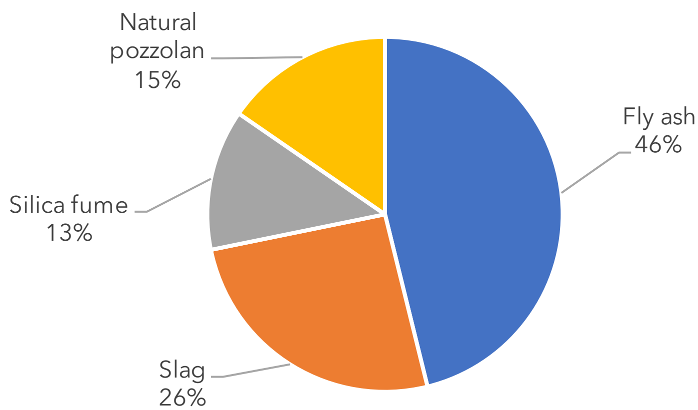
4. To what extent do you typically have a say in what concrete mixes are supplied? Please provide details using the "other" textbox.

To some extent (it is negotiable if we can show options to meet requirements)	18
None (the contractor or owner makes decisions)	2
Other comments	
• We are often confined to the project's concrete specification. However, we have been trying to change the practice and there has been an increase in requests by projects teams/architects/engineers for us to review their concrete specifications and make suggestions for low carbon concrete.	
• We have more flexibility with private builders to provide options that meet end performance requirements. Many public works projects have very restrictive material requirements which limit or prohibit the use of low carbon alternative mix designs.	
• We work with contractors who provide the job specifications to customize mix designs.	
• I design the mixes, but engineers and architects specify them who over-cement mixes.	

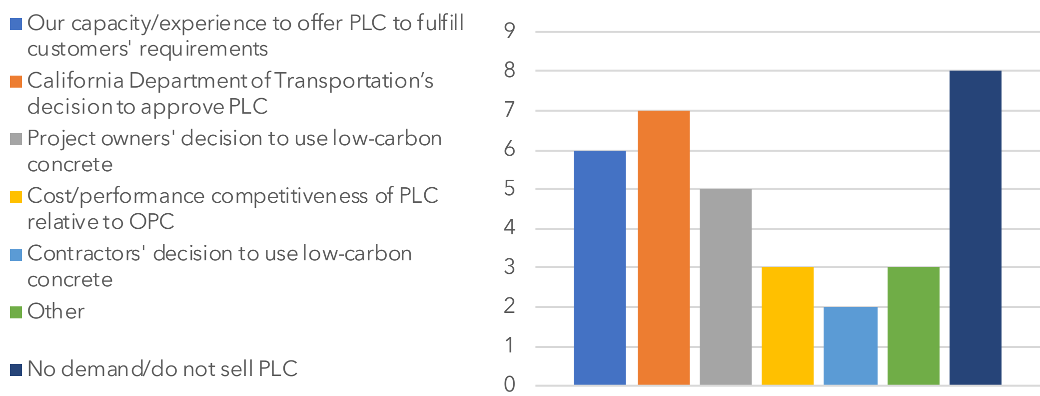
5. What factors are considered by owners, specifiers, contractors, and suppliers to determine an order for concrete mix? Choose up to three answers that are most frequently brought up. Please provide details using the "other" textbox.



6. Which types of supplementary cementitious materials (SCMs) have you been blending? Select all that apply. Please provide details using the "other" textbox.

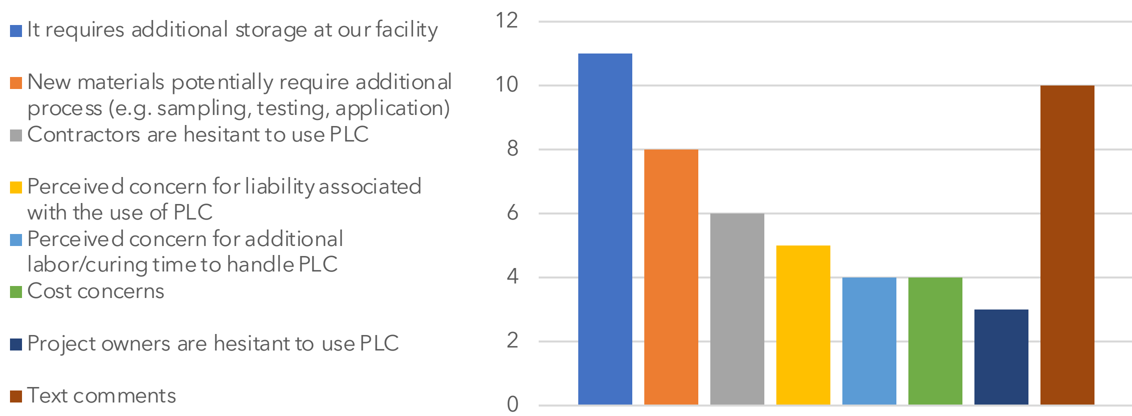


7. If you are seeing increased orders for Portland Limestone Cement (PLC), choose up to three factors contributing to the increased demand. Please provide details using the "other" textbox.



Our capacity/experience to offer PLC to fulfill customers' requirements	6
California Department of Transportation's decision to approve PLC	7
Project owners' decision to use low-carbon concrete	5
Cost/performance competitiveness of PLC relative to OPC	3
Contractors' decision to use low-carbon concrete	2
No inquires or do not sell PLC	8
• One response included that they tested the strength, but the results were not good.	
Other	3
• In some cases, customers request PLC for color requirements (PLC is brighter than Portland cement)	
• Supply/availability in the market affects the order.	
• We promote PLC to be incorporated into the concrete specifications as a strategy to reduce environmental impacts of cement when cement producer have it available.	

8. If you are NOT using or considering using Portland Limestone Cement (PLC), choose up to three reasons. Please provide details using the "other" textbox.



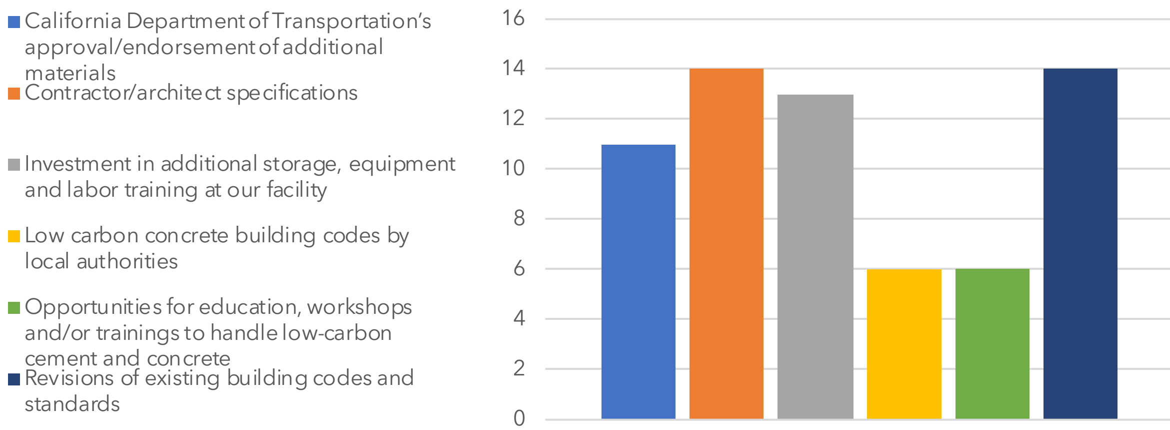
Text comments
Technical concerns
• PLC does not work with Class F fly ash.
• PLC produces weaker concrete; more PLC is needed per mix to defeat the purpose to lower embodied carbon of concrete.
• PLC strength is lower than normal Portland Cement.
• It requires additional equipment and workforce training at our facility.
• We will use it when product is a reality and proven material.
Availability/acceptance issues
• I do not believe it is offered in our area. (Serves District 3 (Marysville/Sacramento))
• When in-state cement plants shut down, it affects material availability as well as the overall environmental performance of cement used in the state, especially if imports come from regions with weak environmental regulations.
• Some structural engineers do not allow the use of PLC, and/or some contractors are unfamiliar with it.
Other
• We are fully committed to the use of PLC and are determined to work through the challenges to accomplish the goal to fully transition from Portland cement.
• We are using Type 1L PLC as much as possible.

9. If you consider supplying new materials such as additional SCMs or alternatives to ordinary Portland cement, what additional actions do you need to take? Which material specifications or testing standards (e.g., ASTM C 31) are you most concerned about when introducing new materials?

Technical Concerns
• Testing is needed for water demand, strength, ASR, chloride attack, etc.
• Some PLC cements can generate higher concrete shrinkage, fast drying and finishing issues and some SCMs could be less effective combating ASR of aggregates.

• Concerns include if the material meet specifications, and if the material will be sustainable in a harsh environment like the Sierra Nevada's.
• There need to be more field testing in the freeze thaw environment.
• Initial research and in-house testing are crucial for any new materials used in concrete mixes.
• Current Caltrans specifications require high levels of fly ash, and current testing protocols will cause high content natural pozzolan mix designs to fail as they do not meet material specifications or cure in the required time.
• ASTM C-618 (Standard Specification for Coal Ash and Raw or Calcined Natural Pozzolan for Use in Concrete) is important
• We are working toward using more Natural Pozzolan, but no standard exists for it.
• Primary concern is spec compliance and meeting customer expectations.
• Concerns include testing and assurance of any performance differences, cost considerations, plant capacities and available silo space, and consistency of materials between locations in a shared market.
• Cost, reliability, customer education are needed
• We need standards that allow the use of these novel materials for concrete.
• We would need to do a substantial amount of additional testing to determine strength. We anticipate it would take more cementitious material to keep strength levels where they are now.
• We are most concerned about project specific specifications, which tend to put the most limitations on the use of SCM's. We don't think ASTM C 31 (Standard Practice for Making and Curing Concrete Test Specimens in the Field) is a concern.
Storage
• Three respondents commented that they needed increased or added silo storage.
Recommendations/statements
• Although most private sector SE firms are still specifying C150 cement, we are constantly advocating for the use of PLC whenever and wherever possible toward a complete PLC transition.
• Please refer to the CNCA roadmap to carbon neutrality update which discusses the role of government in reaching the 2045 zero carbon goals. Additionally, you should access and read the companion CalCIMA roadmap to carbon neutrality for Concrete.
• To easily/quickly/effectively reduce use of cement, simply require all concrete to have 25 oz/cy of high-range water reducer. This will immediately reduce cement consumption by 13 to 15% or more. Reduce cement usage another 15% by extending the test age from 28 days to 56 days.
• SCMs such as fly ash have the same damage to the environment during their process of fabrication as standard cement. It is our belief that using those SCMs is not beneficial if the desire is to reduce a carbon footprint. There are no coal fired plants in California, and bringing in fly ash from plants outside the state further increases its carbon footprint during the delivery process.
• We are largely through the conversion process from II/V cement to PLC at nearly all concrete plants. All of our projects quoted since Q4 2022 have been "Not per Spec" when we see C150 and we quote C595 PLC.

10. What additional resources are needed to increase the use of low-carbon cement/concrete? Please provide details using the "other" textbox.



• A change from prescriptive to performance specifications is needed.
• Key is pricing and availability of SCMs, then testing.
• The quickest initial way to reduce the carbon content of ready-mixed concrete is provide for alternate ages of maturity for concrete when reasonable. The current standard of 28 days assumes the structure will be fully in use or under load or stress at 28 days. That is almost never the case. Later ages of maturity for testing of concrete such as 42, 56, 90 or 120 days would encourage a decrease in the amount of high carbon cement used and the increase in the use of low carbon SCM's. Another issue is the storage and integration of additional SCM's or PLC. Most ready-mixed facilities do not have the resources to store or use additional SCM's or PLC.
• Standard Specifications for Public Works Construction (the "Greenbook") and County specification to approve low-carbon concrete mix and products.

11. Provide details in response to any of the questions and/or comments/concerns/suggestions related to use and promotion of low-carbon concrete.

• There needs to be more testing in a freeze thaw environment.
• The cement and concrete industries are faced with regulations to reduce their embodied carbon, and many such as ourselves are willing to make the move and do so when possible. The engineering community is not required to permit the use of low carbon products, and many continue to use their old prescriptive specifications. This must change. There also other barriers that must be removed.
• Use performance base specification for concrete, that includes changing Caltrans Specification.
• Provide financial incentives to add additional silo capacity in the ready-mixed plants.
• Provide regulations to extent the time of final strength of concrete from 28 days to 56, 90 and 120 days.
• My concerns are in the availability and reasonable expectations in production while maintaining a competitive supplier market. For those that have the ability to add silo space and invest significant capital into their facilities, they will have an edge.
• To reduce CO_2 from concrete, nearly ALL mixes should have at least 25 oz/cy of high-range water reducer. That would substantially reduce the amount of Portland cement in concrete mixes. A 6-sack mix could be reduced to a 5.25-sack mix with 25 oz/cy of HRWR for equal strength.

• If the state is requiring businesses to go green, from the cement they use to the equipment used in its production, it must understand that providing a tax incentive to those businesses would jumpstart the process. Plenty of companies are willing to push the green initiative, but many of us need help getting that started.
• In order to achieve "net-zero" it will take more than just the cement producers and concrete producers to develop low-carbon products. The design community must also embrace the transition through creative design.
• There are a number of ways to lower the carbon content of concrete. Many will require contractors, architects, engineers, and agencies to rethink the design and construction methods to accommodate the innovations.
• Ready-mixed plants need additional silo capacity to store multiple types of cements at their facilities. This takes time and resources to accomplish. Additionally, CARB needs to recognize the long pathway to an electrified or hydrogen powered concrete truck and should continue to support bridge fuels such as Recycled Natural Gas.
• Architects and engineers employ prescriptive specifications (defining maximum water-cement ratios, maximum slumps, etc.). NRMCA has been promoting performance specifications for the past 25 years (define what strength and plastic/hardened properties are needed and let the professional concrete mix designers figure out the best way to achieve those results). As it is, architects and engineers constantly over-specify concrete which results in way too much cement being used.
• Education on what "Low Carbon Concrete" is, 90% of people that call asking for "Low Carbon Concrete" don't even know what it is or what it takes to make it a "Low Carbon Concrete." And then when they find out, they get push back from their own Engineers.

Appendix D: Summary of Public Comments

To date, CARB hosted two public workshops (October 20, 2022, and May 31, 2023) and one community meeting (October 18, 2023) and received a total of 28 public comments.

Commenter	Comment Summary
First Workshop	
Berland-Shane, Laura, Blue Planet Systems	Supported CCU technology that mineralized CO2 in synthetic aggregates
Brandler, Simon, Brimstone	Supported alternative cement technology using calcium silicate
Guerra, Erika, CSCME	Provided comprehensive suggestions on principles of cement decarbonization strategy
Theodoridi, Christina, Natural Resources Defense Council	Offered comprehensive suggestions on cement decarbonization pathways
DeRousseau, Mikaela, Building Transparency	Suggested leveraging and improving EPD and PCR to quantify embodied carbon
Brown, Nora, Charm Industrial	Supported carbon removal technology using biomass
Harper, Adam, CalCIMA	Expressed support for the program
Mayer, Katie, Rondo Energy	Supported technology to provide high heat using heat battery and intermittent electricity
Flanagan, Jordan, Leilac	Supported technology to capture CO2 directly from calcination process
Epstein, Bob, Project 2030	Offered modeling combinations of example GHG reduction solutions related to the cement sector
TOBEY, Alann,	Encouraged innovations such as graphene
Bogdan Tejeda, Victoria, Center for Biological Diversity	Opposed to the use of CCS and biomass as cement decarbonization strategy
Kennedy, Kevin, World Resources Institute	Supported low cement product standard
Second Workshop	
Charley Rea, CalCIMA	Opposed to the idea for concrete producers to report the amount of SCM consumption
Simon Brandler, DC2	Support for advance procurement to promote market entry of alternative materials
Doug Robinson, Solidia	Supported technology to produce cement/concrete that mineralized CO2
Laura Berland-Shane, Blue Planet	Supported CCU technology that mineralized CO2 in synthetic aggregates
Jordan Flanagan, Leilac	Supported technology to capture CO2 directly from calcination process

Steve Bryan, Ecocem	Supported technology to produce high filler low water cement/concrete
Rebecca O'Brien, True North Renewable Energy	Supported expansion of LCFS to allow fuel providers to generate credits supplied to industrial sectors
Cassandra Farrant, Amp Americas	Supported expansion of LCFS or amendment of C&T to allow fuel providers to generate credits supplied to industrial sectors
Bernard Fenner, Ductor	Supported expansion of LCFS to allow fuel providers to generate credits supplied to industrial sectors
Steve Bryan, Ecocem	Support technology to produce high filler low water cement/concrete
Sam Morton, AquaHydrex	Supported green electrolytic hydrogen
Simon Brandler, Brimstone	Supported new policy mechanisms for alternative cement that reduce/eliminate GHG emissions
Christina Theodoridi, NRDC and RMI	Supported novel SCMs, public procurement, advanced purchase commitments, zero emissions cement standard among other strategies
Erika Guerra, CSCME	Provided perspectives on questions raised during the workshop, including definitions of "net-zero" and "cement," treatment SCMs, emissions baseline, and emissions leakage
Atle Lygren, EMC	Supported energetically modified cement
Community Meeting	
Todd Jones, Shasta Economic Development Corp	Voiced support for the economic impacts of startup SCM company in their community
Laura Berland-Shane, Blue Planet	Supported CCU technology that mineralized CO2 in synthetic aggregates
Simon Brandler, DC2	Supported advance procurement commitments to promote market entry of alternative materials
Kevin Barker, SoCalGas	Supported CO_2 pipeline infrastructure network and clean fuels to achieve GHG emissions reduction strategy
Atle Lygren, EMC	Supported energetically modified cement
Charley Rea, CalCIMA	Proposed new cement definition