Comments of the American Council for an Energy-Efficient Economy (ACEEE) on "California Market Transformation Administrator's Request for Ideas on Market Transformation Initiatives"

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Idea Name: Low Carbon Concrete in California (Technology)

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Product description & benefits

1) Please describe the technology or practice.

Cement, the key binding and carbon intensive ingredient in concrete, is used in buildings/infrastructure, and emits 8.8% of industrial sector (CARB 2022) and 2% of all GHG emissions in California (CA). California, the 3rd largest cement producing (USGS 2023), 2nd largest consuming (ACEEE 2023a) state, has 7 cement plants (EPA 2023) and 2045 net zero policies, legislation, strategy for the sector (CARB 2022). Ordinary Portland Cement (OPC) is produced in 3 main steps: (1) Raw materials and solid fuels are pre-processed (ground, crushed, dried). (2) Limestone ($CaCO_3$) is heated (calcined) in kilns at 1500°C to produce clinker and CO_2. (3) Clinker is ground with gypsum and other additives in mills to produce cement. About 60% of the CO_2 is from the basic chemical reaction, and 40% from fossil fuel combustion (kiln heat) and electricity use. Supplementary cementitious materials (SCMs) are used to replace clinker to reduce cost and CO_2 emissions. Fly ash (from coal power plants) and slag (from steel blast furnaces) are the most commonly used SCMs, but their reduced availability nationally and need to import into CA requires new choices. (CalTrans 2016). Calcined clay (CC) is a SCM that can reduce CO_2 emissions through material & energy efficiency to meet state net zero goals for the sector. (1) Clay is a naturally zero carbon raw material (unlike limestone) so more clay in place of limestone-based clinker creates a lower carbon product. (2) Clay is calcined at lower temperature (~800°C), using less fossil fuel to heat the process than limestone. (3) Lower temperatures make electrification using low carbon electricity more feasible. (ACEEE 2023b) CC can be used to create blended cements or can replace up to 50% of OPC in the concrete mix, in the grinding or the ready-mix stage, reducing the need for upgraded equipment at concrete plants. Lifecycle assessment on various LCC blended cements show 40% CO_2 reductions with more possible with electrification. (Scrivener 2019).

2) Describe how the technology or practice saves electricity or natural gas, reduces peak demand, and/or reduces GHG emissions.

CC as an SCM 1) reduces heat needs (1500°C to 800°C), increases energy efficiency, lowers energy emissions; 2) reduce process CO2 emissions (from calcining limestone) up to 40%; 3) 80% of the CA cement industry fuel mix is from high GHG fossil sources (coal, petcoke, natural gas), the lower calcination temperature, allows other fuel sources (electrified kiln, thermal storage, renewable energy) for emission reductions; 4) Clay is abundant in CA & its use reduces transport emissions from fly ash/slag imports; 5) Clay needs less energy intensive grinding (softer) than OPC clinker/limestone. (Scrivener 2019). These translate to a total system benefit (TSB) of at least 25% considering energy savings, GHG reductions, grid benefits based on market adoption rate, carbon cost=$80/t.

3) Are there additional benefits that your technology or practice will provide? If so, please describe these benefits.

Calcined clay producers use recycled raw materials (clay in mine-tailings). Limestone added to calcined clay synergistically improves SCM binding capacity, offsets clay calcination cost, and limestone calcined clay (LCC) cement has favorable mechanical properties (strength, durability) compared to other SCMs >90 days (Scrivener 2019, Purebase 2023a). Bridge pier/girder studies show LCC concrete meets strength requirements, has longer service life, emits less lifecycle CO_2 than OPC or pulverized fly ash (Pillai 2019). LCC has better durability than OPC and fly ash (chloride resistance, alkali silica reaction/ASR resistance), and is better in marine environments (Dhandapani 2018). Recycled aggregate concrete added to LCC improves sustainability retaining mechanical properties (Guo 2022).

Target market description

4) Describe the target market sector and customers that will benefit from your technology or practice in California. For example, commercial, industrial, single family residential, multifamily residential, agricultural, etc., and, if applicable, key subsector. Be sure to specify whether it will benefit hard-to-reach customers, low-to-moderate income markets, disadvantaged communities, etc. and how.

Target market sectors benefitting (emissions, jobs) from LCC use (across lifecycle from material source to application) are mining, cement/concrete manufacture, construction, built environment customers (residential/commercial/industrial/infrastructure). Benefits will extend to disadvantaged/underserved communities near cement/concrete plants, impacted by air pollutant exposures by reducing fossil fuels in cement plants, those exposed to CO_2-related climate change impacts (extreme weather) by reducing CO_2 emissions (clay vs limestone calcination), and by providing jobs and workforce development for low-income communities supplying workers for LCC-related sectors. Retail sales of CC/LCC concrete is feasible with use in hand mixing operations based on international experience.

5) Where, specifically, is the technology or practice available? Is it available to consumers in California? Please provide an example of a specific outlet or service provider, if possible.

Some cement companies have set up/are exploring dedicated calcination equipment at their plants (e.g., Texas, Minnesota, Eastern US). In California, one company reports sourcing clays from mine tailings in Ione (Purebase 2023b). This company recently installed calcination equipment and expects to commercially produce CC for cement/concrete manufacturers in the Western US six months after commencing operations (Redding and San Jose cement plants represent potential nearby customers). Upon further testing of the CC, the company plans to submit their material to CalTrans for evaluation and inclusion on its Approved Materials List (AML). (Purebase 2023c). Since State DOTs can influence half the construction in a state, CC/LCC may achieve State-wide use following CalTrans approval.

6) Describe how the technology or practice is (or will be) delivered to the market. For instance, will it be available for direct purchase by the consumer through traditional retail establishments, or will it be available only through installation by a licensed professional, or something else? Is there a well-established distribution channel that can be used, or would one need to be developed or adapted? Also include any information about potential partnerships or partnership opportunities, including those with community-based or environmental social justice organizations, that would support the advancement of the technology or practice, if applicable.

Market Distribution. Calcined clay producers would need to establish offtake agreements with cement and concrete suppliers/producers to purchase their SCM. Existing distribution channels used for natural pozzolans may offer opportunities that can be adapted for calcined clay SCMs since clays (e.g., metakaolin) are American Society for Testing and Materials (ASTM) C618-designated natural pozzolans. Existing distribution channels for blended cements can also be leveraged as CC/LCC are covered under ASTM c595/c695 standards for blended hydraulic cements. Additionally, if added to the CalTrans Approved Products List, calcined clays would become available for use in state construction projects creating market demand to incentivize product manufacture. The distribution/utilization channels for infrastructure materials would need to be further adapted so that contractors, engineers and others across the construction value chain are aware of the available lower embodied carbon calcined clay material and are trained to specify and obtain them for projects. Concrete producers would require training in mix optimization methods to use the new CC/LCC SCM based on construction project needs. LCC concrete could also be sold through retail outlets for individual, private consumers to use in hand mixing operations for small DIY projects based on international experience over the last 10 years.

Environmental, Social, Economic Justice Impacts. Out of the 8,057 communities in CA, 38% (3,081) are considered disadvantaged according to the Climate and Economic Justice Screening Tool (CEJST 2023). There may be substantial potential for the LCC technology to alleviate industrial exposure burdens in these disadvantaged communities (DACs) across the state when located near cement or concrete plants. For example, in northern California where there is a known clay mine in Ione, there are several DACs within a 25-mile radius, including communities in Calaveras County, Rancho Cordova, Galt, Lodi, and parts of the Stockton area (CSG 2023). These DACs struggle with a mix of environmental and socio-economic burdens with almost all experiencing air quality issues (PM2.5 in the air), legacy pollution, low income, and workforce development issues such as unemployment, linguistic isolation, and low rates of high school education completion. DACs are also located near the cement plant in Cupertino, CA, on the east side of San Jose, where community members (23% of whom are low-income) represent several demographic indictors all above the state average such as: 89% people of color, 17% limited English-speaking households, and 21% with less than high school education (EPA EJScreen 2023).

The LCC technology could extend non-energy benefits beyond carbon and GHG reductions, by providing new jobs and training for low-income DACs increasing direct, indirect and induced jobs. Partnerships with K-12 institutions, trade schools and minority serving institutions could alleviate the educational burdens that these DACs face, and companies adopting the LCC technology can sponsor English as a second language training. Additionally, companies could hold two-way engagement sessions with surrounding communities and DACs to educate them about their operations and address community concerns about pollution. Local environmental and community benefit groups (CBAs) could help build awareness of lower embodied carbon building materials and advocate for electrification of the clay calcination process to achieve even higher carbon reductions from cement production while addressing community needs and concerns. Use of renewable/low carbon energy to operate electrified kilns or flash calciners will be key to meet CA state net-zero and Federal Justice40 Initiative goals by reducing energy burdens and improving overall well-being of DACs. LCC technology pilots may also be pursued using state and federal funding opportunities to maximize potential beneficial impacts to California communities.

<u>7) What is your best estimate of current market adoption of the technology or practice? For instance, how many units or what percentage of the target market(s) have already adopted the technology or practice?</u>

Currently in the US, a version of the LCC technology (with a 10-15% CC substitution) is being piloted by Minnesota DOT (MNDOT) as part of the National Road Research Alliance (NRRA) test bed near Minneapolis. However, there is no known facility producing calcined clays for regular market use in the US. One California company (Purebase 2023d) expects to be in commercial production within six months (late 2023) and will be starting full scale tests to further prove their bench scale models. Once included in the CalTrans Approved Products List, and with adequate commercial production from California companies, LCC may see use in state infrastructure projects and widespread use since state DOTs can potentially influence almost 50% of the construction in a state. Given that California is the third largest producer of cement and the second largest consumer of cement, with adequate LCC supplies and production of LCC cement and concrete, there is strong potential for its use in construction projects if engineers are trained to specify the use of LCC materials. CalPortland, CEMEX and Heidelberg, all operating CA plants indicate blended cements with clays are part of product lines.

Market adoption barriers

<u>8) What is keeping the market from adopting your technology or practice? Please list the key market barriers.</u>

Supply side barriers for low carbon concrete include:

- **Clay sources**. Currently the primary identified source of clay is the Ione mine in Northern CA. Identifying additional clay deposits needs investment and coordination with geologists.
- **Workforce gaps**. Workers across the value chain, including cement plant operators, concrete producers need training in new LCC cement/concrete production methods adding to the ongoing workforce shortage.
- **Limited production/distribution infrastructure.** Production/use of CC/LCC in cement/concrete is at a nascent stage in California by large manufacturers. CalPortland, CEMEX and Heidelberg, all operating California plants generally indicate that blended cements using clays are part of their product lines without additional detail.
- **Intellectual property**. Companies producing calcined clay or related products may be concerned about protecting IP, business interests and market share.

Demand side barriers for low carbon concrete include:

- **Building/Industry/Construction standards/codes**. Need to be updated to allow use of new materials like LCC concrete esp. performance based to avoid prescriptive elements.
- **Professional risks to engineers**. Specifiers and engineers are hesitant to use new products in construction projects due to the learning curve with new concrete mixes, longer strength times, and professional liability concerns over failure in public infrastructure or vertical applications.
- **Trained workforce**. Specifiers, engineers, contractors, suppliers, need to be educated/trained to use the technology in building/infrastructure applications.
- **Economic constraints for end-users**. Construction projects are driven by resource constraints (budget and time) and project owners/developers/construction engineers are under pressure to meet construction/project financing deadlines, hence a preference for known materials to avoid project delays.
- **Lack of regulation/incentives** to use low-carbon cement alternatives like LCC.

<u>9) What limitation(s), if any, does the technology or practice have that must be overcome? What are the technical barriers, if any?</u>

Technical barriers identified in ACEEE research (Srinivasan et al 2023) include:

- **Mechanical properties**. LCC cement may exhibit slightly lower compressive strength in the earlier timelines up to 90 days it can exceed the strengths of Portland cement past 90 days due to main chemical reactions which occur during hydration. This poses a challenge in construction practice which is traditionally centered around meeting 28-day compressive strength requirements that were established based on the mechanical properties of ordinary Portland cement.
- **Higher substitution levels limitations**. At 50% substitution levels of OPC by LCC cement there is considerable reduction in compressive strength and lower flexural strength values.

- **Reactivity**. Clay activated in a rotary kiln system is less reactive and only allows for 15–25% substitution in concrete (FLSmidth 2020).
- **Workability**. The use of calcined clay impacts the workability of concrete, which needs to be mitigated with the use of super-plasticizers but this may have its limits (Specify Concrete 2021).
- **Higher mixing energy**. The substitution of ordinary Portland cement by limestone calcined clay cement requires higher mixing energy due to extended dry-to-paste transition phases as the limestone calcined clay cement content increases. (Wang et al. 2021; Ez-zaki et al. 2021)
- **Use of fossil fuels**. Calcination of clay currently still requires the use of fossil fuels until electric flash calciner technology is fully developed for large scale commercial use. Hence there continues to be some CO_2 emissions associated with clay SCMs.
- **Production and distribution infrastructure.** The lack of infrastructure for producing and distributing limestone calcined clay cement is another barrier.
- **Perceived safety risks.** Due to lack of user experience, engineers and specifiers are hesitant to use a new material. Use in low-risk applications (e.g., pavements) would increase technical confidence prior to scale up in higher risk applications.

<u>10) Beyond the standard or base case technology or practice, what are the alternative competing products or services (direct and indirect), and how does your technology or practice compete with them?</u>

Competing products include: Portland pozzolan cement (PPC)/Portland-limestone cement (PLC), use natural pozzolans/limestone SCMs to reduce clinker. NPs regionally limited, reducing wide PPC use. PLC used for >20yrs, emits 10% less CO2 than OPC, but limited to 10-15% clinker substitution by limestone (Scrivener 2019, PCA 2021). Fly ash/slag traditionally used SCMs (15-20% of market), embedded in standards/codes, but in short supply, require safe processing/imports. Fly ash limited to 35% substitution to optimize performance, slag up to 70%. Disincentivize changes to BAU practice. Ground glass pozzolan, similar TRL as LCC, offers recycled raw material with substitution limits (<40%) to minimize cracking from ASR reactions. Calcium sulfate concrete blends an emerging tech with limited raw material supplies compared to CC/LCC, which are substantially larger with longer successful pilot history.

CC/LCC offers competitive advantages for innovation diffusion: California has relative advantage of substantial raw material resource in state (Ione) saving import-related financial/emission costs. Use is compatible with equipment/processes in the cement/concrete industry and ASTM standards. Compatibility reduces complexity of the MTI (known entities, channels, products, processes); Currently piloted in MN. CA can observe/adapt from the trial as a NRRA member. Both CARB/CalTrans have complementary efforts to bring it to market. CARB is observing the mine source/calciner.

Key MTI pivot points that make it difficult to reverse the change: CC/LCC acceptance by CalTrans' Approved Material List can impact 50% of construction in the state creating market demand leading to structural market changes for producers; Lowering liability risk for engineers will increase confidence to try new materials in projects; Reduced fly ash supply, challenges in extracting ponded coal ash may push producers towards clays; Regulations/incentives to further lower new cement GHGs can advance use of CC/LCC**.**

11) What type of market interventions, assistance, or support do you think are necessary to overcome the identified barriers?

California could lead by example through market interventions, assistance, or support to overcome identified barriers including by:

- **Regulations/Incentives**. Developing supportive policies, providing regulatory mechanisms or incentives for customers to choose low-carbon cement alternatives like CC/LCC; and for companies (manufacturers and suppliers) to invest in low-carbon cement production processes, equipment, infrastructure.
- **Public Procurement.** Adding CC/LCC to the CalTrans Approved Materials List following evaluation and testing would help advance its use in public and infrastructure construction projects and influence its use in private construction projects.
- Working with the insurance industry to reduce professional liability risk or offer protection/indemnification for engineers would allow them to try new low carbon cement and concrete options in construction projects.
- Supporting awareness, education, and training efforts around low carbon concrete alternatives like LCC to increase its use in public procurement projects and promoting workforce training and re-skilling opportunities.
- Supporting updates to building/construction codes that incorporate low carbon concrete alternatives like LCC which would allow its greater use in construction practice.

12) Do you have any additional information that would help the CalMTA evaluate your proposed idea?

CC/LCC meets all 5 CalMTA desired portfolio characteristics offering: 1) GHG reductions (>40%) aligned with CA state 2045 cement sector net zero goals/policies/regulations/ strategies; 2) EJ/equity benefits to CA DACs (improving air quality, green jobs/training; (3) a CA based technology (mine source to infrastructure application) geographically spread across CA to limit foreign SCM (fly ash/slag imports; 4) commercial production in-state in 6 months meeting RFI ramp rate expectations; and 5) potential use in multiple product lines (SCM, blended cements, optimized concrete mixes). California Air Resources Board (developing a plan to reduce state cement GHG emissions) recently visited Purebase (2023e) to gain a better understanding of the carbon reduction potential of its operations.

13) If available, please provide names and links to any recently completed studies, workpapers, measure packages, whitepapers, industry publications, articles, interviews, and other supporting documentation related to this idea.

- ACEEE 2023a https://www.aceee.org/topic-brief/2023/03/planned-strategically-federal-buy-clean-investment-can-increase-its-impact

- ACEEE 2023b https://www.aceee.org/blog-post/2023/06/electrification-key-decarbonizing-concrete-us-investments-should-open-path
- CalTrans 2016. https://purebase.com/wp-content/uploads/2020/07/Cal-Trans-Fly-Ash-Report-2016.pdf
- CARB 2022. https://ww2.arb.ca.gov/our-work/programs/net-zero-emissions-strategy-cement-sector
- Dhandapani et al 2018. https://civil.iitm.ac.in/faculty/pillai/admin/download/Yuvraj%20dhandapani%20mechanical.pdf
- Ez-zaki et al 2021. doi.org/10.3390/ma14113037
- FLSmidth 2020. www.flsmidth.com/-/media/brochures/brochures-solutions/2021/calcined_clay_brochure_2021.pdf
- Guo et al 2022. https://www.sciencedirect.com/science/article/abs/pii/S0959652622024155
- PCA 2021. https://www.cement.org/sustainability/roadmap-to-carbon-neutrality
- Pillai et al 2019: https://lc3.ch/wp-content/uploads/2022/03/Pillai-et-al.-2019-Service-life-and-life-cycle-assessment-of-reinforc.pdf
- Purebase 2023a. https://purebase.com/2023/06/14/favorable-results-on-metakaolin/
- Purebase 2023b. https://purebase.com/2023/06/10/california-calcined-clay-operation/
- Purebase 2023c. https://purebase.com/2023/07/05/phase-1-calciner-now-in-operation/
- Purebase 2023d. https://purebase.com/2023/05/09/construction-of-calcining-facility/
- Purebase 2023e. https://purebase.com/2023/07/17/purebase-corporation-hosts-team-from-the-california-air-resources-board/
- Scrivener 2019: https://lc3.ch/wp-content/uploads/2020/10/2019-LC3FinancialAttractiveness-WEB.pdf
- Specify Concrete 2021. https://www.specifyconcrete.org/blog/lc3-concrete-a-more-sustainable-alternative
- Srinivasan et al 2023. https://www.aceee.org/sites/default/files/pdfs/ssi23/3-129-SRINIVASAN_FNL.pdf
- USGS 2023. https://www.usgs.gov/centers/national-minerals-information-center/cement-statistics-and-information
- Wang et al 2021. doi.org/10.1016/j.cemconres.2021.106421