Summary of Actions on Low Carbon Cement & Concrete

Overview:

Greenhouse gas emissions from cement production in California were 7.8 MMT CO_2e[1] in 2018. Over the last 4 years, there has been very little change in total emissions from cement production (see Appendix 2). If this trend continues, cement will grow from 1.8% to 3% of total California emissions by 2030. Since facility production numbers are not public, there is no way to know if emissions per unit of cement have changed. As we will discuss in this paper, it is possible to reduce the GHG emissions from cement production as well as reduce the amount of cement needed for making concrete.

In this document we recommend 4 Actions that, without any new technology, could reduce emissions from cement in California between 25% and 50% annually by the end of this decade. The evidence for this reduction comes from trends in the California concrete industry and from researching cement facilities in other countries. Cement and concrete mixes used in similar applications have a large variation in emissions due to some cement using considerably less clinker and some concrete mixes using less cement. Clinker is the material produced from calcination of raw materials that is a step in the production of cement. Existing trends, driven by customer interest in sustainability, can be accelerated through the Actions we recommend.

This paper represents the synthesis of information gathered by Project 2030 (see Appendix 1) from multiple reports and interviews with people listed at the end of this paper.

We examine two points of regulation: (1) the emissions from the cement plants in California that are already subject to the Global Warming Solutions Act (AB 32) “Cap and Trade Program”, and (2) the concrete suppliers in California that have the ability to mix different materials when producing concrete and determine the percentage of cement in the mix.

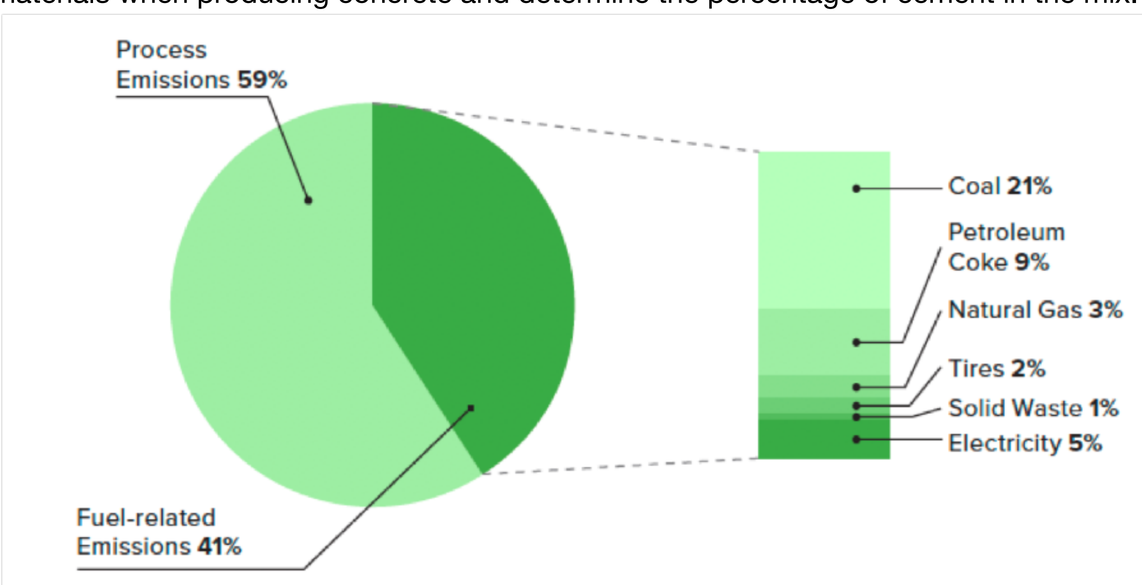

Figure 1: Sources of GHG emissions from California cement companies
Chart from “DEEP DECARBONIZATION ROADMAP FOR THE CEMENT AND CONCRETE INDUSTRIES IN CALIFORNIA” by Ali Hasanbeigi & Cecilia Springer

[1] https://ww2.arb.ca.gov/ghg-inventory-data

Cement Industry: The principal opportunities for GHG reductions for California cement facilities are adding powdered limestone to produce limestone-blended Portland cement, energy efficiency and co-generation, fuel switching, CO_2 sequestration, and use of other cement types (Solidia, LC3, etc.)

Observations:

- The majority of emissions occur from the cement production process that produces the clinker. Appendix 2 shows the emissions from process emissions (about 60%) and energy related emissions (about 40%). In the medium to long term, capturing carbon emissions at the cement plant offers the most reductions and flexibility. However, it will require the cement facility to participate in an overall CO_2 management infrastructure (see Action 4)

- The cement industry is encouraging a transition to portland limestone cement. According to Caltrans METS, this has the potential to reduce carbon emissions from cement by 5 - 10%.
- Some researchers postulate that California cement producers may be less energy efficient than best in class. We found no evidence to confirm or deny this as unit output and the energy inputs are not publicly available.
- The fuel used to heat the cement kiln dominates energy-related emissions. The substitution of alternative fuels (e.g. biomass or low carbon hydrogen) will happen slowly and will be dependent on resource availability near the specific plant and the ability to permit alternative fuels.
- There are alternatives to Portland cement that have reduced process emissions depending on the availability of the materials and the application (discussed below).

Concrete Industry: The concrete industry is highly distributed with approximately 350 separate facilities in California. It sells hundreds of products and formulations. The primary way they can reduce emissions is by designing mixes that use less cement. There are also opportunities to apply waste CO_2 in the curing process to either reduce the amount of cement needed or absorb CO_2 back into the cement during curing.

Observations:

- The most common way to reduce the amount of cement needed is by mixing Supplementary Cementitious Materials (SCM)[2] in the process of creating the concrete mix. This depends on the customer's willingness to specify and accept the mix. It also depends on the availability and pricing of various SCM.
- Carbon Cure[3] sells a process that results in a 5% reduction in emissions from decreasing the amount of cement needed due to the chemical process of curing the concrete in a precisely controlled high CO_2 environment.
- Blue Planet proposes a process of mineralizing waste CO_2 into aggregate that can be blended into cement.
- There are ways to absorb waste CO_2 into the concrete curing process but they are limited by both the very high costs currently associated with purchasing and delivering CO_2 and also the change in pH that will affect certain applications. Action 4 would reduce the high cost by creating a market for waste CO_2 that is separate from the "Food grade" waste CO_2 market.

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[2] https://www.sciencedirect.com/topics/engineering/supplementary-cementitious-material

[3] https://www.carboncure.com/

- Action 3 would incentivize concrete manufactures to produce concrete using less cement and explore alternative cements. It would spur innovation at both upstream and downstream levels in manufacturing and construction - upstream with cement producers, alternative SCM's discoveries and downstream at all levels of design & construction.

As a specific example, changing the mix of clinker with other materials to produce concrete has immediate short term potential emission reductions. The choice of mix is typically specified by the customer. For example, a database of over 20,000 Environmental Product Declaration (EPDs) for concrete maintained by Climate Earth shows that for mixes of 6,000 PSI compression strength concrete, the average kg CO2-equivalent per meter cubed was 490 while the minimum was 178 and the maximum was 692![4] While there are other factors besides compression strength - including cure time and workability - the large variation demonstrates considerable opportunity. Our Action 1 (below) proposes expanding the existing EPD process so it can be used to measure compliance with GHG standards.

GHG Performance: The only government reported measurement of GHG emissions is the CARB required reporting[5] on emissions from the production of cement at the California facilities (displayed in Figure 2 and in Appendix 2). The Portland Cement Association reports annual production for California which is included in Appendix 2. Voluntary Environmental Product Declarations (EPD) used by the concrete industry to report GHG emissions have made remarkable progress in the last few years.[6] The State of California could build on the EPD structure (see Action 1 below on GHG calculation standard.) which would ensure consistency and reduce overall compliance costs.

There is currently no GHG regulation on concrete - only the cement portion. In addition, we can expect that the current practice of mixing fly ash as an SCM, a byproduct of burning coal, will eventually be impractical due to the desired goal of reducing the use of coal for energy production.

Suggested Actions:

We suggest 4 Actions that can transition the cement and concrete industries towards significantly lower GHG emissions.

Action 1: *Sanction standard GHG calculations.* Many suppliers already provide or are asked for Environmental Product Declarations (EPDs). Fortunately, there is significant acceptance of a common approach for EPDs. In February, 2019, the National Center for Sustainability Standards issued Version 2.0 of the Concrete Product Category Rule (PCR).[7] Since that time, hundreds of cement and concrete suppliers have standardized their EPD reporting based on the PCR. Similar to the Low Carbon Fuel Standard (LCFS) pathways, the state could examine the current approach used by industry and develop a standard to audit/authorize its use. Suppliers could then use the state standards (with 3rd party verification) so customers can compare the GHG performance of products. Companies with better GHG performance could apply for special pathways as with the LCFS. Authorizing a standard GHG method of

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[4] https://www.climateearth.com/concrete-selector-2/

[5] https://ww3.arb.ca.gov/cc/reporting/ghg-rep/guidance/cement-product.pdf

[6] https://d2evkimvhatqav.cloudfront.net/documents/concrete_pcr_2019.pdf

[7] https://www.nsf.org/newsroom_pdf/concrete_pcr_2019.pdf

calculation is a required precursor to Actions 3A and 3B.

Action 2: *Caltrans and Local Government approval of lower carbon cement formulas.* Approximately 40% of cement used in California is specified either by CalTrans or by local governments for their roads and sidewalks. Caltrans Department of Materials, Engineering and Testing Service (METS) has identified two promising near-term emission reduction actions: 1) Allow the use of 15% limestone content in cement, which would result in a 5-10% GHG reduction, and 2) Inject purified CO2 into wet concrete to reduce the amount of cement needed. This would result in a 5-10% GHG reduction.

Most cement is purchased by specification rather than a performance standard. The difference is that a performance standard would specify the properties of the cement (compressive strength, curing speed, etc.) while the specification approach states which materials can be used and in what ratios. A performance standard would allow more flexibility for the producer within a range of costs and provide more flexibility to optimize the GHG reductions. Possible changes to local government procurement would include (1) removal of minimum cement contents and replace with performance standards, (2) allow the use of SCMs, allow innovative practices as long as they meet performance requirements. The UC Davis Pavement Research Center has documented that these changes can reduce CO2 per unit of mix by nearly 35%[8]. Local governments should be required to review and update their concrete specifications.

Action 3A: *Create a financial incentive for use of lower GHG concrete.* Within the past year, procurement policies for low-carbon concrete have been proposed in Portland, Marin County, Hawaii, Austin and New York. Since government purchases of concrete is such a large part of the market (estimated at 37% nationally), a competitive bidding process that includes GHG performance as quantified in Action 1 would move the whole market. The choice of concrete mix is currently a trade-off between three characteristics: (1) performance (e.g.. compression strength), (2) workability (e.g. can it be pumped, curing time), and (3) durability (lifetime). This action would require a 4th consideration - GHG emissions. Using all 4 characteristics will drive innovation in the industry. The State of New York recently introduced legislation that requires the establishment of a preferential standard and incentives for low embodied carbon concrete for state projects. Carbon capture and utilization technologies will receive additional financial incentives. This legislation also suggests an EDP tax credit[9].

California could create a financial incentive for suppliers of low GHG concrete produced and cured in California. Each year the required minimum GHG reduction would be increased based on available production capacity. The financial incentive could be any form of allowances provided to the concrete company (or sold on their behalf), tax credit or direct payments.

Another approach would be to authorize the bidding process to recognize reduced GHG as part of the bidding process and allow, for example, up to 8% price premium for lower GHG (scaled to the GHG benefit). The advantages of this approach are to encourage competition based on GHG as well as the price of products that meet the performance requirements. I bidding premium would need to consider two time frames: (1) the minimum performance guaranteed in the contract and (2) the actual performance at the job site. Since there can be a considerable time difference between contract award and delivery of concrete, some contract

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8 http://www.ucprc.ucdavis.edu/ccpic/DownloadHandlerAsync.ashx?Filename=PDF/CCPIC_4-pgr_conc%20mix%20specs_final_21Jun2019.pdf

9 https://nyassembly.gov/leg/?default_fld=&leg_video=&bn=A08617&term=0&Summary=Y&Text=Y

value should be held back to incentivize what can actually be delivered.

Action 3B: *Create a Low Carbon Concrete Standard.* This action is a complement to 3A. Rather than only a financial incentive paid from various sources, CARB would establish a GHG performance level for different strengths of concrete and establish a credit trading system. Those who supply concrete with lower GHGs would receive credits and those who produce concrete higher than the standard would be required to purchase credits. Concrete imported from outside of California would be subject to the same standard. We believe that some air quality districts may already collect much of the information needed. This more ambitious action has the benefits of self funding and market based pricing but also has the problems of regulating a large number of facilities (350) and a large number of concrete formulations. A possible solution to regulating the large number of concrete suppliers would be to have mandatory regulation on the larger suppliers and opt-in for the smaller suppliers.

It is difficult to define a common unit of production. Unlike, for example, transportation fuels in the LCFS that have specific definitions, there are many variations in concrete mixes based on the application and local resources. Our proposal is to establish a set of GHG standards based on compression strengths. Rather than a specific number, a range +- 15% within the target would be considered meeting the target. We recommend starting with the national averages as documented by the National Ready Mixed Concrete Association (NRMCA). We believe these average are typical of California producers and represent the diversity of regional differences. Every few years, the targets would be tightened to reflect progress in the marketplace. Exceeding the range would create credits and below the range would create deficits that would need to be made up by purchasing credits. The target would be ratcheted down over time. Appendix 3 has our recommendations (assuming starting in 2023).

While the majority of GHG emissions occur from the production of Portland cement, we need to encourage innovation at every level of the process from the customer's requirements to the architect and engineers specifying the properties of the concrete to the production of the concrete. In California, we currently only apply regulations at the original emissions source - the cement manufacturer. The concrete supplier is closer to the end customer and has the most opportunity to influence the concrete mix and create a competitive procurement environment for lower GHG cements. Action 3B creates opportunities - and requirements - at the point in the supply chain that has a great opportunity for innovation.

Table I. Relative CO_2 emissions for alternative cements and other binder technologies on a gram-per-gram of material basis compared to ordinary portland cement.[58]

Cement or Binder	Relative CO_2 Emissions (%)	Reference(s)
Portland cement	100	47
Limestone-blended portland cement	70–85	36
Calcium sulfoaluminate cement	51	48
Calcium sulfoaluminate belite cement	84	49
Calcium aluminate cement	53	50
Magnesium phosphate cement	55	52
Chemically activated aluminosilicate binders*	44–64	53

Source: "Innovations in cement-based materials: Addressing sustainability in structural and infrastructure applications". MRS Bulletin - December 2015

While Portland cement has a variety of ways to reduce emissions during production, including the recent push to include more uncalcined limestone in the mix, there are many interesting approaches for other cements. A recent article[10] by Kimberly Kurtis of Georgia Institute of Technology compares estimates from a variety of cements (see chart above). While it is beyond the scope of this paper to predict which of these will gain market acceptance and commercial availability, the concrete industry needs to become an active participant in the search for customer acceptance of new materials that can meet price, performance and GHG reductions.

Action 4: *Create an infrastructure for the capture, distribution and conversion/sequestration of waste CO2.* The goal of carbon neutrality by 2045 requires existence of an infrastructure for the capture, distribution and disposal of CO2 to either (1) geological sequestration or (2) conversion to a "Carbon to Value" (see Carbon Xprize[11] for examples) including (1) concrete curing locations, (2) conversion to petrochemicals, fuels and plastics (for example, CO2 can be electrochemically converted to ethylene and from there to polyethylene).

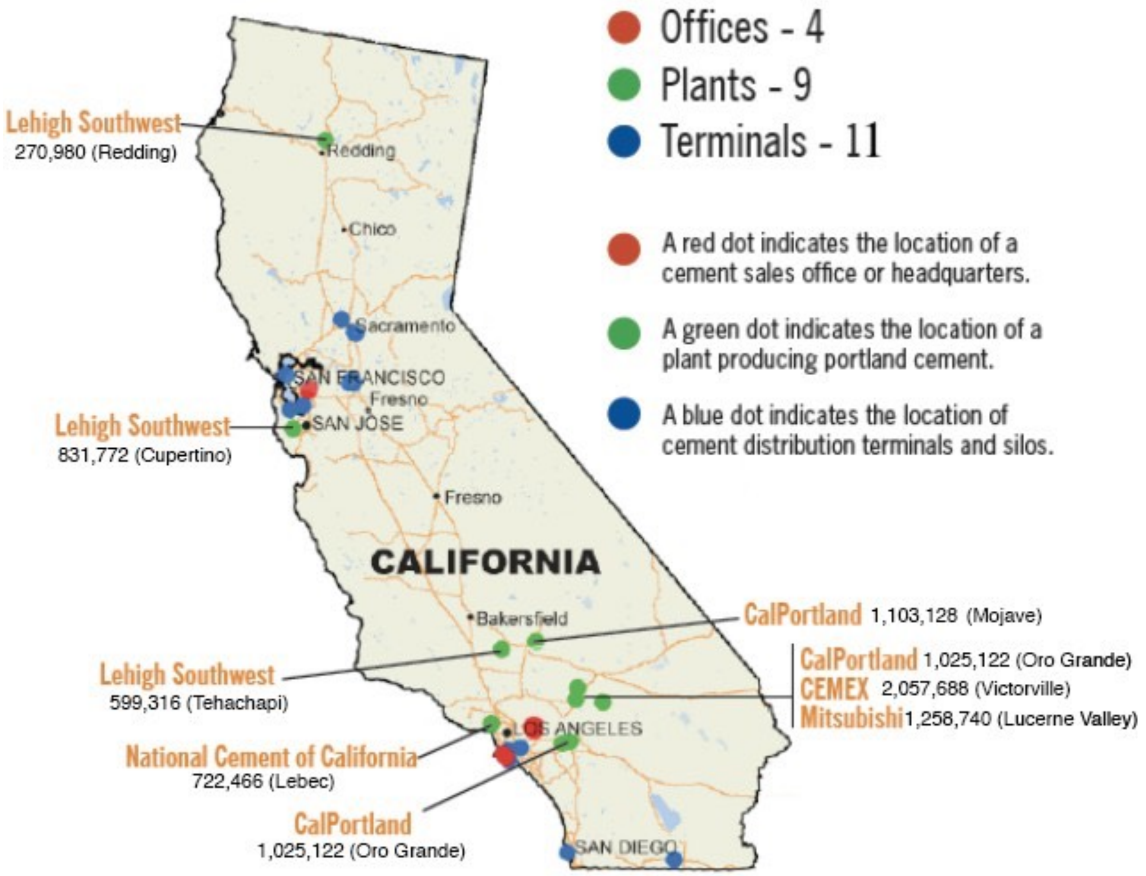

Figure 2: Locations of cement plants in California including 2017 GHG Emissions (ktCO_2e)
Chart from "DEEP DECARBONIZATION ROADMAP FOR THE CEMENT AND CONCRETE INDUSTRIES IN CALIFORNIA" by Ali Hasanbeigi & Cecilia Springer

[10] https://cbid.gatech.edu/wp-content/uploads/2018/12/MRS-2015-Kurtis.pdf

[11] https://carbon.xprize.org/prizes/carbon

Industry is already in the process of serious evaluations of creating CO_2 capture and disposal. For example, Svante, LafargeHolcim, Oxy & Total announced a joint study of carbon capture of emissions from cement for deployment in the Florence, Colorado facility.[12] Svante would provide the CO_2 separation technology. In September 2020, the project received a grant from DOE for $1.5M to cost share in the engineering analysis for evaluating the feasibility of the facility designed to capture up to 2 million tonnes of carbon dioxide per year directly from the Holcim cement plant and the natural gas-fired steam generator, which would be sequestered underground permanently by Occidental.[13]

Closer to home, Chevron Technology Ventures announced an evaluation for a small volume, CO_2 capture for their steam generation facility in Kern County.[14]

The market for waste CO_2 needs to evolve. Currently the main market is for food grade CO_2. For example, ethanol facilities capture CO_2 and clean it to food grade and after distribution it sells for $200/ton and up depending on distance traveled. The market for sequestering CO_2 does not require food grade CO_2 nor can it compete with food-grade pricing. It will benefit from the availability of a separate market. Cement plants can be one of the first producers of non-food grade waste CO_2 used in the market.

Svante Inc. estimates that CO_2 can be separated from the exhaust of a cement plant at a cost of $50/ton of which $30/ton is the capital cost and $20/ton is the operational cost. Since it requires energy to perform the separation, there is a parasitic load loss of 10 - 20% of CO_2 embedded in the energy needed to operate the motors and generate the steam needed.[15]

There are two parts to Action 4. The first is the development of producers and consumers of waste CO_2 that is distinct from the food CO_2 market. Delivery would be by truck. As volumes increase, capture technology improves[16] and carbon prices rise, geological sequestration will become practical and transportation will move from truck to unit train to eventually pipeline. This Action could identify an initial region (for example the Bakersfield area where Lehigh Southwest and CalPortland both have facilities) and a geological sequestration location. The Global CCS Institute is projecting the cost of CO_2 capture from the smokestack at $35 - $45/ton by 2025[17]; however, that can be offset by its value under the Federal 45Q tax credit of $50/ton starting in 2023 and potentially purchasers of CO_2 for commercial uses. A recent joint study by Energy Futures Initiative, Stanford Precourt Institute for Energy and Stanford Center for Carbon Storage provides details on how this can be done in California[18]

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[12] https://svanteinc.com/svante-lafargeholcim-oxy-low-carbon-ventures-and-total-launch-study-for-commercial- scale-carbon-capture-and-end-use-at-u-s-plant/

[13] https://www.lafargeholcim.us/us-department-energys-national-energy-technology-laboratory-announces-investment-further-develop-lh

[14] https://www.businesswire.com/news/home/20200206005545/en/

[15] Estimate provided by Svante in a conversation in October 2020.

[16] https://svanteinc.com/

[17] https://www.globalccsinstitute.com/news-media/events/ccs-talks-the-technology-cost-curve/

[18] https://sccs.stanford.edu/sites/g/files/sbiybj7741/f/efi-stanford-ca-ccs-full-rev1.vf-10.25.20.pdf

This action would be key to developing an overall plan for the capture of waste CO2 and its distribution to the highest value sites. A full operation by 2030 could be a game changer as the major sources of waste CO2 in California could be collected and distributed. The long-term plan should be the construction of a CO2 pipeline once the supply is sufficient. If in the same timeframe, the production of carbon-free hydrogen and demand for hydrogen (transportation, process heat or power) were sufficient, a H2 pipeline could be built concurrently in the same trench.

If a CO2 mineralization process becomes commercially viable, a cement company could also chose to mineralize captured CO2 and either blend the minerals into the cement or sell the minerals to be embedded into any application that can use the resulting aggregate (Blue Planet is an example of such a process[19] but does not have a commercial operation yet).

[19] http://www.blueplanet-ltd.com/

Appendix 1

Summary of Source Interviews:

This paper solely represents the ideas and thoughts of the Project 2030 team. We are grateful to the people listed below who informed us and were very generous with their time:

Dan Lashof, Kevin Kennedy - WRI
Rebecca Dell, Anthony Eggert - ClimateWorks
Jason Mark - Energy Foundation
Chris Busch - Energy innovations
Roland Hwang and team - NRDC
Arpad Horvath - UCB Civil Engineering
Ken Alex, H. Jordan Diamond, Ethan Elkind, Judith Katz, Ted Lamm - Berkeley Law CLEE
Ali Hasanbeigi - Global Efficiency Institute
Jennifer Mitchell - Capital Projects, LinkedIn
Sabbie Miller - UC Davis Civil Engineering
Julio Friedman - Columbia University
John Harvey - UC Davis Civil Engineering
Blue Planet - Brent Constantz
Keith Hoffman, Jacquelyn Wong - California Department of Transportation
Tony Hadley - Baobab Advisory SARL
Deepika Nagabhushan - Clean Air Task Force
Jeremy Gregory - MIT Concrete Sustainability Hub
Roger Aines, George Peridas - Lawrence Livermore National Labs
Chris Erickson - Climate Earth
Megan White - Integral Group
Rob Niven - Carbon Cure
Herb Burton, Juan Gonzales, Alana Guzzetta - Central Concrete
Tom Tietz, Bob Houston, Bruce Magnani - California Nevada Cement Association
Mark McNulty – KeyBridge Research
Erika Guerra - Lehigh Hanson Cement Group
Tien Peng - National Ready Mixed Concrete Association
Charley Rea - CA Construction and Industrial Materials Association (CalCIMA)
Brett Henkel, Dan Miller - Svante Inc.
Steve Lode - National Ready Mix Concrete Company
Kate Simonen, Meghan Lewis - Carbon Leadership Forum, University of Washington
Chris Neidl, Advocate
Jeff Davis, U.S. Concrete (Retired)

About Project 2030

Project 2030's goal is to exceed California's 2030 GHG reduction targets and put California on a path to be carbon neutral by 2045. While Project 2030 is emphasizing efforts in California, the ultimate goal is to work on efforts that are replicable and make economic sense for sub-national, national, and international efforts. Between now and the end of 2022, we will identify opportunities - both policy and business opportunities that can significantly accelerate the ability of California to both reduce greenhouse gas emissions and to sequester CO_2 emissions and atmospheric CO_2 into permanent structures of value.

Our team consists of business and policy leaders who all volunteer their time. Team members are Tony Bernhardt, Diane Doucette, Bob Epstein, Anna Halpern-Lande, Noëlle Leca.

Appendix 2 - GHG Emissions from Cement Production in California

Emissions (MMT CO2e)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Cement Plants	**9.50**	**9.28**	**9.83**	**9.90**	**10.08**	**10.03**	**9.76**	**9.25**	**8.64**	**5.73**
Clinker Production	5.52	5.28	5.82	5.87	6.03	5.96	5.81	5.66	5.28	3.60
Fuel Use	3.98	4.00	4.01	4.03	4.05	4.06	3.95	3.59	3.35	2.13
Fuel %	42%	43%	41%	41%	40%	40%	40%	39%	39%	37%
Production (MMT)							10.6	10.5	9.5	8.8
Emissions/MMT							**0.92**	**0.88**	**0.91**	**0.65**
Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	
Cement Plants	**5.57**	**6.15**	**6.93**	**7.21**	**7.66**	**7.47**	**7.60**	**7.66**	**7.80**	
Clinker Production	3.46	3.70	4.22	4.47	4.78	4.69	4.67	4.85	4.96	
Fuel Use	2.11	2.45	2.70	2.74	2.88	2.77	2.93	2.81	2.91	
Fuel %	38%	40%	39%	38%	38%	37%	39%	37%	37%	
Production (MMT)	8.4	9.5	8.6	9.2	9.5	9.7	9.8	10.0	10.4	
Emissions/MMT	**0.66**	**0.65**	**0.81**	**0.78**	**0.81**	**0.77**	**0.78**	**0.77**	**0.75**	

Production data from Portland Cement Association 2018 report
Emissions data from CARB 2018 inventory

Appendix 3 - Recommended Emission Targets for Action 3

	Target maximum embodied carbon (kg CO2e/m3)			
		Initial Target	20% Reduction	40% Reduction
Min f'c (psi) @ 28 days	**Year 2023**		**Year 2026**	**Year 2029**
		+- 15%		
<2500	267	233-316	214	160
3000	292	255-344	234	175
4000	344	297-402	275	206
5000	407	349-472	326	244
6000	430	371-502	344	258
>7001	498	426-575	398	299
Note: Year 2023 targets are the actual U.S. averages in 2019 as reported by NRMCA				

Averages from 2019 come from NRMCA Member National and Regional LCA[20]

[20] https://www.nrmca.org/wp-content/uploads/2020/02/NRMCA_REGIONAL_BENCHMARK_Nov2019.pdf