Introductory Information

Sector Background

1) The location and/or geographic extent of the sector as it would pertain to the Plan

The extent of effect could include North America and Eastern Asia.

- California: Cement and concrete are produced throughout California.
- Border states: Cement and concrete are delivered to and from the Border states.
- Canada: Cement and fly ash are shipped from Canada to California.
- The United States, other than California: Fly ash and slag are not produced in California, but railed to California from many places throughout the greater U.S.
- China, Thailand, Japan, and Mexico: Cement is shipped to California from these countries.

2) Unique considerations or issues with sector

One of the special considerations in this sector is the importing component of the emissions. It takes a great deal of energy to ship cement across the ocean. If imports were left out of the GHG calculation, it would prevent additional GHG savings for this sector. For instance, if the implementation of concrete strategies were limited to cement produced in California only, an equivalent of 40 percent of the California cement usage would not have to reduce GHG emissions. That portion of the market would have very little GHG savings compared to the portion of the market that could be affected by these strategies (i.e. cement produced in California).

Sector Overview

3) Proposed emission reduction pathway for the sector

In order to reduce GHG from this sector, it is essential to develop a control measure. At this point, the best control measure parameter seems to be a carbon intensity factor (CIF), which is the amount of CO_2 generated per the amount of cementitious materials in the same unit. Cementitious materials are cement and supplementary cementitious materials (SCMs). Traditional control regulations could be used to measure this parameter. The biggest challenge would be the selection of a point to regulate (cement plants, batch plants, precast industries, etc) and the frequency (by load, by year, etc) of control. There is some potential for incentives in this sector for innovative companies.

4) The potential for leakage from the sector

There is a potential for leakage in the cement sector. If the regulations to reduce CO_2 intensity for cement are stringent, and cost effective options are not available, then the cost of cement produced in California could increase. This would give an advantage to imports and cause leakage.

5) Role of local, state, and federal government

The Air Resources Board (ARB) appears to have the authority to enforce much of the emission reductions for this sector. However, policy changes or legislative bills may be necessary to help the implementation process. For instance, it is necessary to change the existing policies to make it easier for cement plants to get permits to use alternative fuels such as recycled solid waste including tires.

A legislative bill would be necessary to limit the carbon dioxide intensity of cement and concrete. It is not believed additional bills would be necessary as flexibility should be given to cement and batch plants to meet their goals. This sub-group is not aware of any pending bills likely to affect this sector. A policy, however, will soon affect this sector, as cement plants will be mandated to report their emissions to ARB. This policy change will provide reliable data to better estimate cement intensity. As concrete intensity would be affected by imported cement, it would also be necessary to have cement plants that export cement to the U.S. report their clinker and cement intensity, as they should be held to the same intensity as clinker and cement produced in the U.S.

One area over which the ARB does not have jurisdiction is the multitude of engineering specifications that are used by engineers throughout California. These specifications are controlled by ASTM, The Structural Engineers Association of California, The American Concrete Institute, Caltrans, Greenbook, the Building Standards Commission, etc. If changes are to be made, they must be in harmony with the specifications that exist.

6) Public-private interface

This is not applicable to this sector as all cement and batch plants in California are privately owned.

7) Interaction with other sectors

Among all the others sectors, there are three that may have ties or impacts with cement.

1. Green Building: There is potential to have some type of link with the concrete sector as they should also be interested in reduced CO_2.
2. Vehicles: The Concrete Industry is populated with trucks that deliver aggregate, sand, cement, and concrete. There may be some opportunity for interaction.
3. Land Use: If there is a desire for additional cement plants in California, there may be helpful coordination with permitting.

8) Integration with regional, national, or global programs

This sector does not need to integrate its emission reduction strategies into any other program as they are self-sufficient within California. The strategies developed within this sector can be used by other states and the WCI to implement similar emission reduction strategies. Other countries such as those that have already adopted the Kyoto protocol (e.g., European Union) must have some type of emission reduction program in place but the sub-group has never met or known of any such programs.

9) Consideration of longer-term goal for 2050

In order to obtain the required 2050 emission reduction for this sector, an increase in the use of SCMs would not be enough as cement consumption alone in 2050 should be almost three times the amount it was in 1990, assuming a linear growth of 2 percent a year since 2005. Thus, it is imperative that a methodology be developed such as sequestration. Sequestration was not a part of the 2020 strategies developed by this sub-group because it is uncertain if this technology would be available.

Emission Reduction Strategies

10) Description of the sector's emission reduction approach

The selected approach was to separate potential emission reductions into cement production and concrete application. The strategies consisted of limiting carbon dioxide intensity from both of these industries. The cement measure was divided into the following strategies:

- Improve energy efficiency,
- Use environmentally friendly fuels,
- Use interground limestone addition,
- Blend SCMs at cement plants.

The concrete measure was divided into the following strategies:

- Reduce concrete waste,
- Use less cement,
- Blend SCM at batch plants.

For more details about these strategies, please see the measure analysis where each of these strategies is described in detail.

11) How were emission reduction measures developed or evaluated?

The selected emission reduction measures evolved during about 20 meetings of the CAT cement sub-group. Each of the major stakeholders of this sector (cement industry, concrete industry, and environmental groups) participated in at least two meetings each. The cement industry also participated in a meeting with concrete suppliers since these two industries work closely together. In another instance, this sub-group met with the lead concrete suppliers. There were also field trips to cement and concrete plants.
The selected metric was million metric tons (MMT) of CO_2 emissions since this is the major GHG released during cement production. The emission reduction associated with each of the selected strategies, under each measure, was a factor to determine if it would advance into the Scoping Plan, but they had to be technically feasible and cost effective. For instance, although sequestration had a great potential to reduce GHG from cement production, it was not selected as a strategy for the 2020 target of AB32 because it is not technically feasible yet. Other strategies were also eliminated because they would not be cost-effective. For instance, the environmental groups wanted all cement plants in California to switch to natural gas instead of using coal. However, that would likely run some cement plants out of business because it would require high capital investment to retrofit their current system and would considerably increase their operational cost as the

price of natural gas is much higher than coal. In addition, the supply of natural gas could be a problem in California.

12) Ensuring real, permanent, quantifiable, verifiable, and enforceable reductions

The implementation of AB32 will be measured in terms of a CO_2 intensity factor, which can be verified and enforced at cement and batch plants. It is expected that fines or penalties will be a part of regulations or bills for companies that do not comply.

13) Existing controls resulting in emission reductions and co-benefits

The co-benefits of using alternative fuels in the cement manufacturing process have already been discussed earlier.

14) Early Action Measures, Discrete Early Action Measures, CAT Early Action Measures

The following three strategies proposed by this sub-group were in the Early Action Measures (EAMs): improving energy efficiency, using interground limestone, and blending SCMs.

15) Public Solicitation Measures

All suggestions and comments received by ARB were discussed not only among the group members but also during meetings with the cement industry and the environmental groups, which are two of the major stakeholders of this sector. This sub-group felt it was important to address public comments and concerns even before they were brought to the group's attention. Whenever technically feasible and cost effective, their suggestions were incorporated into one of the selected measures.

16) Expected reductions from the overall sector approach

The GHG savings associated with the proposed cement and concrete measures are shown in Figure 1 for alternatives I and II, respectively. If both cement and concrete measures are implemented, the CO_2 emission reduction would be 8.13 MMT of CO_2 for alternatives I. Therefore, the total CO2 emissions in 2020 would be 13.74 MMT of CO_2. A reduction to the 1990 level by 2020 is possible.

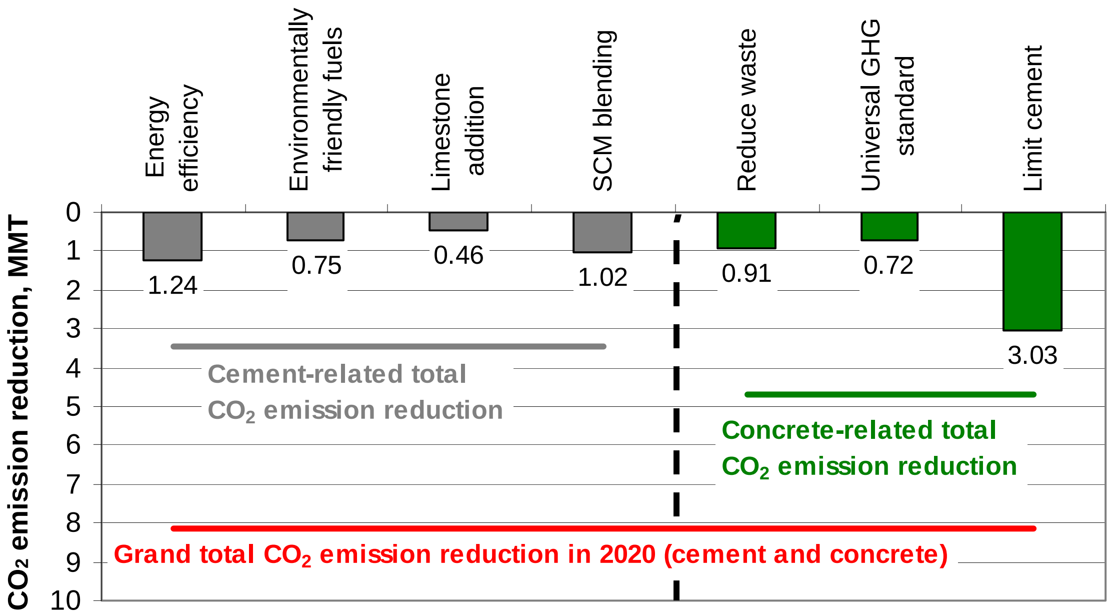

Figure 1. CO_2 emission reduction for cement and concrete (alternative I).

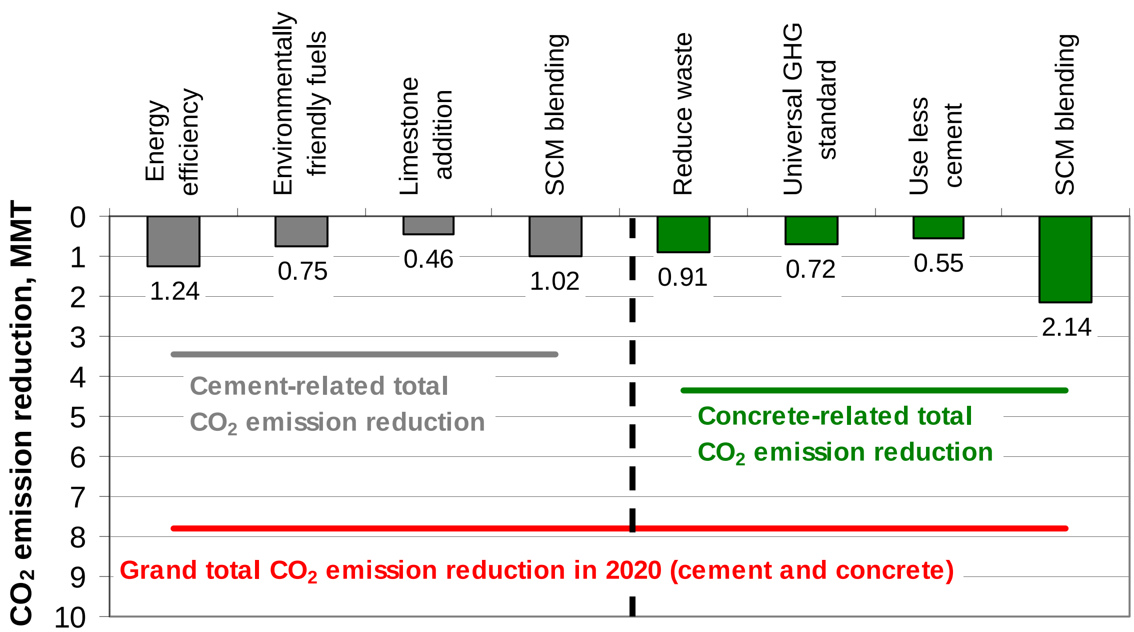

Figure 1. CO_2 emission reduction for cement and concrete (alternative II).

21) Public health effects—Effects on air quality

The strategies proposed by the cement sub-group are not going to adversely affect the public health concerns regarding air quality standards such as criteria pollutant or toxic emissions. These strategies have the potential to improve air quality as less CO_2

emissions and other GHGs (methane (CH_4) and nitrous oxide (N_2O)) will be released during cement production. Some environmental groups are concerned about using alternative fuels such as tire-derived fuel (TDF) but it has not been scientifically proven that it increases criteria pollutants or toxic emissions.

22) Environmental justice impacts

The emission reduction strategies proposed by this sub-group will not have disproportionately negative impacts on health or economics of low-income communities.

Summary and Conclusions

This sector has the potential to make realistic and attainable GHG reductions well before 2020. There is no new technology that is required to achieve the strategies proposed. The sector has the ability to maintain the quality of the concrete and cement, and still achieve reductions of up to 8 MMT of CO_2 prior to 2020. While the industry has multinational billion dollar companies involved who have the capital to make changes, many small business are willing to make changes if the changes are across the board and cost effective.

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1. Measure: Cement GHG Intensity

2. Agency: CARB

3. Measure Description

This measure will reduce greenhouse gases (GHGs) by limiting the amount of allowable GHGs at the cement plants. One of the biggest advantages of this measure is that it gives the cement plants flexibility to reduce their emissions by giving them various options to work with. Cement production emits GHGs because of (1) calcinations and (2) fuel combustion. There is nothing that can be done to control the first source of emission, calcination. Therefore the only controllable GHG source is fuel combustion. If environmentally friendly fuels are used, such as zero sum gain products, there are further savings.

Another way to reduce cement carbon intensity is to add either a filler or supplementary cementitious materials (SCMs). An example of filler would be inert limestone. ASTM allows up to 5% limestone. In terms of SCMs, there are several options that can be used including fly ash, slag, and natural pozzolan. In summary, this measure can be accomplished through several strategies, including improvement of energy efficiency, use of environmentally friendly fuels, and addition of limestone and replacement of cement with SCMs at the cement plants.

Overview

By limiting the cement's carbon dioxide intensity, GHG emissions can be reduced using several strategies. This gives flexibility to the cement plants to reduce their GHG emissions. It is anticipated that cement plants will reduce their carbon dioxide footprint using a combination of the following strategies: improvement of energy efficiency, use of environmentally friendly fuels, addition of limestone, and replacement of cement with SCMs at the cement plants. With the exception of environmentally friendly fuel, these strategies would reduce not only fuel-related GHG emissions but would also avoid the calcination-related emissions in the production of a given amount of cement.

The cement industry in California reports that it is among the most efficient in the world in terms of equipment. Additional improvement in energy efficiency may not be cost effective because the gain in energy efficiency may be too small compared to the cost of equipment replacement. It has been reported that the newest cement plant in California built recently has a GHG intensity of only 0.02 lower than the 2005 California average GHG intensity factor of 0.86. According to the California Cement Industry (2008), the energy efficiency of California cement plants are 15 percent better than the average U.S. value since 1995.

The environmentally friendly fuel strategy would reduce GHG emission by using less carbon intense fuels. Therefore it would avoid all GHG emission sources associated with fuel combustion only. Most of the CO_2 emissions from fuel combustion come from coal. Coal is widely used because it has the most BTU's per pound of fuel. Figure 1 shows that coal constitutes about 73 percent of all emissions from fuel combustion by cement plants in California in 2005. This number has decreased since 1990 when coal was responsible for about 85 percent of all fuel combustion emissions.

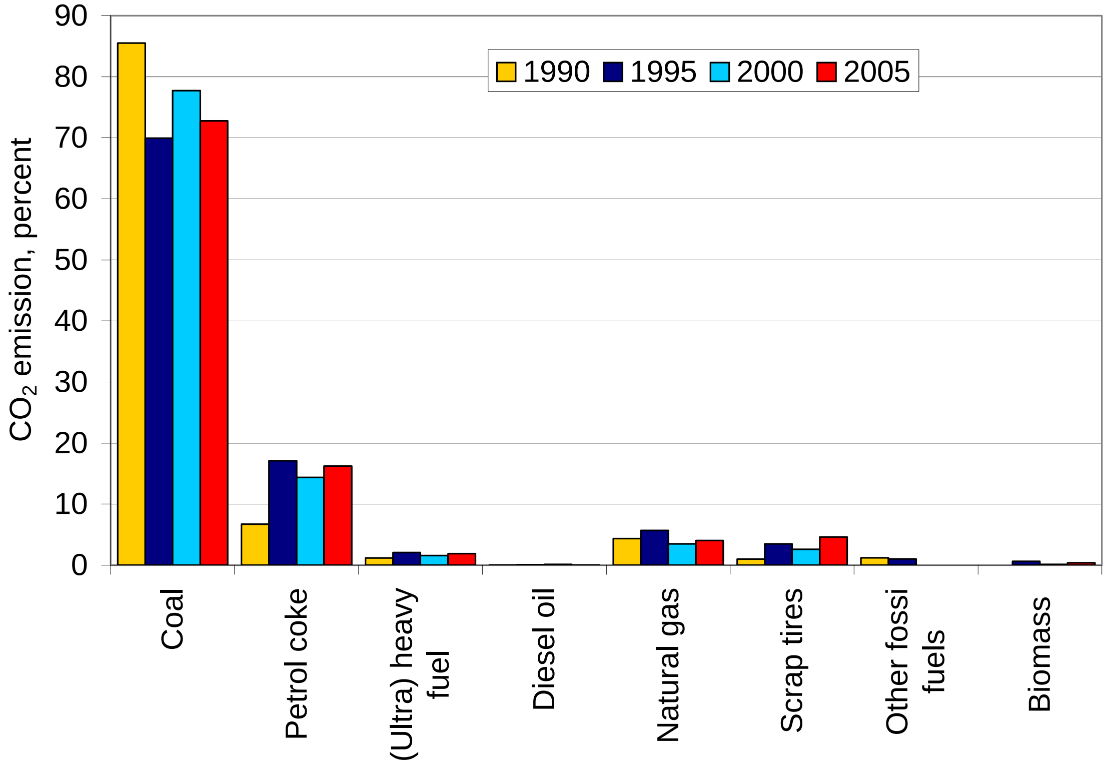


Figure 1. Carbon dioxide emissions from fuel combustion in CA (Source: PCA, 2007).

The limestone addition strategy consists of replacing cement with interground limestone. Since interground limestone is added at the end of the cement production line, the cement-related greenhouse gas (GHG) emissions will be almost proportionally reduced to the amount of limestone added. The GHG savings comes from avoiding GHG emissions associated with cement production, which are mainly the following: (1) calcination and (2) fuel combustion.

Finally, SCMs can be used to replace cement at the cement plant. Similarly to interground limestone, SCMs would be added at the end of cement production avoiding fuel-related emissions. As SCMs are most commonly by-products, the only GHG costs associated with them are those from transportation, which are typically 0.012 and 0.025 ton of CO2 per ton of fly ash and slag, respectively.

<u>Affected Entities</u>

This measure will affect operators and owners of all 11 cement plants in California, as well as entities that use concrete as a construction material. One of the strategies (replacement with SCM at the cement plant) may affect cement customers in California as they may not be able to pursue cement without SCM in some instances. Other strategies such as the limestone addition may not have any effect as cement plants have already being adding limestone to their cement since last year.

Environmental Justice, Small Business, Public Health, Leakage and CEQA

At this point, the cement subgroup has had several meetings with three of the most interested parties in this process: environmental groups, cement plant operators and the concrete industry. During these meetings we have discussed the strategies with them and heard their comments, concerns, and suggestions. All the other interested parties and stakeholders will have an opportunity to comment about this measure during the Scoping Plan process via workshops, subsequent meetings, or written comment. This measure is not going to affect in any way the public health concerns regarding air quality standards and toxic emissions. In fact, this measure has the potential to improve air quality. Therefore, it is not expected that CEQA findings will have any opposition to this measure. Similarly, it does not have any potential detrimental effect on small businesses or leakage, since the cement plants have been given flexibility to reduce their GHG emissions in the most cost-effective way.

At this point, the Environmental Justice Advisory Committee has not participated in the development of this measure, and it is not expected they will have any major comment about this particular measure.

Related Objectives

This measure is motivated primarily by its greenhouse gas emissions reductions. This is the main reason for implementing this measure. It is possible there is some reduction in mercury emissions if fuels other than coal are used. In addition, as the use of recycled materials are incentivized, there is the additional benefit of reducing landfill material.

Measure Metrics

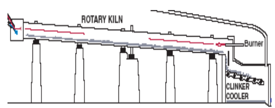
This section intends to define the metrics, whereas next section shows an estimation of the annual GHG savings on a yearly basis. The metrics for each strategy to describe the size, progress, and timing of this particular measure, are described as follows:

- The metrics associated with energy efficiency and type of fuel could be measured in terms of reduction of the carbon intensity factor, which could then be easily converted to MMT of GHG per MMT of cement produced in California. Fuel combustion accounted for a carbon dioxide intensity factor of only 0.40 in 1990. In 2005, this number was reduced to 0.34, as shown in Figure 2. Therefore, there was a reduction of 0.06 in the average carbon intensity factor from fuel combustion between 1990 and 2005. This reduction can be converted to 0.69 MMT savings of CO_2 in 2005. This number is obtained by multiplying the carbon intensity reduction of 0.06 by the 2005 California cement production of 11.56 MMT, according to Van Oss (2004). If alternative fuels are used, there is the potential to reduce fuel-related GHG to a carbon dioxide intensity factor lower than 0.34. For instance, if 10 percent carbon-free fuels are used, this would have represented a savings of 0.39 MMT of CO_2 in 2005.
- The metrics associated with the limestone strategy could be reported in terms of the percent reduction of the carbon intensity factor in a given year, which can be easily converted to the CO_2 from cement production in California in a given year. For instance, it is possible to illustrate the emissions and reduction in MMT of CO_2 based on the cement production in a

given year, as shown in Figure 3 for 2005. It is observed that this measure would reduce GHG by 0.30 MMT if the amount of limestone used is 3 percent. This GHG savings are based on the 2005 California cement production of 11.56 MMT, according to Van Oss (2004) with the U.S. Geological Survey, and the CO_2 intensity of 0.86, according to PCA (2007).

- Similarly to the limestone strategy, the metrics of associated with the use of SCMs should be measured in terms of percent reduction of the carbon dioxide intensity factor. For instance, assuming that in average SCM replaced cement in 10 percent of the total cement produced in California, then this number could be applied to the 2005 carbon intensity factor of 0.86 to calculate the carbon dioxide savings of cement that year. As in 2005, a total of 11.56 MMT of cement was produced, the savings due to the use of SCM at the cement plants would have generated a savings of about 1 MMT of CO_2.

CO_2 intensity factor ($MMT\ CO_2$/cement)



		1990	2005	Change
Calcination	$CaCO_3 = CaO + CO_2$	0.52	0.52	0.00
Fuel Combustion		0.40	0.34	-0.06
	TOTAL	**0.92**	**0.86**	**-0.06**

Figure 2. Carbon dioxide intensity levels from CA cement production (PCA, 2007).

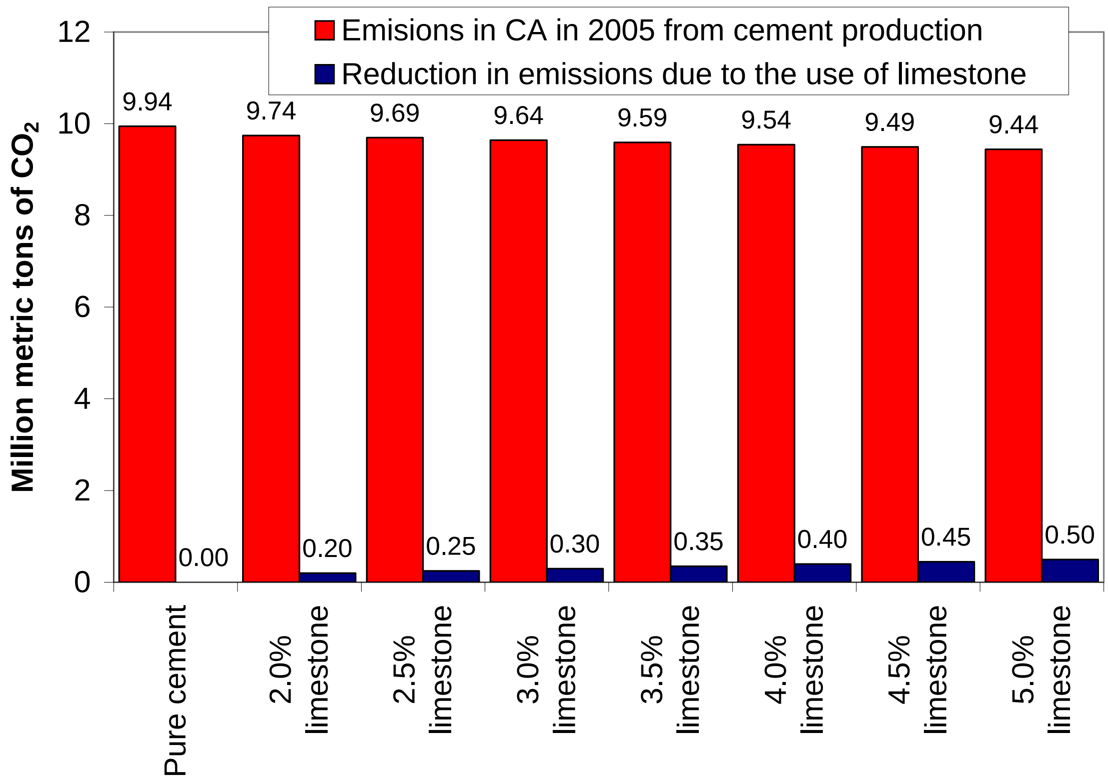


Figure 3. GHG savings in 2005 if limestone addition to cement were allowed in California.

Measure Goals and Potential Implementation Approaches

This section presents the measure goals for the metrics defined in the previous section. The implementation approaches to achieve the 2020 goals are addressed, as well as annual estimates leading to that year. The measure goals for each of the strategies under consideration for this particular measure are the following:

- In terms of energy efficiency, it is not expected that much can be done since the cement plants in California are already among the most efficient in the world. The reduction in CO_2 emissions since 1990 by the cement plants in California will be counted as improvement in energy efficiency when calculating the savings in GHG since 1990. By 2020, it is expected an additional reduction in the GHG efficiency factor of only 0.01. GHG savings in MMT is calculated by multiplying the cement production in a given year by the GHG intensity factor. There is no implementation approach necessary in this case, as the cement plants are free to implement this strategy.
- In terms of fuels, the goal for this measure is to use the least amount of carbon intense fuels such as coal. It is expected that by using alternative fuels, the cement plants in California can reduce the CO_2 emissions by at least 10 percent by the year 2020. GHG savings in MMT is calculated by applying the percent reduction to the cement production in a given year multiplied by the fuel-related GHG intensity factor in that year, which is 0.92 minus 0.52 (calcination-related) minus the improvement in energy efficiency in that particular year compared to 1990. The implementation approach would require the State to make it easier for cement plants to get permits to use recycled solid waste including tires.
- For the limestone addition strategy, the statewide goal is to add 3.5 percent of limestone by the year 2020. Although the cement specification American Society of Testing Material (ASTM) C 150 allows up to 5 percent of limestone, the average nationwide is only 2.5

percent, according to reports from the Portland Cement Association (PCA). Therefore, an addition of 3.5 percent is reasonable and should be the target for 2020. The GHG savings in MMT is calculated by applying the percent reduction to the cement production in a given year multiplied by the overall GHG intensity factor in that year, which is 0.92 minus the improvement in energy efficiency in that particular year compared to 1990. The main reason for such a lower limestone goal than the maximum allowable in the ASTM C 150 is because a limitation on the amount of the loss on ignition (LOI). The implementation approach would require revising California concrete specifications to make sure they allow for limestone addition. It is also suggested to adopt state procurement rules that require the amount of limestone to be reported by each cement plant.

- The cement-related strategy to have the most beneficial effect on GHG reduction is the replacement of cement with SCM at the cement plant. It is anticipated that this measure will account for a GHG statewide reduction from cement production of about 10 percent since it will not be possible to blend all cements with SCM because of market restrictions. The GHG savings in MMT is calculated by applying the percent reduction to the cement production in a given year multiplied by the overall GHG intensity factor in that year, which is 0.92 minus the improvement in energy efficiency in that particular year compared to 1990. The implementation approach would require revising California concrete specifications to maximize the use of SCM in concrete.
- It is expected that the GHG intensity factor be reduced to 0.70 by 2020 from a combination of all above strategies. If a particular cement plant refuses to reduce their GHG intensity, its cement production should be limited to their 1990 values so that their GHG emissions are the same as 1990. In order to verify if cement plants have reduced their GHG intensity since 1990, it is production necessary to have mandatory GHG intensity reporting, which will be implemented by ARB. Also, it is necessary to develop an Assembly Bill to force cement companies to cap their GHG emissions to 1990 levels.

4. Technology

This measure does not rely on any new technology to be implemented. However, studies are recommended to identify the best types of fuels to be used in cement kilns, from a point-of-view of heat value and GHG intensity. In addition, studies to improve concrete mix design with high-volume of SCM are also recommended.

5. Statutory Status

This strategy does require statutory modification (lowering of the intensity) for its implementation. It would be necessary for a statutory modification to mandate cement companies to report the amount of limestone they put in their cement, as well as their current GHG intensity factors.

6. Implementation Steps and Timeline

The major step to implement this measure is the creation of a regulation to limit the combination of cement production and GHG intensity factors of cement plants to the same values as in 1990.

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1. Measure: Concrete GHG Intensity

2. Agency: California Air Resources Board

3. Measure Description

This measure will place a limit to the amount of carbon (intensity) that can attributed to concrete by limiting the amount of cement in concrete, reducing cement usage, reducing waste and replacing high carbon products with low carbon products.

This measure will be focused on concrete batch plants, but will also include all the industries that produce concrete. The measure should be implemented in phases, with tightening limits of carbon. Exceeding the carbon limits may result in monetary penalty. The measure will not prescribe to concrete producers how to make their concrete, or to engineers how to specify concrete, but rather will put limits in place to encourage creativity to use current technology and materials that lower GHG. The measure will place a cap on the ultimate amount of GHG that can be produced with the intent of requiring concrete producers to use flyash, slag or natural pozzolans to replace cement. These materials have a significantly lower GHG footprint than cement, and, in the case of slag and flyash, reduce landfill waste. A minor part of the measure will be to lessen the amount of returned concrete that comes back to a concrete producer and is wasted material.

Overview

There are two alternatives for this measure. One would naturally occur by direct ARB regulation and the other by legislation. Either means would be coupled with fiscal penalties and enforcement with annual reporting. The ARB would be the likely enforcer of the measure. The emission source being targeted is cement, which has an intensity of 0.86 MMT of CO_2 / MMT of cement, for cement produced in California. The reduction event in this measure would not reduce cement production in California, but would ultimately result in better use of the existing production by market redistribution through the following means:

1. Reducing the amount of cement in concrete.
2. Increasing the amount of Supplementary Cementitious Material (SCM) replacement of cement.
3. Reducing waste.

To comprehend this measure, a clear understanding of the difference between cement and concrete is required. On a very basic level, concrete is made from cement, gravel (also called stone or aggregate), sand, and water. Figure 1 shows the four main elements that make concrete: Cement, Sand, Stone, and Water. There is a GHG "cost" to each of the constituents. The goal of the measure is to reduce cement, one of the most GHG producing products that mankind makes.

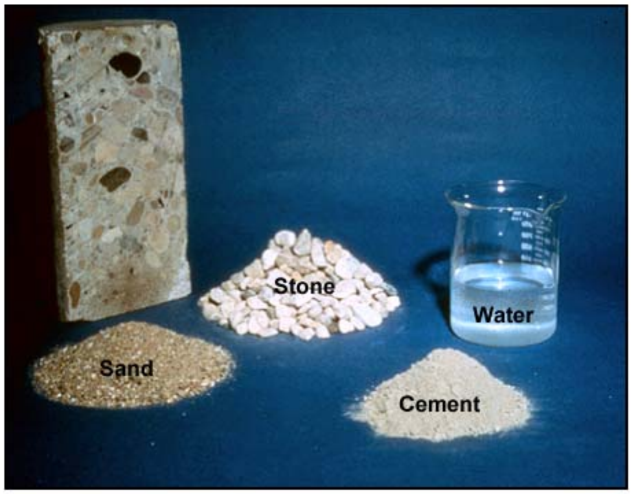

Figure 1. Main concrete elements.

The measure will seek to encourage concrete manufacturers to replace the cement, in concrete, with less GHG intense products. The measure will not prescribe to concrete batch plants how to make concrete, but will either put a limit on the CO_2 intensity of each load, or place a limit on the amount of cement in the concrete. If the limit is exceeded, the purchaser or the plant would pay a fee.

In the case of an intensity, concrete made from the cement imported into California would be required, by measure, to have the same GHG intensity of what is manufactured in California.

Some percentage of the cement in all concrete can be replaced with SCM. SCMs are generally extremely low in terms of their carbon intensities and are generally interchangeable between themselves. Also, admixtures, which are typically liquids, are added in very small amounts (measured in ounces) to the water.

It is inconceivable that concrete will come from out of the country and thus international leakage for concrete would not occur. It is conceivable that concrete will, or does come to California, from border states. Thus, it is recommended, that all concrete purchased for use in California, no matter where it is batched, have the same intensity, or cement requirements.

The possibility of concrete leakage to another state is small, but real. It could occur if there is a California concrete batch plant that sells concrete across the border to another state and the competition is selling concrete at a lower price in that other state, due to the measure's requirements. However, at this time the cost of using GHG friendly materials, such as fly ash, to replace cement, is lower than the cost of pure cement, so leakage is not imminent. Yet, as the price of fly ash rises due to demand, such leakage could occur. This is a very small portion of the concrete made in California.

The measure could have several parts that come into effect at different times, and cover various phases of concrete production.

Fresh Concrete (Phase I)

There are two alternatives to accomplish reducing cement in fresh concrete.

Regardless of which alternative is chosen, the measure will put a limit on the carbon intensity per average cubic yard of freshly batched concrete. Batching is the term for combining and mixing the cement, sand, stone, and water to make concrete. A measure that limits the amount of GHG that is generated for each cubic yard of concrete will allow for fluctuations in the volume of concrete that a plant will produce from year to year. In fact, a measure that controls the amount of CO_2 in each yard will support the companies that are able to make the lower GHG product because there will be no fine on the concrete in terms of cost.

This measure has an important consideration of the different types and applications of concrete. Since cement is the primary element for strength gain, sometimes a great deal of cement is needed for projects such as bridges, parking garages, or pavements. Likewise, not so much cement is needed for patios that carry lawn furniture.

Alternative I

This alternative recommends that dual, or multiple classes of concrete be in the measure that are the primary means of reducing cement, and thus GHG. As a start, there would be engineered concrete, which would have between 400 and 600 lbs of cement per cubic yard, and minor concrete (or non-engineered concrete) which would have less than 400 lbs of cement per cubic yard. There is no limit or prescription on the amount of SCM. These numbers of cement limitation are generous and could be reduced over time by about 50 to 100 pounds.

In this alternative the goal is to judiciously choose amounts of cement that allow for general use, and still reduce cement content without sacrificing concrete properties. This strategy aims to get California very quickly to a reduced cement consumption, while still allowing for an endless amount of combinations of concrete mixtures. This alternative also seeks to provide for a simple formula that is easily understandable by all who might order or prescribe concrete.

Many general uses of concrete never have or need an engineer to design the mix. In general use, concrete is delivered with a factor of safety (of early strength gain) by prescribing a relatively large amount of cement. A homeowner or general contractor may only need about 2000 psi concrete. This 2000 psi concrete only needs about 300 pounds of cement to gain this strength at 28 days. But the home owner may want the strength in 10 or less days, so a mix is asked for that has 700 pounds of cement. This concrete will gain strength in a few days, and ultimately go to perhaps 5000 psi (Caltrans' bridges are generally designed for 3500-5000 psi). If the desire of the state of California is to have less GHG, then less cement can be prescribed and the result is that the homeowner can still get their strength, but in a longer period of time.

(As an example when higher strength is needed… a city maintenance worker, a homeowner, or a building contractor could order 3000 psi concrete and request 400 lbs cement/cy concrete, and request that it have high early strength. The concrete batch plant could add another 100-200 lbs of slag and add an accelerator to get that strength. This concrete would thus be stronger than normal, but be low GHG concrete. The batch plant would have the option to add the SCM, which would really be necessary, but not mandated. The alternative would allow for options while still keeping costs and GHG down.)

So how does this work if an engineer wants high strength concrete with more than 400 lbs of cement without a an engineers stamp? An example is that a concrete supplier gets an order from a purchaser (e.g. a city), that wants a concrete with high cement content, and no stamp from an engineer, then the plant will pass the fee along to the city, to pay for the higher intensity of the concrete. This would not penalize the supplier, but the purchaser.

The idea is to give the public every means to get the concrete it wants, but if it wants higher cement, a GHG fee or an engineer's stamp will be required, so as to reduce unnecessary waste of cement.

Engineered concrete will have to have a professional registered civil engineer stamp the concrete mix for a specific application. A penalty for engineered concrete would be necessary because a concrete plant could have an onsite engineer stamp all mixes and get around a maximum amount of cement. A recommended limit is 600 pounds of cement per cubic yard. Six hundred pounds gives an engineer a lot to work with, especially when coupled with an unlimited amount of SCM. It is assumed that for most uses of high cement content, such as public work projects or work with a large scale building permit, that an engineer will already be involved, and the associated cost of this would be minimal.

In its simplest form, the measure would be a limit of the CO_2 that a batch plant could "spend", per cubic yard. Nevertheless, the intent of this measure is to immediately reduce the amount of cement used in California, while still allowing for unlimited growth. Limiting the consumption of cement would likely have an effect of freeing California cement production to be spread more widely with a direct reduction in imports.

This measure does not seek to put any limits on imported cement, but rather to back calculate in limits of cement that more closely match the current production of cement in California so as to reduce the imports.

A disadvantage to this alternative is that concrete batch plants could use an onsite engineer to put an engineering stamp on every load, and thus load the concrete they sell with excess cement. This might not occur in a tight market where there is price competitiveness. This type of problem could occur in a vertical company that seeks to sell as much of its cement as possible.

Alternative II

This alternative recommends that an intensity be placed per cubic yard that would include the GHG cost to ship the cement from any place in the world. Putting an intensity on the concrete would work to reduce the GHG footprint, but it would take a great deal of policing as well as having international market implications. This alternative would require that batch plants become more sophisticated in terms of their recommended mix designs and might cause inflation due to additional requirements for scientifically trained staff.

This intensity idea is based on a GHG "cost" of each constituent (cement, sand, aggregate) that goes into the concrete. If a batch plant goes over the intensity limit, then the plant would have to pay a fine, or pass the fine to the consumer. As the plants and consumers will not want to pay the fine, they will search for the lowest carbon products to create the concrete. The measure would not define how concrete is to be designed. There are potentially hundreds of different concrete mix designs for each application.

This alternative would encourage the concrete batch plant to be wise and creative in the product it makes, so as not to be penalized. The supplier of concrete would be responsible to work with the purchaser to reduce the carbon intensity by wisely choosing the ingredients. As cement has the largest intensity of all the ingredients in concrete the goal would be to reduce the cement. It would not be recommended in such a scenario that the water or the chemical admixtures have a carbon intensity as their respective intensities are very low by comparison. There are some disadvantages to this alternative:

1. California produces about 12 MMT of cement a year and imports about 4 MMT per year. Even if the consumption of cement goes down with better use of cement and more use of SCMs, there may not be enough cement where it is needed to offset the additional costs of the penalties that would be associated with shipping.
2. There are concrete companies who exclusively import cement. These companies would be severely impacted since the GHG intensity of imported cement would be higher. One such company invested over $4 million to build a storage facility in Stockton just to store the cement it imports.
3. There may be vertical integration of some cement companies (with their concrete batch plants) that would create supply problems in some regions and the result is that some ready mix plants would have to import, and thus cause leakage and increased costs.
4. While there may be demand reduction as more SCM is used, there will be a demand increase with growth, thus the need to import will be sustained, and hurt those companies who solely import their cement, or need imports to fill the gap of growth because local producers cannot meet the need. .
5. Non-vertical batch plants who are very innovative in concrete mix design, and still import their cement, would be hurt by the additional shipping GHG intensity factor even though their concrete has a high amount of SCM.
6. If a concrete batch plant, or existing concrete company of some kind company has set up their business model to purchase cement from overseas, and this alternative is chosen, then an exception must be granted to these companies such that they are not penalized from continuing to purchase cement from that overseas market. This measure would only apply to existing California markets and growth in California.

It is possible to develop a measure that integrates all or portions of both alternatives. In both alternative I and II, there must be exceptions. Exceptions could either be written into a measure, such that all exceptions be exempt from penalties, or they could be accounted for on a project by offsetting the excess with an equal reduction, on the same project.

Other Concrete Entities (Phase II):

This phase would cover all the other manufacturers of concrete, other than ready mix concrete. These other entities which include the precast concrete manufacturers, bag concrete industry, pipe and block manufacturers, soil stabilization contractors and other industries could be phased in at different times.

Except for the bag concrete industry, these entities are largely operating in a business model to maximize profit and minimize cost, and thus they are largely self-regulated to use as little cement as possible.

For example, the manufacturers of precast bridge elements or precast concrete piles are in close competition to quickly produce their products, which are highly engineered. They typically gain their extreme strengths by steam curing their concrete overnight at 130 degrees so that they gain 28 day strength in about 12-15 hours. These industries already do everything they can to meet material, strength, and engineering properties while keeping their costs down. There is very little that can be done to reduce cement GHG intensities of these industries, as excessive GHG intensities would create business costs that would make them uncompetitive.

The bag concrete industry may have some room for additional use of SCM's. If the bag concrete industry purchases cement that is blended at the cement mill to have a high amount of SCM, then that industry will easily meet GHG reductions.

Some of these entities, precast block manufacturers, for example may already be using a less GHG intense concrete. Block manufacturers typically require much less cement per cubic yard for their product with or without the replacement of cement with SCMs.

At this time this strategy does not have enough information to calculate any savings with the other concrete entities. Further study is recommended. Approximately 25% of the cement usage in California goes to these other entities.

Returned Concrete (Phase III):

The measure will further seek to reduce the intensity of concrete by seeking ways to reduce waste. It is estimated that approximately 5-8% of the concrete that is made in California every year is returned to the plant as waste. Considering that California consumes about 16 MMT of cement each year, this correlates to approximately 1.1 MMT of CO_2 excess per year (assume only 75 of the total cement usage is applied to Ready mix, and the intensity is 0.86). It is recommended that a cost be placed on unused returned concrete. This action may increase the cost of the last loads that are delivered to jobs every day.

The result of an increased cost for returned concrete will be an effort to reduce "returns". Returns are generated for two main reasons. The main reason for a return is that a load of concrete is not completely used. The other reason is that a load of concrete is rejected by an inspector due to the mix not meeting some characteristic specified.

The worst case for a return in terms of GHG excess, is when the plastic concrete is separated back to sand, gravel, and water, and the cement was then truly a waste product.

Concrete is always left over at the end of a job, usually because it is better to overestimate rather than be short of the material needed. If a foreman is responsible to place a concrete slab for a shopping center, and he has 10 people working to place that material at a daily cost of $5000 an hour, the last thing he needs is to be short a truckload at the end of the day and have the crew wait or come back the next day. Thus the cost to turn a truck of unused concrete back, at about $800 per truck, is well worth the overall cost of the job, even though it may be entirely wasted.

There are a few ways that the foreman and the concrete batch plant can work together to reduce waste, and thus reduce green house gas.

1. Better estimating of total need of the concrete.
2. Use of volumetric trucks to handle the exact needs of the last quantities of the day.
3. Design of places at a job site or at a concrete batch plant to use the returned or left over concrete. The concrete batch plants in California often have forms set up for which to make concrete blocks for later sale. Another way to reduce waste is to use that last truck to make sidewalks that may have been planned for a later placement. This might cause overtime if a crew has to stay late and use the excess concrete to make the sidewalk, but there would be no waste. To make this work, the cost of the crew to finish work would have to be less than the cost (read: monetary penalty) of the returned concrete.

Summary:

These strategies will have a significant impact in reducing CO_2 by allowing the concrete producers to be have maximum flexibility in choosing their materials within limits. The measure does not tell the engineer or the concrete batch plant how to make the concrete they need, but it does provide an enforceable framework to generate significant CO_2 savings by encouraging best construction practices. There are many choices that the concrete suppliers can make that will not compromise the quality of their product.

The measure will set a standard carbon intensity for each of the components of concrete such that an overall intensity for the concrete can be calculated. The measure will also set a carbon fee for returned concrete.

Affected Entities

Every plant (there are over 600) that makes concrete in California could be affected by this measure. A decision will need to be made for how small of a batch plant will not be affected by this measure. Ultimately, it is likely that all the suppliers of the materials that go into the concrete will be affected. In other words, this measure could affect the vast majority of concrete in California.

Who would this scenario impact, assuming Alternative No. I:

Concrete supplier: The concrete supplier is responsible for the cement, and thus the CO_2 intensity of the material that they manufacture. They will be the enforcer of the regulation as every call for concrete comes in. If a load is non-engineered, the plant will have to work with the purchaser to provide a load that meets the needs of the purchaser, with a maximum of 400 pounds of cement, or a penalty if the purchaser wants more cement. The batch tickets would need to record what type of mix was being delivered. The batch plant would also have to record if the mix was engineered, and if so, record on the ticket who the engineer is. For engineered mixes, there would be no penalty if the mix was below 600 pounds of cement.

Homeowner / Homebuilder: The average homeowner / homebuilder who orders concrete for their patio or driveway will not likely see any difference in their concrete. Rarely would the homeowner have knowledge of how to place an order for concrete such that the carbon intensity would be lowered. The concrete batch plant will need to inform the homebuilder / homeowner of any changes to the properties of the concrete such as strength gain, set time, ultimate strength, etc. that they may have expected with a batch that uses very high amounts of cement. Also, if the homeowner only needs 2000 psi concrete for their patio, there is little need for delivering concrete that will gain a strength of 5000 psi. The homeowner / homebuilder may need to wait for a few more days for their concrete to gain strength.

Municipality: A municipality, such as a city, may need to make changes to the concrete they order for building sidewalks, curbs, gutters, etc. They will need to compare the cost to the strength-age / set time requirements, to decide if they need to involve their city/county engineer. Government agencies may need to make changes to their specifications for concrete and for concrete's applications.

Cement supplier: The cement suppliers in California would be affected by the desire of many concrete plants to receive SCM blended cement. The cement supplier who premixes SCM with their cement may see an advantage, as this would simplify the addition of SCM at the batch plant, particularly for small batch plants that do not have additional silos. Also, for concrete plants that do have additional silos, premixed cement with SCM would be an advantage to making ternary mixes (mixes that at least 3 cementing agents in the cement). Furthermore the cement supplier who premixes an SCM will have an advantage to selling to bag concrete suppliers who need to reduce their intensity.

The international cement producer would also be affected in that all cement that is shipped into California would have to have the same carbon intensity.

Aggregate supplier: As the GHG intensity of the aggregate is not considered, the aggregate supplier would see no impact.

Admixture Supplier: The admixture for concrete business is a huge multi-billion dollar industry. Every load of concrete generally has some type of water reducer, accelerator, retarder or other admixture to affect the qualities of strength or set time of the concrete. There are hundreds of different admixtures. The most common admixtures are powerful chemicals that can stop the concrete from setting on hot days so that the workers can spread and texture the concrete before it sets, or reduce the water, for strength gain, or accelerators, that increase the strength gain properties of the mix. While there is a cost to these admixtures, they can be used to reduce GHG through the reduction of cement. The concrete batch plants may begin to utilize this technology even more as less cement is used.

General consumer: The occasional consumer of concrete will not see a change in what they might expect from the concrete. The occasional consumer expects that concrete will be delivered to their job or business and it serve some purpose as a hard, durable, product. They will order concrete and state the needs of it to the concrete batch plant. The concrete batch plant will deliver a material that meets their needs, but will also be a low carbon product that will meet or exceed the concrete carbon intensity requirements. It is unknown if there will be price increases.

Environmental Justice, Small Business, Public Health, Leakage and CEQA

All interested parties and stakeholders will have an opportunity to comment about this measure during and after the release of the Scoping Plan Process via workshops, subsequent meetings, or written comment. This measure is not going to affect in any way the public health concerns regarding air quality standards and reducing toxic emissions. Similarly, it does not have any potential detrimental effect on small businesses or leakage.

At this point, the Environmental Justice Advisory Committee has not participated in the development of this measure but it is not expected they will have any major comments about this particular measure.

This measure is designed such that it will not promote leakage of GHG to offshore or out of state concrete suppliers.

Related Objectives

- Resource conservation: This measure will promote the use of recycled waste. The two major sources of this waste are fly ash and slag. Other minor sources of SCM include silica fume from the computer chip industry and rice husk ash from agriculture.
- Pollutant reduction: All the associated pollution (fuel spills, mercury, diesel idling, etc.) that occur from construction activities would be reduced as efficiencies in concrete production and delivery are employed.

Measure Metrics

The GHG savings come from a reduction in cement production. The realistic outcome will be less need for foreign cement as California production of cement more closely matches California's demand for it. Cement production is unique in that it not only consumes prodigious amounts of fossil fuel, but also produces pure CO_2 from calcination of limestone ($CaCO_3$ + fossil fuel $\Rightarrow$ $CaO + CO_2$)

This section intends to describe the size, progress, and timing of this measure. Calculations of GHG reductions were based on the following intensities:

- **Cement:** 0.86 ton of CO_2 /ton of cement.
- **Supplementary Cementitious Materials:**
  - **Flyash:** 0.016 ton of CO_2 /ton of cementitious material (to rail 500 miles).
  - **Slag:** 0.032 ton of CO_2 /ton of cementitious material (to rail 1,000 miles).
  - **Natural Pozzolan:** 0.032 ton of CO_2 /ton of cementitious material (to rail 1,000 miles).
- **Aggregate:** A GHG footprint may be useful if assigned to delivery of the materials to and from the concrete batch plant. This idea is not fully discovered yet.

Measure Goals and Potential Implementation Approaches

This strategy will be measured in MMT CO_2.

4. Technology

In the simplest of terms, the way to reduce GHG in concrete is to use less cement. Cement makes up only about 11-14% of the total volume of concrete, as shown in Figure 2.

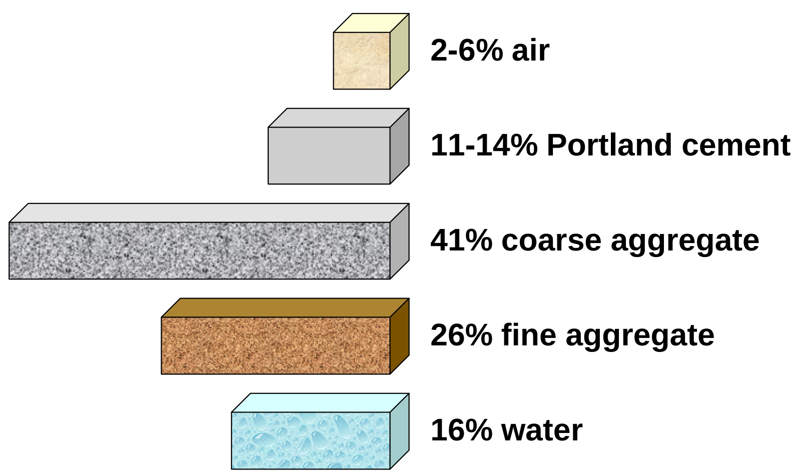

Figure 2. Constituents of concrete.

Cement is the glue that holds the matrix of sand and gravel (coarse aggregate) together. Cement is also used to fill the very small voids between the sand and gravel. Water is required to make the cement chemically react and form crystalline bonds.

There is a tremendous amount of GHG savings that can come from changing the way that concrete is designed, batched, and delivered. Requiring a cap on the amount of GHG that can be generated from concrete will still allow for countless changes to the way that concrete is made. Some of these changes are as simple as changing the materials that already are available.

This simple example shows some flexibility with one simple project. With this in mind, what are some of the technologies that can be used to reduce cement and thus lower the GHG intensity in the concrete?

1. **Use less cement:** This is the most obvious first step toward reducing the intensity. There is construction all over California that is likely using concrete that is over designed. While a bridge deck needs 750 to 850 pounds of cement per cubic yard, a residential driveway does not.
2. **Substitute cement with flyash:** Substituting Cement with fly ash is the current strategy being used by the Department of Transportation and some of the concrete industry. Caltrans currently replaces over 90% of the cement in its concrete with 25% fly ash. Much of the concrete industry currently replaces about 15% of its cement with fly ash. There are different types and qualities of fly ash, and not all can be used.
3. **Substitute cement with slag:** Slag is an excellent product for replacing cement but its availability is currently limited on the west coast. Slag has an advantage in that typically higher amounts of it can be easily substituted than fly ash.
4. **Use less water (and thus need less cement):** This strategy is straightforward in that using less water makes the concrete stronger, but also less workable. This strategy would involve some additional cost for a plasticizer admixture or a water reducing admixture, but this may be compensated for by cost savings of using less cement.
5. **Use an accelerating admixture:** Cement is the product that gives strength to concrete. When high early strength is needed, say because a building contractor wants to put carpenters on the slab the next day to build a house, then extra cement may be added to the concrete to give it strength sooner. Admixtures can be added to the concrete to accelerate the strength gain rate.

So what is this technology? The technology to reduce cement usage already exists. The means to implement this technology is through the computers already required to print the batch tickets. The GHG savings of each truckload of concrete can be calculated rather simply and be printed on each batch ticket. The batch plants' computers that generate the batch tickets can be used to summarize and track the concrete production of the plant. There would be an unknown capital cost to these changes and upgrades.

5. Statutory Status

The batching of concrete is currently highly regulated in terms of air quality (release of cement and other dust to the air), water quality (runoff of storm water and reuse of mix water) and in some cases, noise. There is also strict regulation by Weights and Measures as to the certification of each batch of concrete for the accurate and precise proportions of the ingredients in the concrete. The entity that is ordering the concrete, such as Caltrans, gives the specifications to the concrete batch plant for the fresh and hardened properties of the concrete.

There will be a need for either a measure, enforced by the ARB or a legislative bill, still enforced by the ARB to mandate a limit on cement in concrete. This measure will need careful consideration and full vetting to ensure that the industry understands the reasons for the measure and the means for implementation.

6. *Implementation Steps and Timeline*

2008

- Prepare draft guidelines of the measure for a concrete GHG intensity. Present to industry and determine the reaction and corresponding future work. Seek to find an early action goal such that all the industry of cement and concrete is starting to not only reduce GHG emissions but also change the mindset for future changes.
- Meet with cement and concrete industries to discuss and explore the impacts of a concrete intensity for California.
- Write, advertise and award a contract, (say $400,000) to accomplish work described below for 2009.
- At the ARB board, set concrete CO_2 intensity targets for the year 2009 on a voluntary basis, with the understanding that mandatory intensities will be implemented in the future.

2009

Determine ways to collect data from concrete companies on their voluntary concrete CO_2 intensity targets for California.

Before any regulation of GHG in CA can occur, the full spectrum of cement and concrete usage needs to be determined. The goal of the report is to understand the uses of concrete in California and determine where changes can be made on a time frame that is workable the concrete industry. A report would cover the following topics:

1. *How much concrete is batched in California.*
2. *Average amounts of cement per batch, for different applications.*
3. *Average amounts of SCM used per batch.*
4. *Determine where cement is used versus where it is manufactured.*
5. *Supply of SCM to California.*
6. *Current specifications being used in California for concrete and whether these specifications could become performance specifications.*
7. *Future supplies of SCM's to concrete.*
8. *Ability and cost of admixtures to reduce cement.*
9. *Effects of using less cement on the construction market of California.*
10. *Potential for reduction by all industries other than ready-mix who use cement.*

This research should be contracted to a private consultant for completion in 6-9 months.

This report would need review and comment by the cement and concrete industries of California as well as those who purchase and specify concrete.

2010:

Fully adopt measures for implementation.