



Report on Decarbonization in Concrete and Pavements

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ClearPath

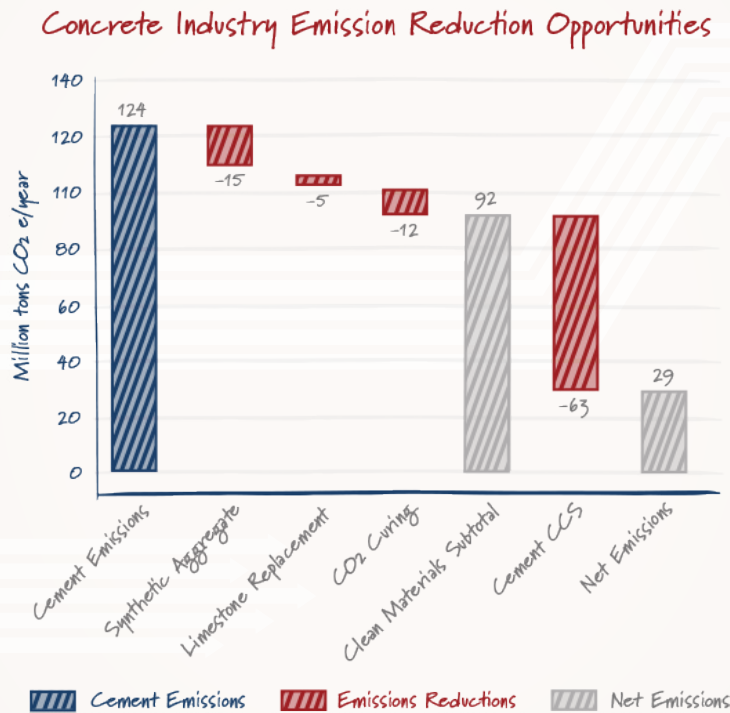
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Decarbonization in Concrete and Pavements

Executive Summary

For centuries, concrete has helped advance society as the basic building block in our roads, buildings, and bridges. Today, cement (i.e., the “glue” in concrete mixtures) is produced at an annual rate of 86 million tons in the U.S., and 4.1 billion tons worldwide. Current production methods of cement generate significant carbon emissions, and globally, cement facilities account for 8% of anthropogenic carbon dioxide emissions, equivalent to roughly one-third of all power plant emissions. Since cement will also continue to be an essential commodity in the years to come, noted by a projected demand increase of 12% by 2050, it is important to accelerate low-cost technology solutions that can reduce the environmental footprint of the cement and concrete industries.

In this report, we have identified three primary opportunities for the decarbonization of the concrete industry: (1) carbon capture at cement plants, (2) alterations to concrete mixtures, and (3) new materials with stored CO₂. Their impact on the cement industry’s emissions is shown below:



In sum, nearly 100 million tons of CO₂ can be avoided with the combined measures shown here. This is equivalent to about two-thirds of the cement emissions and about 1.2% of U.S emissions. Based on magnitude and feasibility of near- and long-term impact, we recommend the following R&D policies:

- 1. Demonstration and Deployment** - Fund pilot or demonstration carbon capture projects at cement plants.
- 2. Research and Development** - Increase research for supplementary cementitious materials and materials produced with carbon mineralization
- 3. Regulatory Revisions** - Increase disclosure of data surrounding material ingredients, properties, and performance. Encourage regulating bodies to shift to performance-based specifications in asphalt and concrete.

Decarbonization in Concrete and Pavements

Introduction - Reducing Emissions from Pavement

Since the Roman Empire, cement has been used to facilitate societal growth. Its unmatched strength and durability provided to concrete mixtures have helped to cement itself as an essential building material across the world. Today, at a use rate of 4.1 billion tons per year, cement is the most used man-made material on the planet.¹ Unfortunately, its current production method is very carbon-intensive, accounting for 8% of global anthropogenic CO₂ emissions.² With a projected growth in production of 12-23%,³ universities, companies, and governments around the world are supporting research and development to improve cement's environmental footprint. Recently in the United States, new economic drivers have emerged, including federal incentives, corporate sustainability goals, and emerging domestic and international regulations. Therefore cement – the key ingredient in the concrete used in major public works projects like highways, bridges, and buildings – presents an opportunity to decrease a large portion of U.S. industrial emissions. Now more than ever, with advanced technologies and bipartisan support for new infrastructure investments, serious attention to decarbonization opportunities in the concrete industry could result in significant emissions reductions.

Traditionally, the power sector has been the focus of clean energy technology policy. Clean power technology and business model innovations, from cheap renewable power to abundant low-carbon natural gas, provide a template for reductions in the industrial sector, the source of 22% of U.S. carbon dioxide emissions.⁴

Concrete and Pavement Terms Defined

Concrete is primarily composed of cement, aggregates, and water. Cement (also called "binder") acts as the glue in concrete mixtures, while aggregates provide volume and stability.

Cement + Aggregates + Water = Concrete

The mixture most commonly known as "concrete" uses portland cement, and is also called portland cement concrete. Alternatively, asphalt concrete uses asphalt cement, and does not use water in its production. This is further illustrated in Figure 1. While these two mixtures are products of two separate industries which compete with each other, they share the need to decrease embodied emissions and will both be discussed. For the purposes of this report, the two mixtures will be referred to as "concrete" and "asphalt," respectively.

Concrete vs. Asphalt

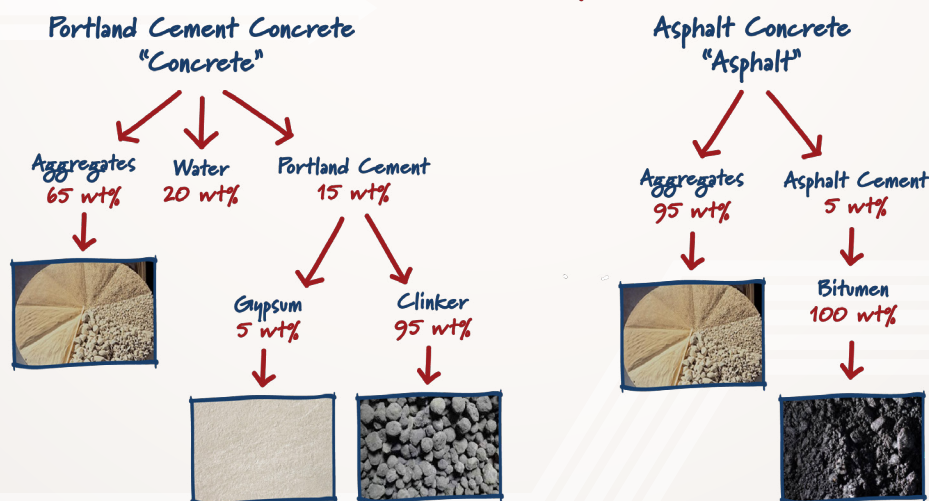


Figure 1: Comparison of the approximate amounts of ingredients in concrete⁵ and asphalt⁶

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One of the major uses of concrete and asphalt is pavement. Pavement refers to a smooth artificial surface on the ground typical of U.S. roadways, for which both concrete and asphalt are used to produce. In the U.S., about 94% of paved roads are surfaced with asphalt.⁷ The two pavement types can often be distinguished by color - concrete is typically grey or white, while asphalt is typically black. While concrete roads are generally only used in highways and bigger cities, concrete is the more widely used material overall due to its applications in buildings, bridges, dams, and more (see Figure 2). Asphalt is produced at a rate of about 350 million metric tons per year,⁷ compared to about 570 million metric tons produced of concrete.

Concrete Products vs. Asphalt Products

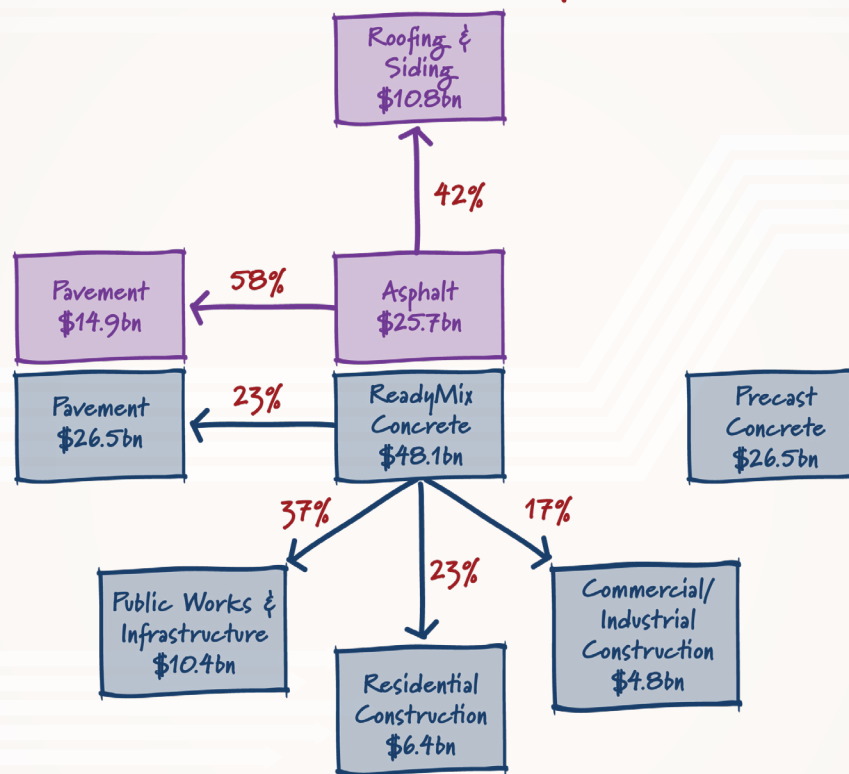


Figure 2: Comparison of Products from Concrete and Asphalt Industries.
Data from IBISWorld ^{8,9,10}

A more contrasting characteristic of concrete and asphalt is their emissions: concrete emits an estimated 144 kg CO₂ per ton, compared to about 61 kg CO₂ per ton of asphalt.^{29,39,40} To understand the source of these emissions, it is important to first examine the most carbon-intensive ingredients of concrete and asphalt, which are shown in Figure 3.

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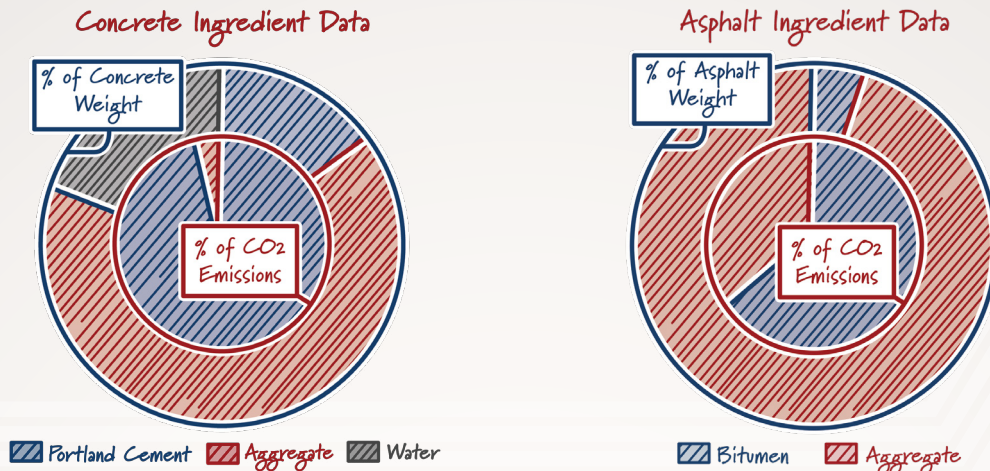


Figure 3: Relative contribution of portland cement- and asphalt-based concrete ingredients to the overall mixture weight and CO₂ emissions

Interestingly, the ingredients with the lowest contribution to weight (portland cement in concrete and bitumen in asphalt) have the largest contributions to CO₂ emissions. Therefore, small alterations in these mixture recipes could yield significant emissions reductions.

The major emissions source for concrete is the production of clinker, which is the main ingredient in portland cement. In this process, abundant naturally occurring rock called limestone (calcium carbonate) is mixed with other materials like clay and heated at very high temperatures (> 2700 °F), producing clinker and CO₂. The basic reaction is shown in Figure 4.

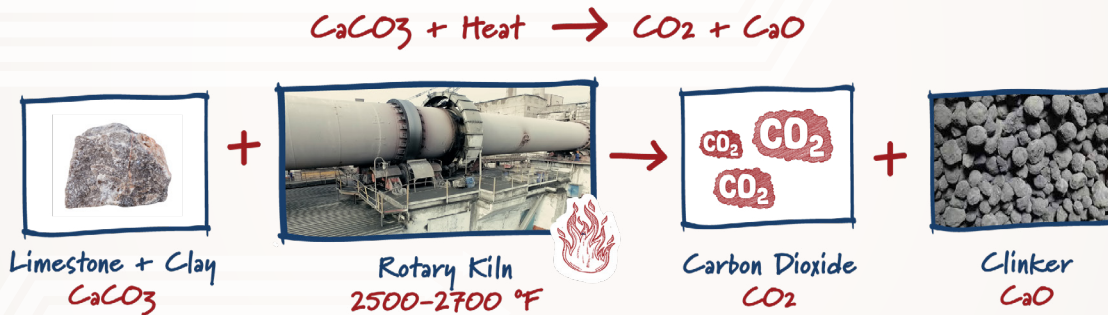


Figure 4: Clinker production process with basic chemical reaction

The CO₂ emitted in this reaction is referred to as “process emissions,” as opposed to the “combustion emissions” that result from the combustion of fossil fuels to supply heat for the reaction. About 60% of a cement plant’s emissions are process emissions, which cannot be mitigated by use of carbon-free energy. This underscores the need for carbon capture or production of alternate clean materials to decrease concrete’s carbon footprint.

Upfront emissions and costs from production do not tell the full story of a pavement’s environmental impact. Designing new roads requires the balance of initial costs of production with lifecycle costs of maintenance, material usage and carbon emissions. As such, pavements that decrease emissions at production may still result in a net-increase of emissions over their lifetime. Further, use of new pavement technologies is limited by the abilities of local and state agencies, which may lack funding to support higher initial pavement costs, and are better equipped to finance the repeated maintenance costs of pavements with decreased longevity.

Decarbonization in Concrete and Pavements

It is important to note a portfolio of solutions is needed to decarbonize the industry. The remainder of this report outlines several opportunities for the decarbonization of concrete and pavements, and identifies the best options to optimize impact in both the near and long term. These opportunities pertain to the pavement production phase, while discussion of environmental impacts associated with the use phase are outlined elsewhere.¹¹

Decarbonization Opportunities

1. Carbon Capture at Cement Plants

Big takeaway: Cement plants are a low-hanging fruit for carbon capture, which can result in significant carbon reductions for the industry. A few early demonstration projects are helping its development, but more are needed to drive down the costs and bring the technology to scale. If applied to all U.S. cement plants, carbon capture could avoid up to 72 million tons of CO₂ emissions per year. This is equivalent to taking more than 15 million cars off the road.⁴¹

Description: Process emissions resulting from cement production can be avoided through post combustion carbon capture technology, which removes carbon dioxide from a facility's exhaust gas before it is released into the atmosphere. The captured CO₂ can be stored or converted to a useful product, in turn generating revenue through market sales and, potentially, the U.S. federal carbon capture tax incentive, 45Q. A number of capture processes can be applied to cement plants, including amine scrubbing, calcium looping, and oxycombustion. New processes are also being explored, such as the single-tube direct separation system by Project LEILAC.

Benefits:

- **Invests in existing infrastructure.** Because carbon capture leverages existing infrastructure and facilities, it can be deployed relatively quickly.¹²
- **Reduces emissions in line with global targets.** A combined 72 million tons of CO₂ per year could be captured with carbon capture retrofit technology at all cement plants in the U.S. This is distributed among 91 different plants, as shown in the below map. The majority of cement plants generate 100,000 to 1 million tons of CO₂ each year.
- **Federal monetary support.** The U.S. Department of Energy released a call for front-end engineering design studies for carbon capture at industrial sources.¹³ If the CO₂ captured at cement plants is utilized or geologically stored, it is eligible for the U.S. federal carbon capture tax incentive, 45Q. Section 4002 of The Energy Act of 2020 established a carbon capture technology program to improve the efficiency, effectiveness, economics, and environmental performance of carbon capture in the industrial sector, among other sectors.¹⁴
- **Low-hanging fruit for carbon capture.** The flue gas concentration of CO₂ affects the cost of carbon capture, where it is more expensive to capture from a more dilute stream. The concentration of CO₂ in flue gas at cement plants is relatively high (up to 33%), compared to about 12% and 4% for pulverized coal and natural gas combustion, respectively. Furthermore, because 96% of a cement facility's process emissions are emitted through a central exhaust stack, the installment of one retrofit carbon capture system could capture nearly all of the plant's process emissions.¹²

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US Cement Plants With Possible Storage Sites for CO₂

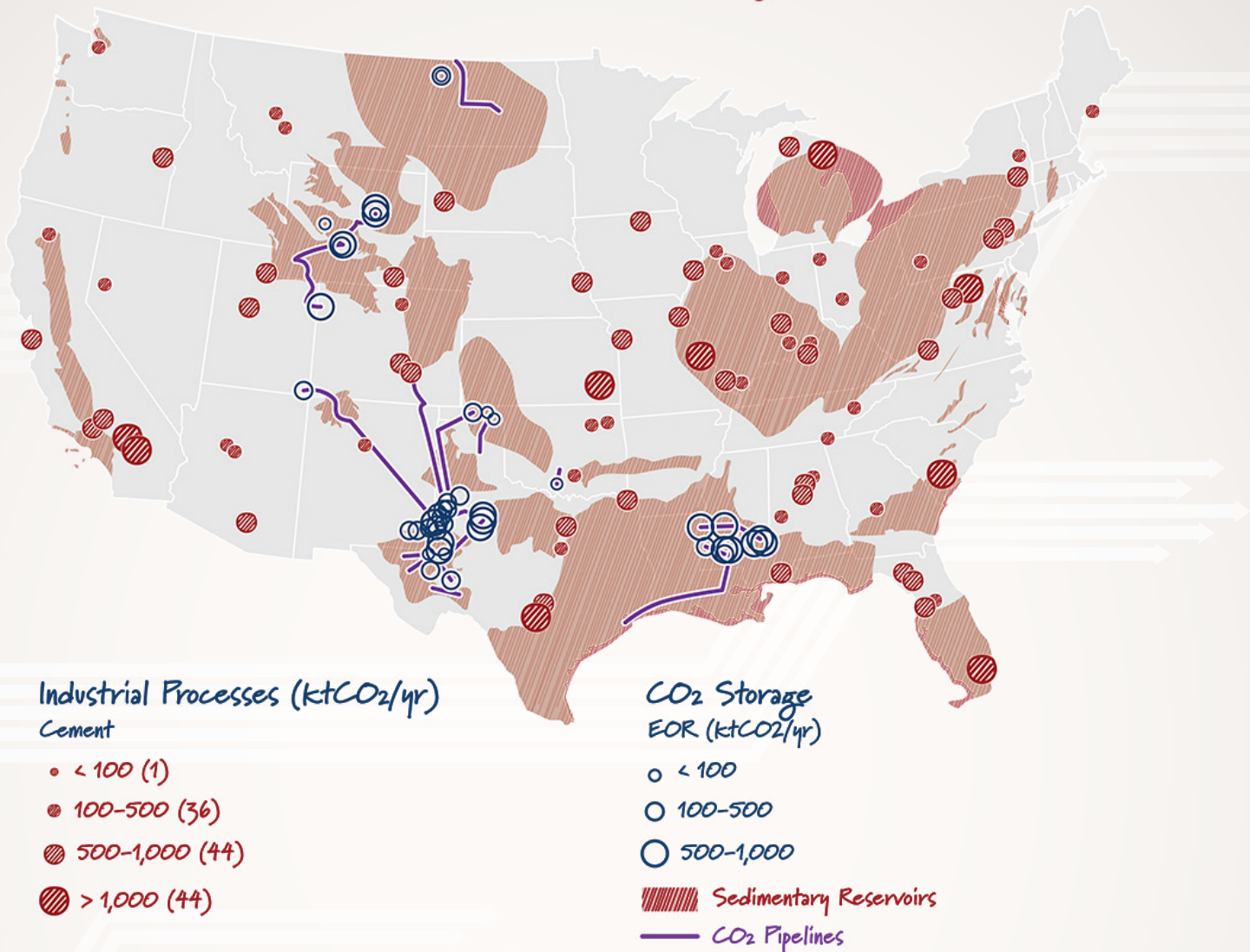


Figure 5: Map of US cement plants with possible storage sites for CO₂¹²

Challenges:

- **Cost.** Installing carbon capture equipment, especially in the industrial sector where carbon capture has not yet been widely implemented, requires significant investment. Estimated costs range from \$17 to \$164.6 per ton CO₂ avoided. Combining oxycombustion with calcium looping is likely to be the most economical option, with an average cost of \$39.4 per ton CO₂ avoided.¹⁵
- **Permissions and spacing.** Equipment installment at cement plants could also be problematic. Some plants do not have the space required for a carbon capture system, or would require some rearrangement of plant equipment. Increases in land area or plant height could bring objections from local government and/or residents.¹⁶ The complications of spacing and permissions, along with the inherent risk of large investments in a relatively new technology, can cause some plant managers to be hesitant to make significant changes to the equipment in place.

Decarbonization in Concrete and Pavements

Current Examples: Commercial and large scale projects are underway across the world.

Holcim Portland Cement Plant¹⁷

In the beginning of 2020, Svante Inc, LafargeHolcim, Oxy Low Carbon Ventures, and Total initiated a study to evaluate commercial-scale carbon capture at the Holcim Portland Cement Plant in Colorado. The facility would capture up to 725,000 tons of CO₂ per year, to be permanently sequestered by Oxy Low Carbon Ventures. The initiative merges Svante's proprietary low-cost "sorbent" capture system with a federal carbon capture tax credit (45Q) to make a profitable project.

Norcem Brevik CO₂ Capture Project¹⁸

The Norcem project started as one of four post combustion capture pilot projects in Norway in 2014. In 2019, Norcem was one of two facilities chosen to scale up to capture 400,000 tons of CO₂ per year. The CO₂ will be transported to Norway's west coast for temporary storage. A primary objective of this demonstration phase is to increase the use of waste heat already present within the plant evaluations, decreasing the additional energy needed to power CCS at the cement plant.

Low Emissions Intensity Lime and Cement (LEILAC)¹⁹

This pilot was constructed in 2018 in Belgium, and introduced a new way to produce cement clinker that makes it easier to capture the process emissions. The technology is called single-tube direct separation, and is shown in Figure 6. While this technology has been commercialized by Calix Limited for more than two years to produce magnesia, applying it to cement production will require much higher temperatures. Accordingly, pilot-scale tests will be undergone to confirm more than 95% of emissions can be captured at high temperatures.

*Single-tube direct separation CO₂ capture system,
to be used by Project LEILAC*

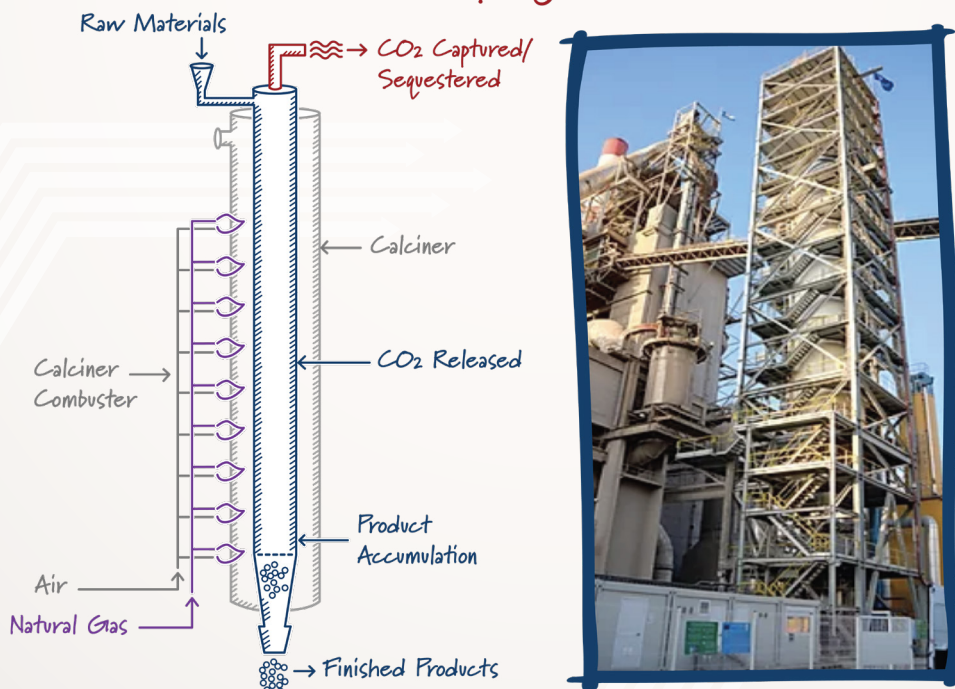


Figure 6: Single-tube direct separation CO₂ capture system, to be used by Project LEILAC¹⁹

Decarbonization in Concrete and Pavements

2. Alterations to Concrete and Asphalt Mixtures

Big Takeaway: For decades, concrete mixtures have been altered to reduce raw materials costs by replacing portions of cement with cheaper materials like industrial wastes or limestone, simultaneously reducing concrete’s carbon footprint. Similarly, emissions and costs from asphalt can be reduced by decreasing production temperatures and increasing recycled material usage. While many of these practices are not new, they suffer from outdated regulatory specifications and/or lack of communication on best uses. In some cases, R&D is also needed to evaluate new materials and their effect on long-term material properties.

Concrete Alterations - Description: Because cement is concrete’s primary source of cost and emissions, replacing cement with alternative materials is a practice that has become relatively common in the industry, and has been examined previously by the U.S. EPA.²⁰ In the concrete industry, these alternatives are called “supplementary cementitious materials” (SCMs).

Some concrete mixtures replace a portion of the portland cement with limestone, a mixture called portland-limestone cement. This can significantly reduce cost and emissions, but the reports of its effects on concrete properties are mixed. Based on average literature values, the decrease in strength for concrete is minimal at limestone replacement levels below 10%, with significant strength losses past 17.5%.²¹ The relation of loss in strength and avoided CO₂ emissions is shown in Figure 7.

CO₂ Emissions Avoided and Concrete Strength Due to Limestone Replacement in Concrete

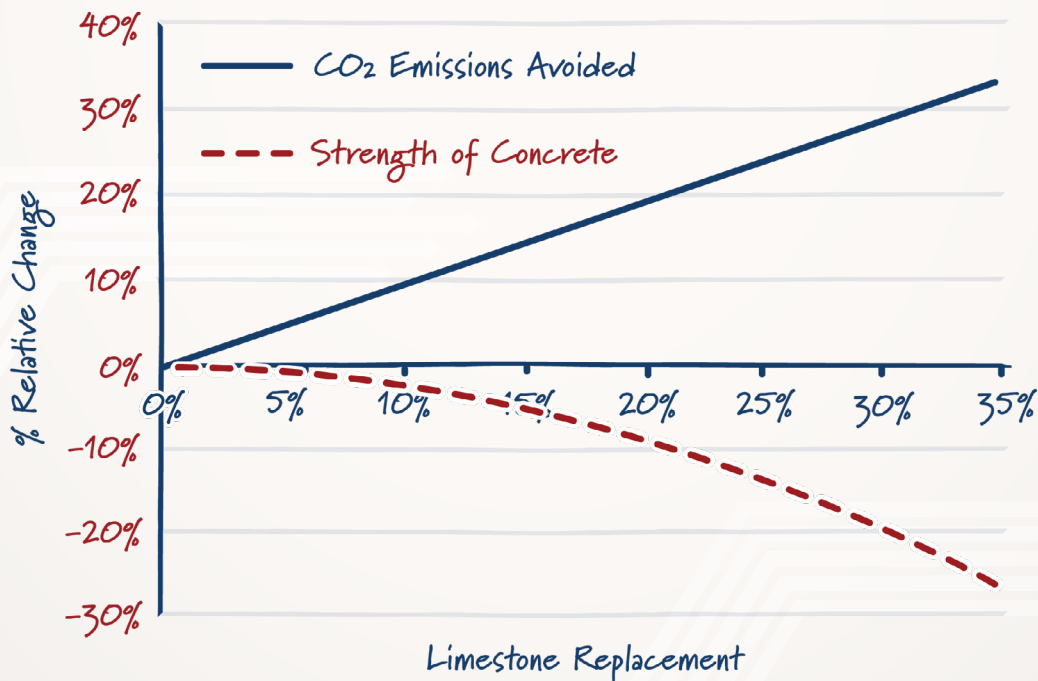


Figure 7: Comparison of the relative change in CO₂ emissions avoided and concrete strength due to limestone replacement in concrete

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For a sense of scale, if a 15% limestone replacement is applied to a quarter of all concrete produced in the U.S., it would avoid nearly 3 million tons of CO₂ each year from portland cement production. Further, if this technique is applied to new concrete pavement, it would result in about 90 tons of CO₂ avoided per mile of pavement, a reduction of about 14%.

Concrete Alterations - Benefits:

- **Reduce costs and emissions.** For more than 50 years, SCMs have been used in concrete mixtures to enhance long-term strength and durability properties, decrease costs, and more recently, decrease emissions. These are often wastes from other industries, the two most common being from coal combustion (fly ash) and iron production (blast furnace slags).
- **Waste reclamation.** Several alternate materials are available with varying chemistry and availability, most of which are wastes from industrial processes.²²

Concrete Alterations - Challenges:

- **Material availability.** A 2008 EPA report listed the advantages of several SCMs, and emphasized fly ash and blast furnace slags.²⁰ Now, nearly half of the fly ash and all of the blast furnace slags produced in the U.S. are already used as SCMs.^{23,24} Due to the decreased use of coal in the power sector and the economic struggles of the steel industry, new materials need to be sought out to sustain, or increase, the economic and environmental impact of SCMs.
- **Research and development.** Many of the potential materials to use as SCMs are available on the scale of millions of tons per year, but more research is required to determine their ability to replace cement without sacrificing performance.
- **Regulatory restrictions.** Limestone is a promising alternative due to its wide availability and its established use in the U.S., but a shift to performance-based standards is required to increase the permitted replacement levels of limestone and other new SCMs.

Asphalt Alterations - Description: One method to reduce energy consumption in asphalt production is to decrease the production temperature. Hot mix asphalt (HMA) is the traditional asphalt mix and is produced at 300-350 °F. Alternatively, warm mix asphalt (WMA) is produced at much cooler temperatures, resulting in reduced costs and emissions due to a decreased fuel demand.²⁴ Another sustainable method is using recycled asphalt (e.g., reclaimed asphalt pavement, cold in-place recycling).

Asphalt Alterations - Benefits:

- **Can be implemented quickly.** With Federal Highway Administration support, WMA was adopted very widely and rapidly in the last decade, with a 777% increase in WMA usage from 2009 to 2017.²⁵ About 39% of asphalt in the U.S. was made using WMA in 2017, up from just 5% in 2009.
- **Reduces carbon emissions.** Using WMA is estimated to give a 10-15% carbon footprint reduction compared to HMA production, equating to emissions reductions of about 4.5 to 11 tons of CO₂ per mile of WMA pavement. In 2017, recycled asphalt accounted for 20% of asphalt mixtures. This avoided the production of additional asphalt cement and virgin aggregate, and resulted in a combined CO₂ avoidance of about 1.5 million tons.²⁵

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- **Broader impacts.** Aside from decreasing fuel consumption and emissions, WMA enables the paving season to be extended into winter months, material to be hauled longer distances, and more recycled materials to be used.²⁵ Use of recycled asphalt also saved nearly 50 million cubic yards of landfill space and more than \$2 billion during the 2017 construction season.

Asphalt Alterations - Challenges:

- **Material availability.** Due to issues with quality control and processing, recycled asphalt is assumed to be able to constitute up to 40% of an asphalt mixture,⁶ which is about double its current amount. In 2017, asphalt producers cited material availability, along with specification limits, and plant capabilities, as limiting factors for increasing use of recycled asphalt.²⁵
- **Research and development.** The various types of available recycled materials require further research to determine optimal use cases.²⁶
- **Regulatory restrictions.** Despite the availability and potential advantages of recycling agents for asphalt mixtures, it was found that most state agencies and contractors do not use or allow the use of them. Acceptance of these practices could be improved through broader education on the available options and continued efforts to adjust regulatory specifications.²⁷

3. Synthesizing New Materials with Stored CO₂

Big Takeaway: Building materials can be synthesized containing CO₂ in the form of mineral carbonates. This can take the form of synthetic aggregates, CO₂-cured concrete, or alternative cement, some of which have already seen some commercial success. Funding is needed for additional R&D and life cycle analysis. Technologies would also benefit from additional incentives to help compete with the cheap established materials. If applied to all U.S. concrete, we estimate synthetic aggregates and CO₂-cured concrete could avoid nearly 15 and 12 million tons of CO₂, respectively.

Description: Using a technology called carbon mineralization, building materials can be synthesized by reacting CO₂ gas with an alkaline feedstock. These materials permanently store CO₂ in the form of solid carbonate minerals, like those that make up seashells. Further, the materials often exhibit superior strength and durability properties compared to conventional building materials. Thus, this method presents an opportunity to replace materials that produce CO₂ with materials that contain CO₂, all while improving the performance of the final product. Moreover, the use of CO₂ to produce these materials qualifies as a utilization method in the 45Q tax incentive, improving the economics of the technology.

Background: Alkaline feedstocks rich in calcium or magnesium are readily available in industrial wastes and mined materials. Industrial wastes are advantageous because their small particle size makes them more reactive, and they are produced annually at facilities that produce CO₂ streams. Examples include steelmaking slags, coal fly ash, and cement kiln dust. As previously mentioned, some of the wastes suitable for mineralization feedstock are already utilized as SCMs. Hence, the field would benefit from characterization and identification of additional feed sources. Alternatively, alkalinity can be obtained by mining ultramafic rocks. While these mined rocks might be more pure than industrial wastes, the mining operation can be cost- and energy-intensive.

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Current Examples: There are several companies that are commercializing carbon mineralization to produce building materials. As illustrated in Figure 8, the companies can be categorized into two pathways: those that are making changes to portland cement-based concrete mixtures (Pathway 1), and those that are making alternative building materials without portland cement (Pathway 2).

Companies Commercializing Carbon Mineralization Come in Two Types

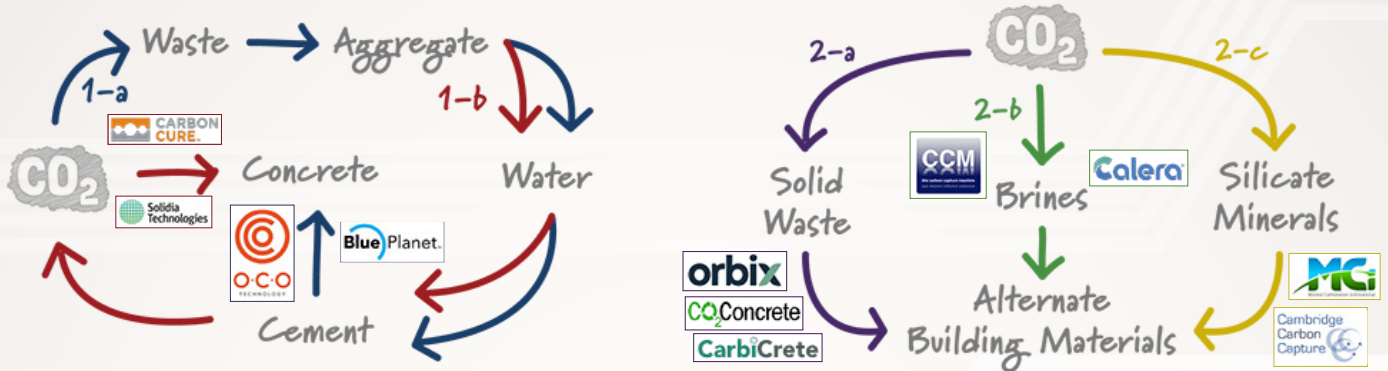


Figure 8: Companies commercializing carbon mineralization come in two types: Pathway 1 - making changes to portland cement-based concrete mixtures, or Pathway 2 - making alternative building materials without portland cement

Pathway 1-a: Synthetic aggregates

Aggregates are essential to concrete, bringing its volume and stability. The global aggregate market, including sand, gravel, crushed stone, and others, amounts to about 53 Gt/year.²⁸ Because conventional aggregates are low-value commodities with relatively low associated emissions (7.85 kg CO₂-e per metric ton),²⁹ synthetic aggregates produced by carbon mineralization should present superior qualities and/or contain large amounts of CO₂. O.C.O Technologies (U.K.) and BluePlanet (U.S.) are examples of this pathway.

Pathway 1-b: CO₂-cured Concrete

Immediately after concrete has been placed, its properties begin to develop through hydration reactions, the rate and extent of which are affected by moisture presence and temperature. The process of curing involves regulating moisture content and temperature to allow the specified properties to be achieved. While curing generally occurs due to water presence, it can also be achieved with CO₂. This technique securely stores CO₂ while enhancing the strength and durability properties of concrete. CarbonCure (Canada, U.S.) and Solidia (U.S.) are examples of this pathway.

Pathway 2: Alternative cement materials

These companies use different alkalinity sources to produce building materials free of portland cement. The primary alkalinity source varies among solid industrial wastes (e.g., steel slags, coal fly ash), water desalination brines, and naturally occurring minerals (e.g., lizardite), as shown in the figure above. Companies here are still in development phases, and have not yet reached the same scale as some Pathway 1 companies. Orbix (Belgium), CO₂Concrete (U.S.), and CarbiCrete (Canada) are examples of Pathway 2-a. Carbon Capture Machine (U.K.) and Calera (U.S.) are examples of Pathway 2-b. Cambridge Carbon Capture (U.K.) and Mineral Carbonation International (Australia) are examples of Pathway 2-c.

Decarbonization in Concrete and Pavements

Benefits:

Improved Properties: O.C.O Technologies creates a versatile, lightweight aggregate that can replace or accompany other aggregates. Blue Planet's layered aggregate can be produced in sizes ranging from that of sand to gravel.³⁰ CarbonCure's process results in a stronger overall concrete that requires less cement to achieve the same strength.³¹ Solidia's process sequesters CO₂ during curing and can produce strength and durability properties that exceed conventional concrete.

Current Funding Opportunities: In addition to the 45Q tax incentive, other avenues to fund these projects currently exist. Three of the companies here – CO₂Concrete, Carbon Capture Machine, CarbonCure – are finalists in the NRG COSIA Carbon XPRIZE,³² which is scheduled to announce the winners of a \$20 million prize in Fall 2020. CarbiCrete was also a Carbon XPRIZE finalist, but withdrew after receiving funding from Sustainable Development Technology Canada to build a limited production facility at a pre-existing concrete plant.³³

Scalable: The NRG COSIA Carbon XPRIZE finalists benefit from pilot-scale testing required for the competition, and CO₂Concrete is planning to perform additional pilot tests at the National Carbon Capture Center in the near future.³⁴ CarbiCrete has received more than \$5 million combined from the Canadian government and Harsco Corp to help fund an industrial-scale pilot project.³⁵ Additionally, Mineral Carbonation International plans to design a demonstration plant that can process 5,000-10,000 tons of CO₂ per year.³⁶ Orbix's Carbstone Technology is in development at Belgian steel and brick facilities. O.C.O Technologies has three facilities in the UK, the first of which was built in 2012 and is undergoing an expansion to double its capacity to produce more than 50,000 tons of aggregate per year. CarbonCure's technology has been installed at several concrete facilities in the U.S. and Canada.

Flexible Business Models: A common theme among the more successful companies here is business models that ease adoption for existing manufacturers. CarbiCrete's business model is to license its technology to precast concrete manufacturers, providing the means and support for its partners to produce high-quality, carbon-negative concrete. Orbix has developed a mobile container that can be transported to concrete manufacturers as a way for them to replace cement while maintaining control over the process.³⁷ As their name suggests, Carbon Capture Machine constructs modular "Carbon Capture Machines" that can be installed at plants with access to waste CO₂ and alkaline brine streams. CarbonCure technology is easily retrofitted at a concrete plant and has already been installed in locations across the U.S.³⁸ Solidia's process can be carried out with the same equipment and raw materials already used in the cement industry.

Challenges:

CO₂ Source: Also important is requirements for the CO₂ source. Technologies which require a pure CO₂ stream, like CO₂-curing, would have to obtain it from DAC or post-combustion capture. CO₂Concrete, Calera, and potentially other companies here, are testing their mineralization technologies using raw flue gas, removing the additional cost of capture and compression.

Life Cycle Assessment: Although many of the companies list the amount of CO₂ contained in their products, it is difficult to know the net amount avoided on a lifecycle basis. This is because there is likely

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a considerable amount of energy required for process conditions of temperature and pressure, along with mining feedstock or synthesizing other reagents. More R&D could be put forth into these efforts.

Performance-based Specifications: Most of the technologies listed here also suffer from restrictive regulations on concrete mixtures. A shift to performance-based specifications will help to allow the use of new carbonate-based concrete materials that satisfy the requirements of strength, durability, and longevity.

Summary of Options

A portfolio of solutions is necessary for the decarbonization of concrete and pavements. Summing up all the decarbonization opportunities, it is feasible to develop concrete with about two-thirds less carbon emissions than conventional cement today using known technologies and processes. These opportunities, however, are unlikely to be implemented without addressing systemic barriers, such as costs and restrictive regulations. Several decarbonization options were discussed in this report, and they are aggregated in the two waterfall charts in Figure 9. Concrete mixture proportions used in this chart are based on the values given in Figure 1. On the left, the emissions for the U.S. concrete industry are reduced by two-thirds. A 25% limestone replacement is applied to 25% of U.S. concrete. Because this would reduce the amount of cement produced, CCS is applied to the remaining 75% of U.S. cement production, avoiding up to 63 million tons of CO₂ per year (as opposed to the 72 million tons mentioned earlier in the report). Additionally, a case of concrete pavement per mile was given on the right, showing the possibility of becoming CO₂-negative.

Concrete Industry Emission Reduction Opportunities

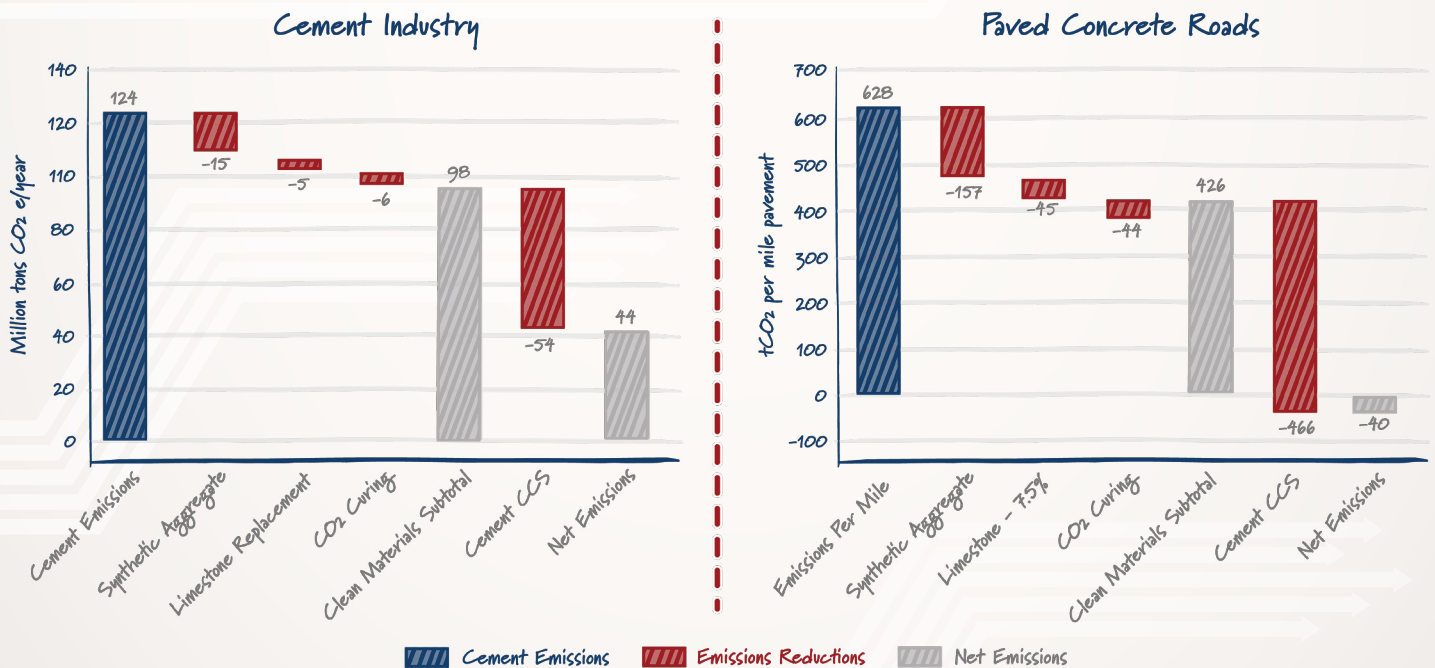


Figure 9: Cumulative reduction of cement emissions various decarbonization options. Left:- Impact on emissions of U.S. cement industry, per year Right: Impact on emissions of concrete pavement, per mile

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The decarbonization opportunities discussed are further summarized in the table below:

Option	Technology	Impact on Emissions	Scalability	Status	Area of Need
1	Carbon Capture	Could capture 96% of process emissions; 72 MtCO ₂ /year	Restricted by available plant space	European demonstration projects ongoing	Fund demonstration projects
2	Limestone Replacement	Directly replace cement; ~900 kg CO ₂ avoided per ton cement replaced	Vast resources available	Established in many countries, but reports of effects on performance vary	Performance-based specifications, identify applications
	Other Supplementary Cementitious Materials	Likely slightly less reduction than limestone	Various materials produced at ~100s Mt/year	Some used in niche applications	Research effects of alternate materials on concrete properties
	Warm Mix Asphalt	About 15% reduction compared to hot mix asphalt	Limited by manufacturer adoption (install equipment)	Used in ~40% of US asphalt, but could be 100%	Increased education and communication
	Recycled Asphalt Materials	Replaces portion of asphalt cement, but difficult to quantify full reduction	Limited by amount of waste asphalt	Used in ~20% of US asphalt, but could be ~40%	Increased education and R&D; performance-based specifications
3	Synthetic Aggregate	Could contain 50-200 kg CO ₂ per ton aggregate full reduction	Limited by availability of alkalinity sources	Commercialized on small scale	Incentives to compete with cheap natural aggregates
	CO ₂ -Curing	Could contain up to 50 kg CO ₂ per ton concrete, but needs life cycle assessment	Could theoretically be applied to all concrete	Commercialized on small scale	Incentives; R&D for life cycle assessment
	Alternate Building Materials	Could contain significant CO ₂ , but process might also significantly emit CO ₂	Limited by availability of alkalinity sources	Pilot-scale testing	Funding and incentives; performance-based specifications

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Recommendations

Several impactful opportunities exist to decarbonize the concrete industry, all at varying readiness levels. When selecting among the options to make policy recommendations, the most important factors are short- and long-term impact and likelihood of adoption. The industry is very reluctant to change existing practices due to liabilities and costs associated with unfamiliar technologies. Further, preservation of strength and durability, along with costs, are prioritized over any economic concerns.

Based on the above considerations, the following recommendations are made:

- 1. Fund demonstration projects for carbon capture at cement plants.** Of the decarbonization opportunities discussed here, this is the most ready technology, and has the most minimal impact on current production practices. Captured CO₂ streams could be allocated to help develop CO₂-curing projects
- 2. Increase research for lower-carbon supplementary cementitious materials (“SCMs”) and materials made with carbon mineralization.** This includes the effect of increased limestone replacement, as well as new SCMs to supplement declining supply of coal fly ash and blast furnace slag. The program should identify safe levels of use for various applications. Research in mineralization materials would accelerate advancement of a technology that has not yet reached wide adoption, but has potential for large-scale carbon reductions. Characterization and identification studies of potential feedstock sources should be performed. Improvements to life cycle assessment of building material products should be made. Research in all of these areas should also consider long-term impacts on emissions during the material’s use.
- 3. Encourage regulating bodies to move to performance-based specifications in asphalt and concrete.** Change from specifying mixture proportions to requirements of strength, durability, etc. This would help to increase adoption of limestone replacement, SCMs, recycled asphalt materials, and (eventually) alternate building materials

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ClearPath's mission is to develop and advance conservative policies that accelerate clean energy innovation. To advance that mission, we develop cutting-edge policy and collaborate with academics and industry. An entrepreneurial, young, strategic nonprofit, ClearPath (501(c)(3)) partners with in-house and external experts on nuclear, carbon capture, hydropower, natural gas, geothermal, energy storage and energy innovation to advance our mission.

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