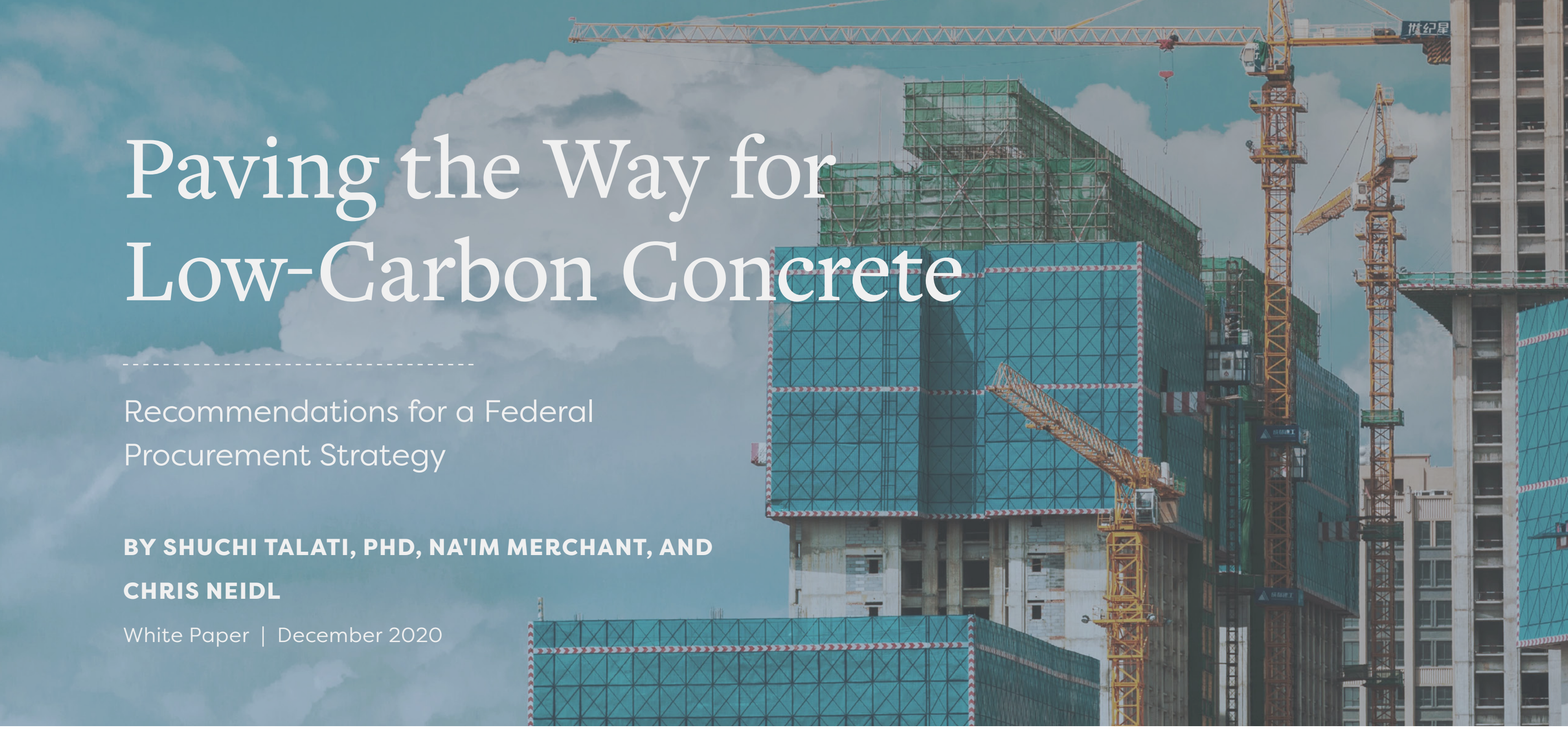

Paving the Way for Low-Carbon Concrete

Recommendations for a Federal Procurement Strategy

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White Paper | December 2020

Concrete is the most used building material on the planet,[1] and its current and future relevance to the climate crisis is both complex and distinct.

The carbon footprint of the material is largely a function of the scale on which it is applied in the modern built environment. But the internal makeup of conventional concrete, and one ingredient in particular, is of central importance. Portland cement, conventional concrete's binding ingredient, is a leading source of industrial carbon dioxide (CO_2) emissions globally.[2]

Carbon180

1. Introduction *(Continued)*

It is also one of the most difficult emissions sources to mitigate due to the inherent carbon intensity of the chemical reactions that are integral to its production. As a result, increased plant energy efficiency and low-carbon fuel substitution together can lower but not completely eliminate cement plant emissions. Further, while there are cost-effective, widely available low-carbon substitutes that can partially displace cement in concrete mixtures today, these alternatives will likely deliver no more than 10% of the sector-wide emissions reductions required by 2050.[3]

The full decarbonization of cement will necessitate the large-scale deployment of carbon capture, utilization, and storage (CCUS) technologies at production sites.[4] But concrete's long-term climate relevance is not limited to emissions reduction. Conventional concrete can also serve as a carbon sink, permanently locking away emissions that would otherwise reach and warm the atmosphere. This can be done by integrating CO_2 captured from point sources (such as power plants or cement plants) as well as ambient air in the concrete production process. New and emerging technologies enable CCUS across nearly every major concrete component. At scale, these solutions can one day lead to carbon negative concrete, the point at which more emissions are captured and stored in the material than are generated in its production and use.

The United States federal government has an outsized role to play in accelerating the technology and market readiness of low-carbon concrete solutions within a timeframe that matters to the climate crisis. In particular, government procurement policy can leverage public purchasing power to build strong early markets for low-carbon concrete alternatives, catalyzing access throughout the economy at large.

This white paper provides background on concrete's relevance to the climate crisis; a survey of state and municipal low-carbon concrete procurement initiatives that can inform federal policy directions; and a comprehensive set of policy recommendations focused on opportunities to accelerate low-carbon concrete commercialization through the power of federal government procurement standards.

1. International Energy Agency & Cement Sustainability Initiative. (2018, April). *Technology Road Map: Low-Carbon Transition in the Cement Industry.* https://www.iea.org/reports/technology-roadmap-low-carbon-transition-in-the-cement-industry

2. Lehne, J., & Preston, F. (2018, June). *Making Concrete Change: Innovation in Low-carbon Cement and Concrete.* Chatham House, The Royal Institute of International Affairs. https://www.chathamhouse.org/sites/default/files/publications/research/2018-06-13-making-concrete-change-cement-lehne-preston.pdf

3. Czigler, T., Reiter, S., Schulze, P., & Somers, K. (2020, May). *Laying the foundation for zero-carbon cement.* McKinsey & Company. https://www.mckinsey.com/industries/chemicals/our-insights/laying-the-foundation-for-zero-carbon-cement

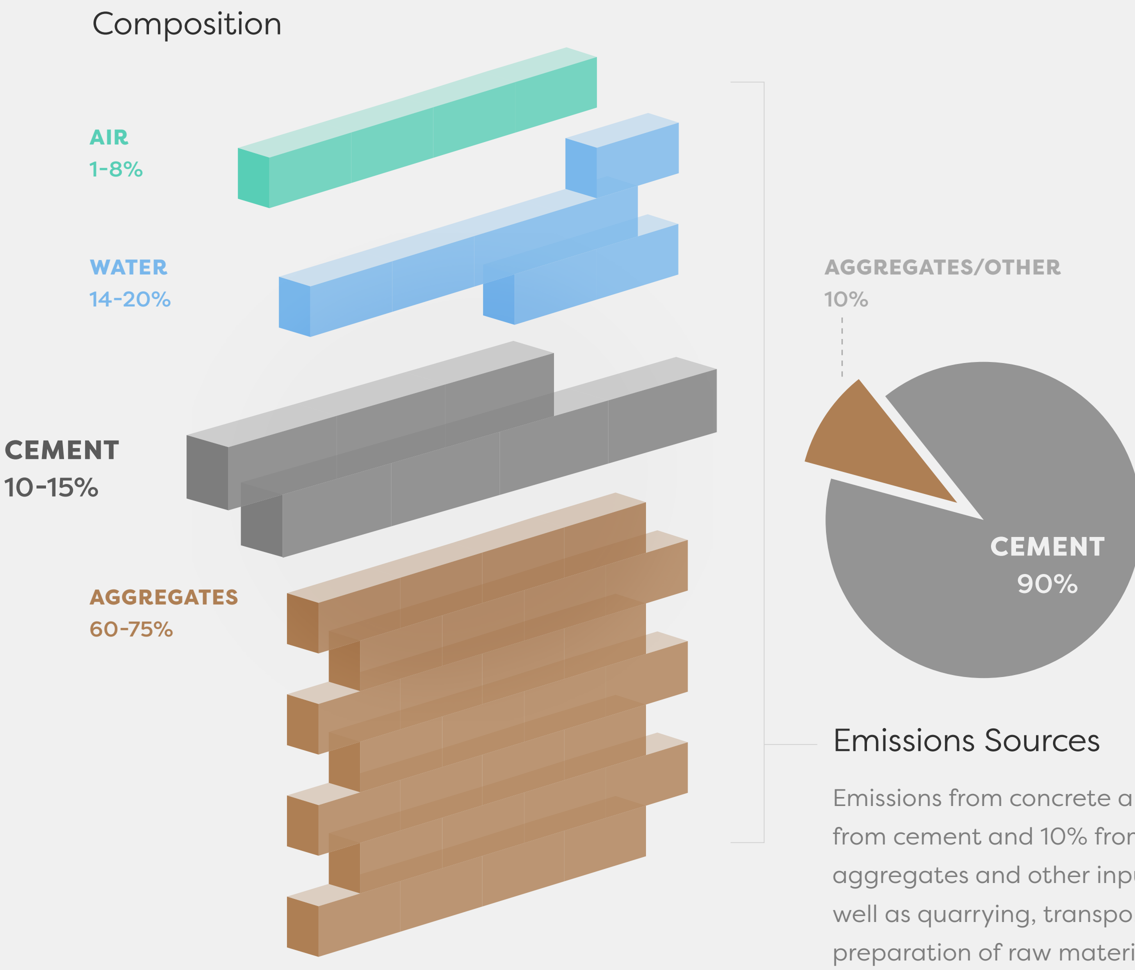
4. International Energy Agency & Cement Sustainability Initiative. (2018, April). *Technology Road Map: Low-Carbon Transition in the Cement Industry.* https://www.iea.org/reports/technology-roadmap-low-carbon-transition-in-the-cement-industry

CEMENT V. CONCRETE

Cement refers to the binding agent in concrete, a building material.

FIGURE 1. Comparing the Composition and Emissions Sources of Concrete

The components that make up concrete and their proportional contribution to concrete's greenhouse gas emissions.



Emissions Sources

Emissions from concrete are 90% from cement and 10% from aggregates and other inputs as well as quarrying, transport, and preparation of raw materials.

Source: Adams, M. P.[5]

5. Adams, M. P. (2020, November 16). Reducing the Embodied Carbon in Concrete. Presentation.

2. Background: Decarbonizing Concrete

2.1 Concrete and its uses

Concrete is the most used building material in the world and a major driver of industrial greenhouse gas (GHG) emissions.[6] Excavations in Lower Galilee show how Neolithic societies used a form of concrete when constructing the floors of their dwellings over nine thousand years ago.[7] Cement makes up only 10–15% of an average concrete mixture but is the key ingredient holding together the aggregates (fine and coarse rocks) that, alongside water, compose the bulk of concrete. In the 1800s, the advent of Portland cement, named for its resemblance to a building stone used in the Isle of Portland in England, revolutionized concrete production and spurred the modern concrete industry. A powder derived from burning and grinding a mixture of limestone and clay, Portland cement remains the most common form of cement and is used in 98% of concrete produced today.[8]

Hailed for its relatively low cost, strength, and durability, concrete is nearly ubiquitous in modern-day construction. Concrete is widely used in the construction of residential and commercial buildings, critical infrastructure like dams, seawalls, sewers, culverts, piers, roads, and bridges, as well as smaller scale projects like sidewalks, fences, and driveways. The use of concrete building materials is showing no signs of letting up — the global production of Portland cement currently amounts to 4 billion metric tons per year and is projected to rise to 5 billion metric tons per year by 2030.[9]

2.2 Portland cement: concrete's core component and major emissions source

Though concrete is made up of just 10–15% cement, cement production makes up the majority of concrete's greenhouse gas emissions. Globally, the cement industry is responsible for a quarter of industrial CO_2 emissions and 7% of all CO_2 emissions (more than double the emissions from global air travel).[10] Cement's emissions take the form of process emissions and combustion emissions. Process emissions are the result of chemical reactions that are an integral part of cement production. Combustion emissions come from the burning of coal or natural gas necessary to heat raw materials at very high temperatures. Unlike operational emissions, which can be reduced through improved efficiencies, embodied carbon emissions — the total emissions generated to build something — are locked in place as soon as something is built. Embodied carbon in the building products and construction sector more broadly is currently responsible for 11% of global emissions and is expected to continue growing, making it clear that urgent action is necessary to reduce emissions from concrete and cement.[11]

In response to growing public urgency and in anticipation of a carbon-constrained

6. International Energy Agency & Cement Sustainability Initiative. (2018, April). *Technology Road Map: Low-Carbon Transition in the Cement Industry.* https://www.iea.org/reports/technology-roadmap-low-carbon-transition-in-the-cement-industry

7. Garfinkel, Y. (1987). Yiftahel: A Neolithic Village from the Seventh Millennium B.C. in Lower Galilee, Israel. *Journal of Field Archeology*, 12(2), 199-212. https://doi.org/10.2307/530140

8. Timperley, J. (2018, September 13). *Q&A: Why cement emissions matter for climate change.* Carbon Brief. https://www.carbonbrief.org/qa-why-cement-emissions-matter-for-climate-change

9. Ibid.

10. Czigler, T., Reiter, S., Schulze, P., & Somers, K. (2020, May). *Laying the foundation for zero-carbon cement.* McKinsey & Company. https://www.mckinsey.com/industries/chemicals/our-insights/laying-the-foundation-for-zero-carbon-cement

11. Architecture 2030. (n.d.) *New Buildings: Embodied Carbon.* https://architecture2030.org/new-buildings-embodied/

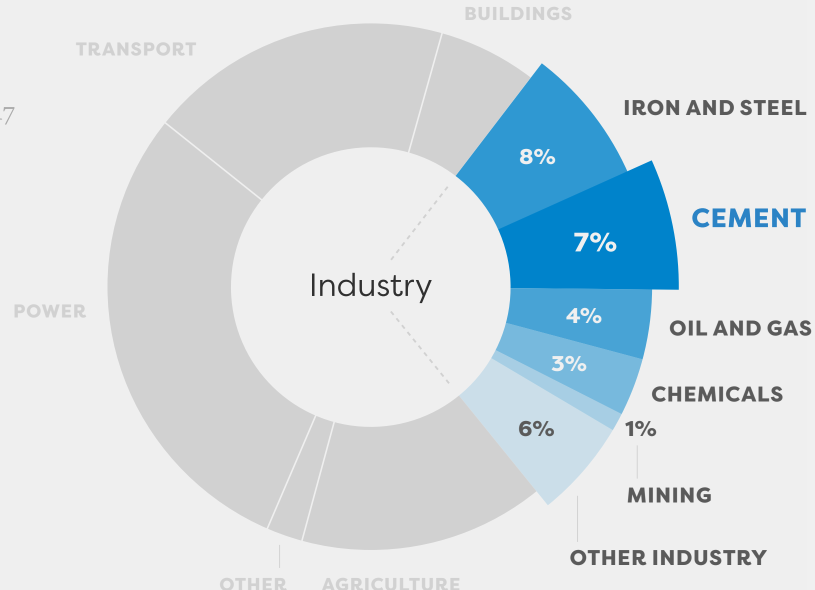
EMBODIED CARBON

The total greenhouse gas emissions generated to build something, including the extraction, manufacturing, transportation, and assembly of every component, as well as the disposal and end-of-life of the material, excluding operational emissions of the product.

FIGURE 2.

Cement Production's Share of Global CO_2 Emissions % in 2017

The share of global carbon dioxide emissions by sector. Cement production, part of the industrial sector, contributed 7% in 2017. Unless steps to decarbonize are taken, this number is likely to increase as demand for concrete continues to grow.



Source: McKinsey[12]

future, the global cement industry has in recent years shifted to a more proactive and solution-oriented posture than in the past. Many of the sector's largest private producers and industry organizations have formally incorporated ambitious strategies to meet or exceed Paris Agreement targets. Most prominently, LafargeHolcim and HeidelbergCement, the first and fourth ranked global producers by production volume respectively, have pledged to achieve carbon neutrality in their operations by 2050.[13, 14] The Portland Cement Association, the leading trade organization representing US cement producers, recently announced plans to produce a roadmap that will guide the industry as a whole to carbon neutrality within this same timeframe.[15]

The path to realizing these and similar commitments will involve a multitude of technical, commercial, and policy interventions; while some are well established today, many others are still emerging or only at a conceptual stage of development.

2.3 Ways to limit emissions from concrete production

Given that cement makes up the majority of concrete productions's CO_2 emissions, impactful reduction pathways must focus on lowering process and combustion emissions from Portland cement, as well as increasing availability of alternative cements and components. To date, that has proven extremely difficult. Some

12. Czigler, T., Reiter, S., Schulze, P., & Somers, K. (2020, May). *Laying the foundation for zero-carbon cement*. McKinsey & Company. https://www.mckinsey.com/industries/chemicals/our-insights/laying-the-foundation-for-zero-carbon-cement

13. LafargeHolcim. (2020). *Our net zero roadmap*. https://www.lafargeholcim.com/our-net-zero-roadmap

14. Heidelberg Cement. (2020). *Energy and Climate Protection*. https://www.heidelbergcement.com/en/energy-and-climate-protection

15. Portland Cement Association. (2020, November 17). *Portland Cement Association to further sustainability goals by creating carbon neutrality roadmap for the cement and concrete industry*. https://www.prnewswire.com/news-releases/portland-cement-association-to-further-sustainability-goals-by-creating-carbon-neutrality-roadmap-for-the-cement-and-concrete-industry-301174836.html

progress has been made through efficiency improvements and the use of alternative fuels for combustion processes, which has reduced the carbon intensity (CO_2 emissions per ton of cement produced) of cement production by 18% over the last few decades.[16] However, with concrete demand growing, much more needs to be done. Fortunately, new solutions at various stages of market readiness can have a transformative effect on concrete's emissions today and in the near future:

- **CEMENT PLANT EFFICIENCY:** The Environmental Protection Agency's (EPA) ENERGY STAR Program's energy performance indicator (EPI) tool provides energy efficiency ratings and best in class certification for cement manufacturing facilities as part of a voluntary program for cement producers in the US. Over 10 years, this has led to savings of 1.5 million metric tons of energy-related carbon emissions.[17]
- **ALTERNATIVE FUELS:** Achieving high temperatures in the production process requires energy-dense fuels that are difficult to decarbonize. The use of alternative fuels, like renewably produced hydrogen, could help reduce combustion emissions.
- **ALTERNATIVE MATERIALS:** Replacing or substituting limestone-based Portland cement with lower-carbon alternative materials can result in significant emissions reductions.
- **CARBON UTILIZATION:** The integration of CO_2 as part of the concrete production process can further reduce concrete's carbon footprint. CO_2 can be used to alter the properties of Portland cement–based concrete, or can be used to make alternative concrete without Portland cement.[18] CO_2 can be used as a substitute, input, or enhancement for various conventional concrete components, including water, aggregates, cement, and supplementary cementitious materials (SCMs).

While Portland cement in concrete can be substantially replaced by a variety of SCMs, and alternative cements do exist for some applications, large-scale displacement in the near term is challenging because of the reduced efficacy or availability of other materials. Due to the inherently carbon-intensive production process, emissions cannot be completely mitigated through higher plant efficiencies and fuel substitution alone. Substantial deployment of technologies that capture carbon from cement plants or directly from the atmosphere with subsequent carbon utilization or storage will be necessary.[19, 20, 21]

- **CARBON CAPTURE, UTILIZATION, AND STORAGE (CCUS):** The installation of CCUS to capture emissions directly from the cement production process can significantly reduce combustion emissions for plants that use fossil fuels like coal and natural gas. The captured carbon can then be used in the cement production process itself, in other industrial processes, or stored underground. The Canadian technology company Svante is an early entrant in the cement

16. Timperley, J. (2018, September 13). *Q&A: Why cement emissions matter for climate change*. Carbon Brief. https://www.carbonbrief.org/qa-why-cement-emissions-matter-for-climate-change

17. Energy Star. (2019). *ENERGY STAR Focus on Energy Efficiency in Cement Manufacturing*. https://www.energystar.gov/industrial_plants/measure-track-and-benchmark/energy-star-energy-1

18. Woodall, C. M. (2020, September). Report on Decarbonization in Pavements and Concrete. ClearPath. https://static.clearpath.org/2020/09/cement-report.pdf

19. International Energy Agency & Cement Sustainability Initiative. (2018, April). *Technology Road Map: Low-Carbon Transition in the Cement Industry*. https://www.iea.org/reports/technology-roadmap-low-carbon-transition-in-the-cement-industry

20. Lehne, J., & Preston, F. (2018, June). *Making Concrete Change: Innovation in Low-carbon Cement and Concrete*. Chatham House, The Royal Institute of International Affairs. https://www.chathamhouse.org/sites/default/files/publications/research/2018-06-13-making-concrete-change-cement-lehne-preston.pdf

21. Czigler, T., Reiter, S., Schulze, P., & Somers, K. (2020, May). *Laying the foundation for zero-carbon cement*. McKinsey & Company. https://www.mckinsey.com/industries/chemicals/our-insights/laying-the-foundation-for-zero-carbon-cement

SUPPLEMENTARY CEMENTITIOUS MATERIALS (SCMs)

Material inputs that can serve as substitutes for cement. They can improve structural performance and durability, lower costs, or reduce environmental impact and embodied carbon. Common forms include industrial waste products as well as naturally occurring materials.

CCUS space, with demonstration and full commercial deployments executed or planned for the near term in both Canada and the US.

- **DIRECT AIR CAPTURE (DAC):** DAC is a technology that can remove CO_2 emissions directly from the atmosphere. While CCUS installation can reduce combustion emissions, DAC can remove process emissions as well as legacy emissions generated in the production of concrete. When paired with CCUS, DAC can eventually move concrete production closer to carbon neutral, and even carbon negative. Carbon captured by DAC on or near a cement plant can be used in the concrete production process or permanently stored underground. DAC is a critical carbon removal technology that can make concrete production part of the climate solution, but it has faced policy barriers to scaling. Incentivizing its

LEGACY EMISSIONS
Greenhouse gas emissions that have been emitted in the past and remain in the atmosphere.

FIGURE 3. Pathways for CO_2 Use

Carbon capture emissions reduction pathways in cement and concrete manufacturing. CO_2 can be captured through either point source systems or mineralization. Once CO_2 is captured in either a gaseous or mineralized form, it can be used or stored in different ways.

CO_2 Point Source Capture

Point source CO_2 emissions are captured directly at cement production facilities using pre-combustion, post-combustion, or oxyfuel technologies.

STORAGE
Captured CO_2 is transported to suitable geological sites for sequestration.

UTILIZATION
CO_2 is utilized as a feedstock in the production of commodities and materials for the industrial chemical, fuel, agriculture, and construction material sectors.

CO_2 Mineralization

Gaseous CO_2 from industrial point sources or the ambient air is converted into solid carbonates that augment and/or substitute concrete components.

CO_2 CURING
CO_2 replaces energy intensive steam curing to reduce cement content and increase strength, while mineralizing and storing carbon in precast and ready mix concrete.

CARBONATION
CO_2 reacts with Ca or MgO to form a solid carbonate. This material substitutes or augments conventional concrete components (e.g. aggregates, SCMs).

CO_2-BASED CEMENTS
CO_2 is used as an input in the cement manufacturing process, displacing conventional Portland cement.

incorporation into high-emitting industries can help it grow at the pace we need.

2.4 Government and industry role in limiting future concrete emissions

In many countries, governments are the largest buyers of construction materials[22] and, among other regulatory options, can create a market-friendly pathway for the cement and concrete industry to transition to low-carbon alternatives. First, governments can encourage the creation of industry-wide standards for measuring efficiency, emissions intensity, and embodied carbon, and require reliable CO_2 footprint labeling.[23] Second, they can restructure competitive bidding processes for building materials in public projects that integrate embodied carbon considerations by setting maximum embodied carbon levels or minimum cement-replacement levels. These changes to bidding processes can generate competition among suppliers to reduce the embodied carbon levels of their products in a market-friendly manner. Finally, they can establish clear market signals by setting target dates for achieving net-zero carbon emissions in concrete production.

Industry players are ready to meet an increased demand for low-carbon concrete with a suite of innovative solutions. New Jersey-based Solidia recently partnered with LafargeHolcim, one of the world's largest cement producers, to improve their novel sustainable cement offerings and make them available in new markets. LafargeHolcim also recently partnered with Svante, a carbon capture technology company, to outfit a Colorado-based cement plant to capture and sequester the plant's CO_2 emissions. CarbonCure, which retrofits concrete plants to inject captured CO_2 into concrete mix, is already installed in over 200 concrete plants nationwide and has reduced over 90,000 tons of CO_2 to date.[24] Recent investments in low-carbon concrete companies including CarbonCure, Solidia, Blue Planet, and CarbiCrete by investors like Amazon, Breakthrough Energy Ventures, Mitsubishi, Kleiner Perkins, and others validate the underlying technology while enabling the companies to meet growing demand for low-carbon concrete.

3. Today's Landscape: Existing Policies and Proposals

In recent years, the importance of achieving deep and rapid emissions reductions in the industrial and construction materials sectors has gained greater recognition and urgency. One tool, government procurement, has inspired new regulatory and policy approaches. Such policies are intended to directly reduce the carbon footprint of government operations while more broadly establishing strong, early, and consistent markets for low-carbon construction materials, including concrete and cement. The federal government is a major market for such materials — the US federal government's annual procurement budget exceeded $500 billion in fiscal

22. Lehne, J., & Preston, F. (2018, June). *Making Concrete Change: Innovation in Low-carbon Cement and Concrete.* Chatham House, The Royal Institute of International Affairs. https://www.chathamhouse.org/sites/default/files/publications/research/2018-06-13-making-concrete-change-cement-lehne-preston.pdf

23. Existing federal resources such as the Energy Star energy performance indicator (EPI) tool and certification program could be integrated and leveraged for this purpose. Jointly administered by the Environmental Protection Agency (EPA) and Department of Energy (DOE), the EPI is used to derive and apply energy efficiency ratings to industrial facilities, including cement plants, as part of a voluntary industry certification program. Energy Star. (2019). *ENERGY STAR Focus on Energy Efficiency in Cement Manufacturing.* https://www.energystar.gov/industrial_plants/measure-track-and-benchmark/energy-star-energy-1

24. CarbonCure. (n.d.) *Reducing Carbon, One Truck At A Time.* https://www.carboncure.com

year 2020, with nearly 30% of total funds allocated for construction projects across multiple agencies.[25] The following policies represent a sample of existing influential procurement-based precedents.

3.1 State and municipal policy leadership

Early action has occurred most notably in states and municipalities where formal emissions reductions targets are legally in place.

3.1.1 THE BUY CLEAN CALIFORNIA ACT

Signed into law in October 2017 and placed in effect in July 2019, California Buy Clean is the first government program of its kind to establish environmental performance standards for four leading construction materials used in state building projects: steel rebar, flat glass, structural steel, and mineral wool-board insulation. Notably, cement and concrete are exempt from this regulation. Starting in 2020, the law required private material suppliers to submit Environmental Product Declarations (EPDs) as part of the competitive procurement process. In early 2021, the state will publish maximum eligible Global Warming Potential (GWP) values based on aggregated EPD data for all regulated materials. Beginning on July 1, 2021, providers will be required to demonstrate compliance with published values as a condition of eligibility for state construction contracts. As of October 2020, legislation similar to California Buy Clean has been introduced in both the Washington and Oregon state legislatures, and is being considered for introduction in the state of Minnesota.

3.1.2 THE CITY OF PORTLAND'S LOW CARBON CONCRETE INITIATIVE

In 2016, the City of Portland identified concrete manufacturing as a leading source of carbon emissions among major construction materials procured by the city government. In January 2020, a new Low Carbon Concrete Initiative placed in effect a mandatory EPD submission requirement for bidding contractors proposing to use concrete in city construction projects. In April 2021, the City will publish maximum acceptable GWP criteria for concrete materials and in 2022, all concrete for city contracts will be required to not exceed published GWP thresholds. In parallel, the State of Oregon's Department of Environmental Quality implemented an EPD promotion program that provides a financial rebate to offset EPD technology setup costs.

3.1.3 THE CITY OF HONOLULU'S RESOLUTION, SUBSEQUENT USCM RESOLUTION, AND THE CITY OF AUSTIN RESOLUTION

Passed in April 2019, The City of Honolulu's Resolution 18-283 requests that the city administration "consider post-industrial carbon dioxide mineralized concrete" for Honolulu City and County construction, provided that utilization "does not significantly increase the costs of or significantly delay the project." The resolution

25. Associated General Contractors of America. (2020). AGC Summary of Federal Construction Accounts (FY 2020 Appropriations) https://www.agc.org/sites/default/files/Copy%20of%20Copy%20of%20FY20%20approps1%20final_0.pdf

ENVIRONMENTAL PRODUCT DECLARATION (EPD)
An independently verified document that communicates information about the life cycle environmental impact of products in a transparent and comparable manner.

GLOBAL WARMING POTENTIAL (GWP)
Measures greenhouse gas emissions associated with the manufacture and use of a product or service.

also directed the City Department of Budget and Fiscal Services to consider implementing an incentive program to encourage the use of CO_2 mineralized concrete in all city contracted construction projects. Honolulu's Resolution was the basis of an identical resolution proposed and passed by the United States Conference of Mayors (USCM) in June 2019. The resolution urges the conference's 1,400 member constituency, representing all US municipalities with populations over 30,000, to consider utilizing CO_2 mineralized concrete in public construction projects. A version of the resolution was also adopted by the City of Austin, Texas.

3.2 Climate competition: New York's proposed market-based procurement approach to addressing cement emissions

The New York State Low Embodied Carbon Concrete Leadership Act (LECCLA) is currently introduced legislation that would establish a climate impact procurement standard for all state and state-funded construction projects for concrete purchases exceeding 50 cubic yards. The legislation was introduced in the New York State (NYS) Assembly in September 2019 and in the State Senate in September 2020.

LECCLA's design incorporates some elements of prior policies described above. However, the legislation is distinguished by some novel elements:

- **CLIMATE COMPETITION:** LECCLA includes a mechanism that aims to drive carbon reduction primarily through a market-based producer incentive rather than mandatory compliance thresholds. Following California Buy Clean and the Portland Low Carbon Concrete Initiative, LECCLA establishes GWP values submitted via EPDs as its core climate impact metric. This GWP basis for comparison and evaluation is technologically non-prescriptive and solution agnostic. It grants participants the flexibility to pursue multiple decarbonization options while optimizing for compliance impact, cost, availability, and other factors.

  Under LECCLA, GWP scores do not function to establish compliance thresholds for public contracts. Rather, scores directly influence the competitiveness of individual producer bids in the form of a price discount rate applied during proposal review. In a competitive solicitation, providers voluntarily submit EPDs for all concrete mixes included in their proposal. An aggregate GWP value for all mixes, weighted for volume, is assigned to each bid. Bids are ranked according to their GWP scores, with the lowest scores attaining the highest ranks. The price of the bid with the top GWP rank will be discounted by 5%. Lower GWP-ranked bids would be assigned discount rates at or below 5%, proportionate to the top ranked bid's GWP score. Bids that did not submit EPDs would receive no discount.

- **INCENTIVIZATION OF CCUS AND OTHER "BREAKTHROUGH" INNOVATIONS:** Inspired by Honolulu's Resolution 18-283, LECCLA's incentive design reflects the critical imperative to accelerate the technical development and market entry of CCUS. Whereas Resolution 18-283 narrowly directs consideration of one category of emerging carbon utilization technologies (carbon mineralization or curing technology), LECCLA includes a supplemental price discount rate for CCUS technologies as well as other designated breakthrough innovations that have the capability to substantially reduce GWP. Qualified CCUS and breakthrough technologies would be certified by the state. An additional maximum 3% price discount, above the baseline 5% rate, would be applied to top GWP ranked bids that incorporate state certified CCUS/breakthrough technologies. This supplemental discount rate would be GWP performance based, with greater discounts applied to solutions with greater GWP impact. This market-based approach would help drive innovation by incentivizing private providers to adopt new CCUS/breakthrough alternatives as they emerge, but within the constraints of cost, availability, and operational limitations.
- **FACILITATING RAPID EPD TECHNOLOGY ADOPTION WITH TARGETED PRODUCER TAX CREDIT:** Following the example of the State of Oregon, LECCLA incorporates financial recompensation for both concrete and concrete component manufacturers that invest in information technology to generate EPDs at their production facilities. Private, tax-paying facilities within the state can claim a tax credit equal to the lesser of $3,000 or 100% of technology set up costs per plant, for a maximum of eight plants per tax year. Credit eligibility will last for a period of two years following implementation before expiring. The function of the credit is to both limit the financial burden of program participation by private plant owners and to accelerate broad EPD adoption, upon which the program's efficacy depends.

CARBON MINERALIZATION
A chemical reaction that transforms CO_2 into a solid mineral, such as a carbonate. Carbonates formed from captured CO_2 can be used as material inputs in concrete and alternative cements.

4. A Federal Vision: Policy Recommendations on a National Scale

A federal procurement standard would likely be overseen and enforced by the General Services Administration (GSA) and the EPA. Relevant technical guidance and support would likely be needed from the Department of Transportation and the Army Corps of Engineers, among others.

4.1 Policy recommendations

To envision what a federal low-carbon concrete bill might look like, we considered the NYS LECCLA bill, existing city and state measures, and additional novel components that would be more expansive. As described earlier, the NYS bill includes a state government–wide low-carbon concrete procurement standard, an incentive based on a climate competition bidding framework using EPD values and a price discount rate, and a supplemental discount rate for bids that incorporate CCUS technologies. For a federal bill, we propose building on NYS LECCLA elements with the following:

- **EXPAND THE CCUS CREDITS AND INCENTIVES:** A CCUS system for a cement production plant would allow for capture and use or storage of emissions that are otherwise unable to be mitigated. Additionally, creating a source of captured carbon at or near where it will be utilized could facilitate an increase in the amount of low-carbon concrete produced. We propose adding additional measures to a federal program to incentivize the adoption of a CCUS system onsite, both through higher discount rates in the bidding process as well as upfront tax credit incentives due to high capital costs. Discount rate credits as well as a potential tax credit should apply to DAC systems as well. In parallel, we also recommend lowering the threshold for DAC to qualify for the 45Q tax credit. DAC integration at the plant level is possible, but is currently too small to qualify.
- **IMPROVE EPDS AND EXPLORE OTHER LIFE CYCLE ASSESSMENT (LCA) TOOLS:** The EPD is an established, well-known tool that has evolved over time, compatible with emissions LCAs for concrete. It has been used in many procurement standards, including California Buy Clean. However, it is an imperfect assessment. Research funding should be made available within the Department of Energy (DOE) to determine how EPDs can be made more robust and to understand gaps, needs, and benefits of other LCA tools moving forward.

LIFE CYCLE ASSESSMENT (LCA)

Determines the environmental impact of products, processes, or services through their life cycle (including production, usage, and disposal).

- **ACCELERATE DEVELOPMENT OF DAC APPLICATIONS TO CEMENT THROUGH RESEARCH, DEVELOPMENT, DEMONSTRATION, AND DEPLOYMENT (RDD&D) FUNDING:** Linking DAC to carbon utilization in cement and concrete would provide long-term carbon storage in an industry that would continue to be a growing consumer. DAC is necessary to capture the full emissions from cement and concrete production that are not captured by a CCUS system. Establishing a DAC and carbon use system for cement and concrete that is financially and environmentally beneficial requires a significant increase in RDD&D funding.

4.2 Fitting into existing legislation and plans

A federal low embodied carbon procurement standard could function as a stand-alone measure or could easily fit into broader proposed procurement policies that have been suggested by members of Congress and the incoming Biden Administration.

- **THE CLEAN FUTURE ACT:** The CLEAN Future Act, introduced by Representatives

Pallone, Tonko, and Rush, includes a "buy clean" measure, similar to that of California.[26] This bill stipulates that the federal government and any construction project receiving federal funding would be required to only use materials achieving a minimum GHG standard. A federal procurement standard for concrete rooted in climate-based metrics works with such a standard, and could fit easily into this bill. The market-based incentive structure of NYS LECCLA could be combined with a "buy clean" mandatory compliance threshold, with the former driving high GWP performance and the latter establishing a minimum GWP eligibility floor that aligns with overall emissions reduction targets. Further, state-based "buy clean" programs, as well as federal policy modeled after them,[27] involve a phased multi-year implementation approach that aims to mitigate against undue stresses imposed on industry and government. Implemented at an early phase, an incentive-based approach modeled after NYS LECCLA could serve to facilitate learning and adjustment by both industry and government in the lead-up to an economy-wide compliance mandate while also accelerating emissions reductions through the introduction of a competitive market signal.

- **"MADE IN AMERICA, INNOVATE IN AMERICA":** President-elect Biden's procurement plan "Made in America, Innovate in America" includes specific provisions for a large investment in procurement in tandem with the clean energy and infrastructure plans.[28] A federal low embodied carbon procurement standard would fit into this plan, helping US-based companies while also building towards climate goals through procurement- and market-based incentives.

5. Conclusion

Addressing CO_2 emissions from the concrete production process will be critical to meeting climate goals and federal procurement of low-embodied carbon concrete would be an enormous step forward in decarbonizing the entire industrial sector. The recommendations discussed in this paper outline key steps that the US can take to decarbonize this sector through non-prescriptive incentivization, allowing companies to take whatever measures they deem most feasible to the greatest extent possible. Building off of bipartisan state and city work will allow the US to capitalize on existing coalitions of support and successfully implement policies to access the full range of climate and economic benefits of low-embodied carbon concrete.

26. House Committee on Energy and Commerce. (2020, January 28). E&C Leaders Release Draft CLEAN Future Act Legislative Text to Achieve a 100 Percent Clean Economy. https://energycommerce.house.gov/newsroom/press-releases/ec-leaders-release-draft-clean-future-act-legislative-text-to-achieve-a-100

27. Ibid.

28. Biden For President. (2020). *The Biden Plan to Ensure the Future is "Made in All of America" by All of America's Workers.* https://joebiden.com/made-in-america