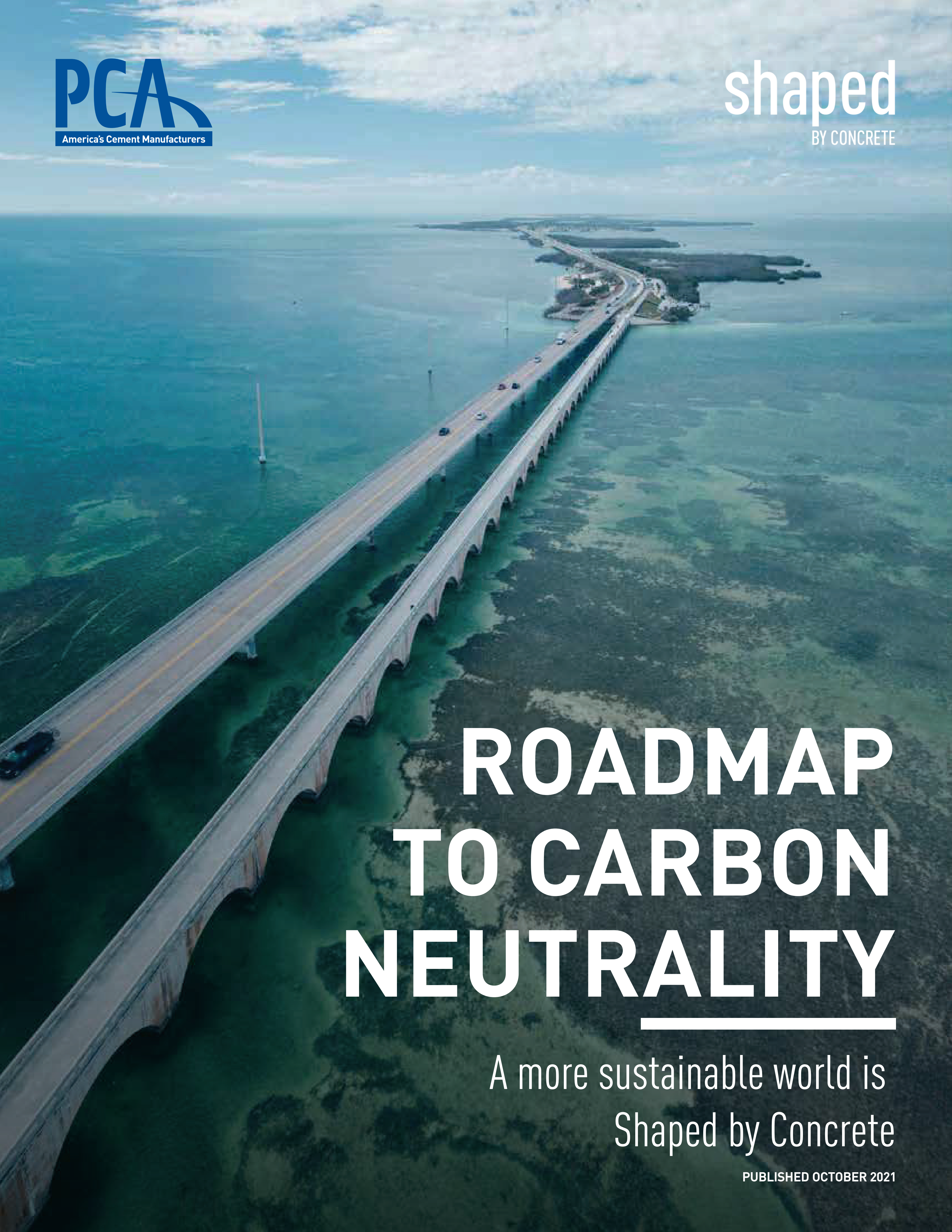


PCA
America's Cement Manufacturers

shaped
BY CONCRETE

ROADMAP TO CARBON NEUTRALITY

A more sustainable world is Shaped by Concrete

PUBLISHED OCTOBER 2021


Skaggs School of Pharmacy
& Pharmaceutical Sciences

A LETTER FROM PORTLAND CEMENT ASSOCIATION CHAIR AND VICE-CHAIR

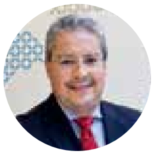
Long before smart phones, GPS, turn-by-turn voice directions, and self-driving cars, there was the ubiquitous roadmap. It was more than just a table of distances between cities with a roadway network laid on a geographic map. It turned a dream into a destination. The Portland Cement Association (PCA) Roadmap to Carbon Neutrality is no different. Our "drive" is our determination to reach the industry's destination of carbon neutrality by 2050. Within these pages you will discover the value chain of clinker, cement, concrete, construction, and carbonation (concrete as a carbon sink) – a value chain that is an integral part of today and tomorrow's circular economy, and the actions that can be taken at each step in this value chain to reach the industry's destination. Each link has its own part to play in the Roadmap, just as each company and industry has a role to play in addressing climate change. Considering the recent Intergovernmental Panel on Climate Change (IPCC) reports and realities that we see unfolding each day, the time for decisive action to combat climate change is now.

Behind this value chain is an industry that drives the American economy and represents more than 6% of gross domestic product. This is an industry that drives architects, engineers, builders, contractors, owners, and consumers. It is also an industry that is engaged with government, academia, entrepreneurs, scientists, and researchers.

PCA is uniquely positioned to lead this effort in collaboration with industry partners across the value chain. PCA member companies produce the majority of cement manufactured in the U.S. Many of these companies also manufacture ready-mix concrete and cement-based materials used in construction. This collective experience, and the hard work and dedication of member company experts that advised PCA staff, provided the foundation for this Roadmap. PCA member companies also have an acute appreciation of the market and policy challenges manufacturers face in reaching carbon neutrality, and the role that others will play in achieving success.

We are America's cement manufacturers, and this is our Roadmap.

Ron Henley
Chairman of the Board, PCA
President, GCC of America, Inc.



Filiberto J. Ruiz
Vice Chairman, PCA
President, Votorantim Cimentos North America

ABOUT THE PORTLAND CEMENT ASSOCIATION

PCA, founded in 1916, is the premier policy, research, education, and market intelligence organization serving America's cement manufacturers. PCA member companies represent the majority of U.S. cement production capacity, having facilities across the country. PCA promotes safety, sustainability, and innovation in all aspects of construction; fosters continuous improvement in cement manufacturing and distribution; and promotes economic growth and sound infrastructure investment. For more information, visit **www.cement.org** and **shapedbyconcrete.com**.

CLIMATE AND SUSTAINABILITY COUNCIL TASK GROUP LEADERS

Clinker

Adam Swercheck, Environmental Director, Lehigh Hanson, Inc.

Michelle Ferguson, Director of Environmental Affairs, Buzzi Unicem USA

Cement

Nick Popoff, Vice President Product Performance and Development, St Marys Cement, a Votorantim Cimentos Company

Concrete

James Mack, Director - Market Development, CEMEX USA

Carbonation

Gina Lotito, Corporate Vice President of Sustainability, GCC of America, Inc.

Lillian Deprimo, Director Environmental, CEMEX USA

Construction

John Pontarollo, Vice President Sustainable Development and Innovation, Ash Grove Cement Company

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EXECUTIVE SUMMARY

PCA member companies are committed to achieving carbon neutrality across the cement and concrete value chain by 2050.

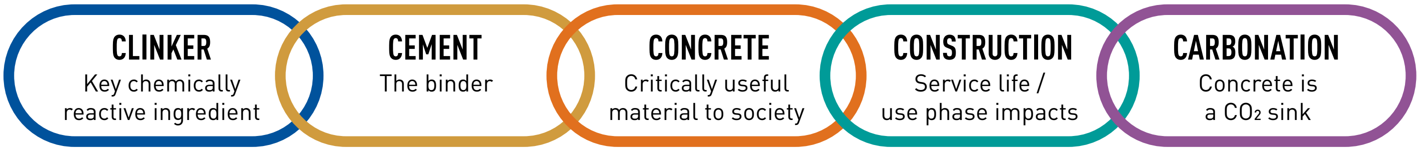
The PCA Roadmap involves the entire value chain starting at the cement plant and extending through the entire life cycle of the built environment to incorporate the circular economy. This approach to carbon neutrality leverages relationships at each step of the value chain, demonstrating to the world that this industry can address climate change.

The cement and concrete industry cannot do this alone. To bring down CO_2 emissions from all sources, including the building sector, one must recognize the way that our world is interconnected. Stakeholders must work together to ensure that the building sector is creating a built environment that is actually sustainable – this is why PCA member companies are embarking on a journey to carbon neutrality as a full industry and inviting others across the value chain to join this effort. Government agencies, non-governmental organizations, and academic institutions all have a role and the industry looks forward to collaborating on this mission to achieve carbon neutrality across the value chain.

The five links in the value chain include the production of clinker, the manufacture and shipment of cement, the manufacture of concrete, the construction of the built environment, and the capture of carbon dioxide using concrete as a carbon sink.

Each link identifies specific targets, timelines, technologies, and policies to reach the goal of carbon neutrality. The approach in this Roadmap leverages each step of the value chain from the farthest upstream to the final reuse and recycling phase. PCA member companies can specifically work on actions to reduce emissions associated with the manufacturing of clinker and the production of cement. Many PCA member companies also produce concrete products. Additionally, PCA member companies sell to concrete producers and can seek to effect change there as well. Cement and concrete manufacturers do not control every link in the value chain, but this Roadmap provides direction and incentives that spur action.

On the next page are the pathways for unlocking emissions reductions along the cement and concrete value chain, now and in the near future.



CLINKER
Key chemically reactive ingredient

CEMENT
The binder

CONCRETE
Critically useful material to society

CONSTRUCTION
Service life / use phase impacts

CARBONATION
Concrete is a CO_2 sink

PRODUCTION: AT THE CEMENT PLANT	
Replace raw materials with decarbonated materials	Using decarbonated materials eliminates CO_2 emissions from processing traditional raw materials, like limestone.
Use alternative fuels	Replacing traditional fossil fuels with biomass and waste-derived fuels lowers greenhouse gas (GHG) emissions and keeps materials out of landfills.
Continue efficiency improvements	Increasing energy efficiency reduces the amount of CO_2 emitted for each ton of product.
Implement carbon capture, utilization, and storage (CCUS) technology	CCUS directly avoids a significant portion of cement manufacturing emissions.
Promote new cement mixes	Creating new cements using existing and even alternative materials reduces emissions from mining for new materials, while optimizing the amount of clinker used ensures emissions correspond to necessary production.
Increase use of portland-limestone cement (PLC)	As an existing lower-carbon blend, universal acceptance of PLC will reduce clinker consumption and decrease emissions.
CONSTRUCTION: DESIGNING AND BUILDING	
Optimize concrete mixes	Considering the specific needs of the construction project and using only the materials necessary, avoiding excess emissions.
Use renewable fuels	Switching to solar, wind and other renewable sources of energy directly reduces emissions from other energy sources.
Increase the use of recycled materials	Diverting these materials from landfills.
Avoid overdesign and leverage construction technologies	Designing for the specific needs of the construction project reduces unnecessary overproduction and emissions; incorporating just-in-time deliveries.
Educate design and construction community	Improve design and specifications to be more performance oriented which will permit innovation in cement and concrete manufacturing. Encourage the use of advanced technologies to improve structural performance, energy efficiency, resiliency, and carbon sequestration.
EVERYDAY: CONCRETE INFRASTRUCTURE IN USE	
Incentivize energy efficient buildings	Increasing buildings' energy efficiency can cut energy use and resulting emissions from heating and cooling.
Reduce vehicle emissions by improving fuel efficiency	Because of its rigidity, concrete pavements enhance the fuel efficiency of vehicles driving over them, reducing vehicle emissions.
Decreased maintenance	Due to their durability, concrete structures (buildings, pavements, bridges, dams, etc.) last longer and require less frequent maintenance.
Recycling	Concrete in place can be 100% recycled, limiting the use of raw materials and production emissions.
Carbonation	Every exposed concrete surface absorbs CO_2 and over the course of its service life, a building can reabsorb 10% of cement and concrete production emissions.


MARKET ST.

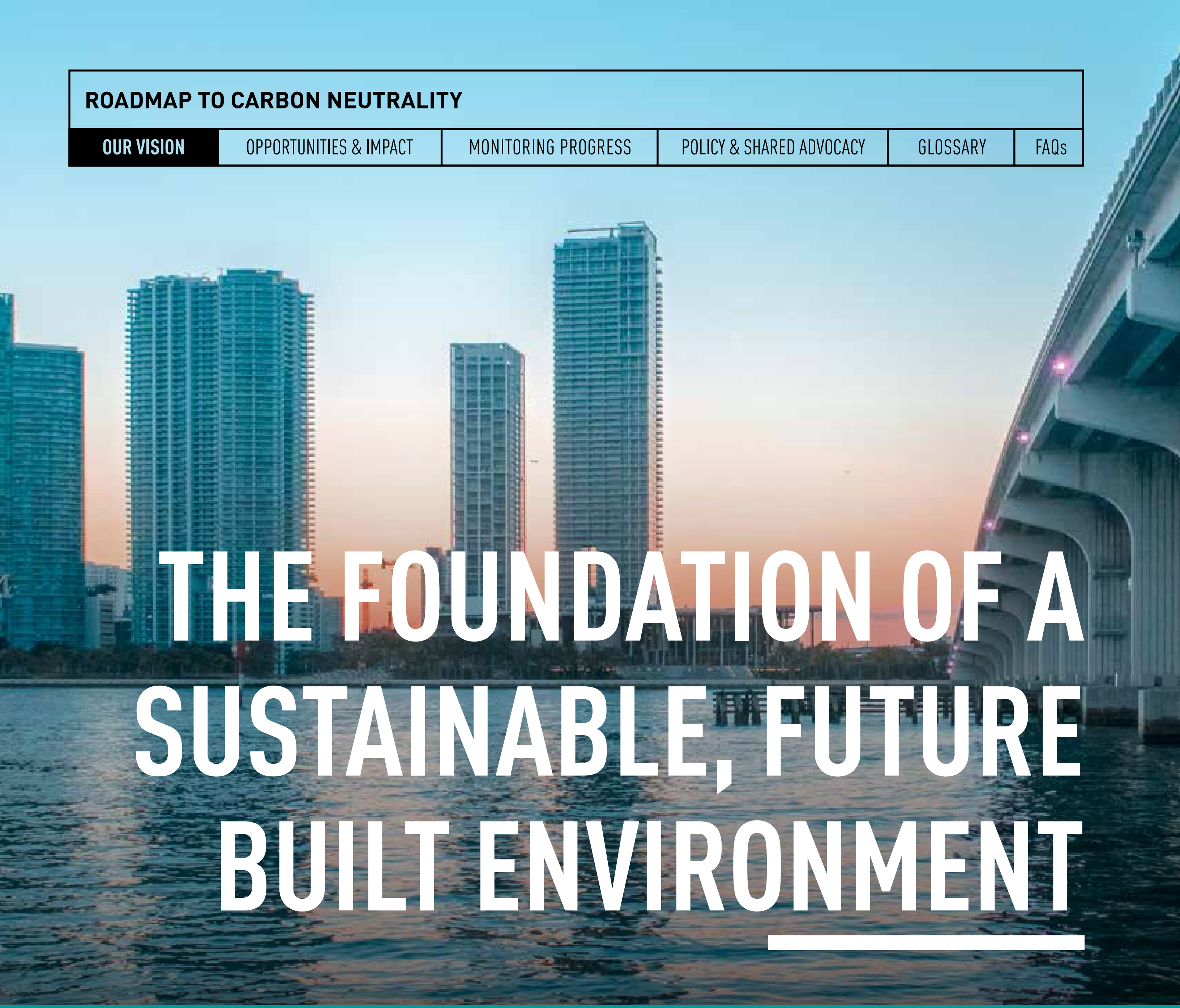
SHARED ADVOCACY IS CRITICAL

The Roadmap to carbon neutrality is more than targets, timelines, and technologies for each link within the value chain. Each of these require significant policy support, including a market-based price on carbon. This Roadmap also provides ten major policy necessities that, together with market innovations, regulatory refinements, and funding requirements will stimulate, support, and sustain the cement and concrete industry as it becomes a leader in achieving carbon neutrality. The industry encourages:

1. Accelerated research, funding, and investment in manufacturing, material innovation, and CCUS technologies and associated infrastructure.
2. Streamlined regulation, siting, and permitting practices for facility and infrastructure modernization.
3. Recognition and credit for industry reduction levers.
4. Community acceptance of coal combustion residuals (CCRs), alternative fuels, CCUS, and other technologies.
5. Consideration of a market-based carbon price – such as a cap-and-trade mechanism – consistent with core principles, including fairness, transparency, and innovation.
6. Market acceptance of low-carbon alternative cements and concrete.
7. Adoption of performance-based standards for building materials.
8. Consideration of the full product, material, and building life cycle in procurement standards and policy.
9. Investments in clean fuel, energy, transportation, and industrial infrastructure.
10. Leakage protections for domestic manufacturers competing against less regulated imports.

Leading collaboration

PCA represents U.S. cement manufacturers and on behalf of the industry has developed this Roadmap, which identifies the targets, timelines, technologies, and supporting policies needed to achieve and potentially accelerate the goal of achieving carbon neutrality by 2050 across the value chain. PCA is uniquely positioned to lead this effort in collaboration with the cement and concrete industry and other stakeholders and looks forward to expanding its network of alliances as this Roadmap evolves.



THE FOUNDATION OF A SUSTAINABLE, FUTURE BUILT ENVIRONMENT

SOCIETY IS AT A CRITICAL MOMENT.

How do we create a more sustainable world?

How do we build cities that can withstand climate change?

How do we increase the industry's role in the circular economy?

Recent events have made clear that we need the structures and roads that make up our cities to do more. We need resilient infrastructure that meets the demands of the future – sustainability, circularity, and climate adaptation.

We can build and shape our world and prepare our cities and communities to be stronger, while also meeting environmental goals. A key part of the solution lies with materials that surround us but are often overlooked – cement and concrete.

Concrete made with cement has long proven its value as a durable, cost-effective, available material that is resistant against extreme temperatures and natural disasters. Simply put, modern society has been built using cement and concrete. Concrete is critical to U.S. infrastructure, and is used to make things like homes, buildings, hospitals, schools, bridges, pavements, runways, dams, water pipelines. These materials are used throughout our daily lives to shape the world around us. Because of its unique versatility, durability and strength, concrete enables us to build more sustainably, improve our communities, and create a more durable and prosperous nation.

Now the cement and concrete industry is embarking on an ambitious journey to enact changes to the value chain to ensure that concrete is also a sustainable solution critical for the smart cities of the future.

America's cement manufacturers have committed to the goal of reaching carbon neutrality throughout the value chain by 2050. PCA, representing the U.S. cement industry, has developed this Roadmap which identifies the targets, timelines, technologies, and supporting policies needed to achieve and potentially accelerate this goal.

Cement is the critical ingredient in concrete. This product is the foundation of the built environment. PCA member companies produce the majority of cement manufactured in the U.S.; many member companies also manufacture ready-mix concrete and cement-based materials used in construction. PCA has always collaborated with those that use cement and hopes to lead collaboration in bringing cement and cement related products, like concrete, into the circular economy.

Notably, many of the solutions included in this Roadmap are products, technologies and approaches that exist today – and by bringing together collaborators across the value chain, PCA hopes to begin to shift mindsets and increase awareness and adoption of these solutions to enact near-term benefits. Other solutions are not yet available but are possible with the right policies and research to accelerate their development and deployment.

The construction sector is poised for growth, with the U.S. predicted to add another 121 billion square feet of buildings by 2050, the equivalent of constructing New York City every year for the next 20 years. This does not account for the trillions of dollars the country is poised to spend reviving infrastructure, rehabilitating existing roads and bridges, and expanding construction in growing cities.

Development at this scale means the cement and concrete industry has a once-in-a-generation opportunity to set a global example on building sustainably, utilizing new approaches, and advocating for updated technology.

Moving forward, every dollar spent on infrastructure should be aligned with preventing, reducing, and withstanding climate change.

The cement and concrete industry – like many other industries – emits carbon dioxide (CO_2) and GHGs. The value chain approach provides a pathway that reduces CO_2 for the entire industry. The progress that can be achieved across the value chain will positively impact anyone that uses cement or concrete.

Currently, based on U.S. Environmental Protection Agency (EPA) carbon emissions data, the manufacture of cement accounts for 1.25% of U.S. CO_2 emissions – with demand for cement and concrete projected to increase, climate issues and the needs of society can both be addressed using the entire value chain of cement and concrete.

Cement is to concrete as flour is to cake – concrete is the material that people experience every day and cement is the binder, or glue, that allows builders to take advantage of the benefits of concrete. Together, these industries and materials have been pivotal in building resilient communities that enable people to live safe, productive, and healthy lives via a built environment that withstands natural and man-made disasters. These materials are also key to shaping our future. From mitigating the effects of climate change to providing long-lasting, durable infrastructure, to contributing to a robust economy, cement and concrete play a key role in creating a more sustainable and resilient world.

WE CAN BUILD THE FUTURE WE WANT.

An even more sustainable concrete ....

... is within our reach.

... can help us tackle the issues linked to climate change.

... changes the face of the built environment for the future.

CLIMATE MITIGATION AND ADAPTATION

Concrete structures play a critical role in making communities stronger and safer. Concrete is recognized as the material of choice to mitigate the impacts of extreme weather events and other natural and man-made disasters.

Words often associated with concrete are **durability, resiliency, and safety**. Concrete has an unparalleled ability to stand up to normal wear and tear over a long service life. Concrete is the best choice for construction because it lasts longer and costs owners much less in maintenance and repairs over the lifetime of the structure.

One of the safest places to be during a major storm is in a reinforced concrete building. In fact, most safe rooms and shelters are made with concrete. A structure's resiliency, be it residential, commercial, or public property, is determined by whether occupants can safely shelter there during natural disasters, and whether the structure itself can survive. If a structure can be repaired rather than replaced following a disaster, it is a faster and less expensive return to normal for the residents of the homes and a quick return to business operations for commercial establishments.

Concrete can be incorporated into structures in several ways to make them more durable and disaster resistant:

- Using concrete walls, floors, and roofs offers an unsurpassed combination of structural strength and wind resistance.
- Concrete is non-combustible and concrete walls, floors, and roofs are given an outstanding fire rating by the International Code Council. Most concrete structures (those with a thickness of 3 to 5 inches) are more fire resistant than structures built with other materials, making them more likely to withstand fires and giving occupants more time to safely evacuate.
- Concrete is not subject to rot, warp, or mold which occurs in wood when exposed to warm, wet conditions.
- Hardened exterior finishes, like those offered by concrete, for walls and roofs of a home or business provide the best combination of strength and security.

Resilient communities start with comprehensive planning and a preference for robust structures with long service lives. More durable buildings with resilient features promote community continuity.

Over the life of a building, the expected cost of maintenance and post-disaster repair can exceed initial building costs—making an economic case for investing up front in resilient construction. Concrete is cost competitive when making initial decisions about building materials, but the overall cost of construction is less about material costs and far more about the costs of operations and maintenance.

A built environment with resilient design and materials is better able to recover following disasters, such as hurricanes or fires. Builders, architects, and designers have come to recognize that more durable buildings, homes and businesses – often built with concrete to resist damage from natural disasters – also reduce the impact our communities have on our planet. The most sustainable building is the building that is only built once.

The environmental footprint of resilient structures can be spread over many decades, and their durability can prevent materials from being landfilled due to maintenance and replacement. Preventing organic building materials, such as timber, from being landfilled avoids the subsequent decomposition and the generation of landfill gas, which contains roughly 50% methane - a gas that is 28 times more harmful than CO_2.

THE INDUSTRY'S MISSION

Carbon neutrality

Carbon neutrality is achieving net-zero CO_2. This can be done by balancing emissions of CO_2 with removal or elimination of emissions from society. The reality is that the cement and concrete industry will still be emitting CO_2 in 2050. However, through direct reductions and avoidance measures, the industry can offset its remaining CO_2 emissions.

By 2050

Progress is contingent on changes in state and federal policies, standards, and specifications, and the time required for research and development to deliver technological advances. This can take time but is critical to driving preference and adoption among design professionals, builders, and ultimately consumers. There is inherent institutional inertia that must be broken through, and this Roadmap can start the conversation and identify decisive actions to allow the process of breaking through those log jams.

While PCA is focused on the U.S., many PCA member companies operate globally. PCA efforts are aligned with the ambitions of the Global Cement and Concrete Association, which has developed its roadmap to enable carbon neutrality across the industry value chain by 2050 for cement and concrete manufacturers around the world.

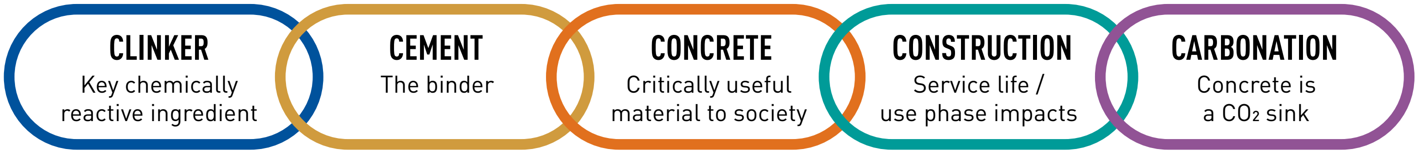
A life cycle approach - across the value chain

In 2021 there is no single process, product, nor technology that can get the cement and concrete industry to carbon neutrality. But even if there was a "silver bullet," considering clinker, cement, or concrete in isolation would prove counterproductive for long-term climate ambitions. Cement is just one of many intermediate inputs into the desired end product – a durable, safe, resilient, and energy efficient low-carbon built environment. Just as a product's environmental impacts should be considered over its full life cycle, decarbonization strategies should consider the direct and indirect impacts any change will have across the life cycle of the final project. Simply shifting emissions from one point in an industry's value chain to another is not progress.

The approach in this Roadmap leverages each step of the value chain from the farthest upstream to the final reuse and recycling phase. Cement companies do not control every link in the value chain, but this Roadmap can provide direction and incentives that spur action. PCA member companies can specifically work on actions to reduce emissions associated with the manufacturing of clinker and production of cement. Additionally, many PCA member companies also produce concrete products and can seek to effect change there as well.

Cement plants produce clinker as an intermediate product before it is ground and shipped as cement. Cement is the key ingredient in concrete and concrete is the key building material in constructing the built environment. While concrete often lasts many decades – or in some cases hundreds or thousands of years – when a structure reaches end-of-use, the concrete can be recycled as aggregate for new concrete or potentially used as a raw material in the cement manufacturing process.

The value chain



CLINKER
Key chemically reactive ingredient

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Service life / use phase impacts

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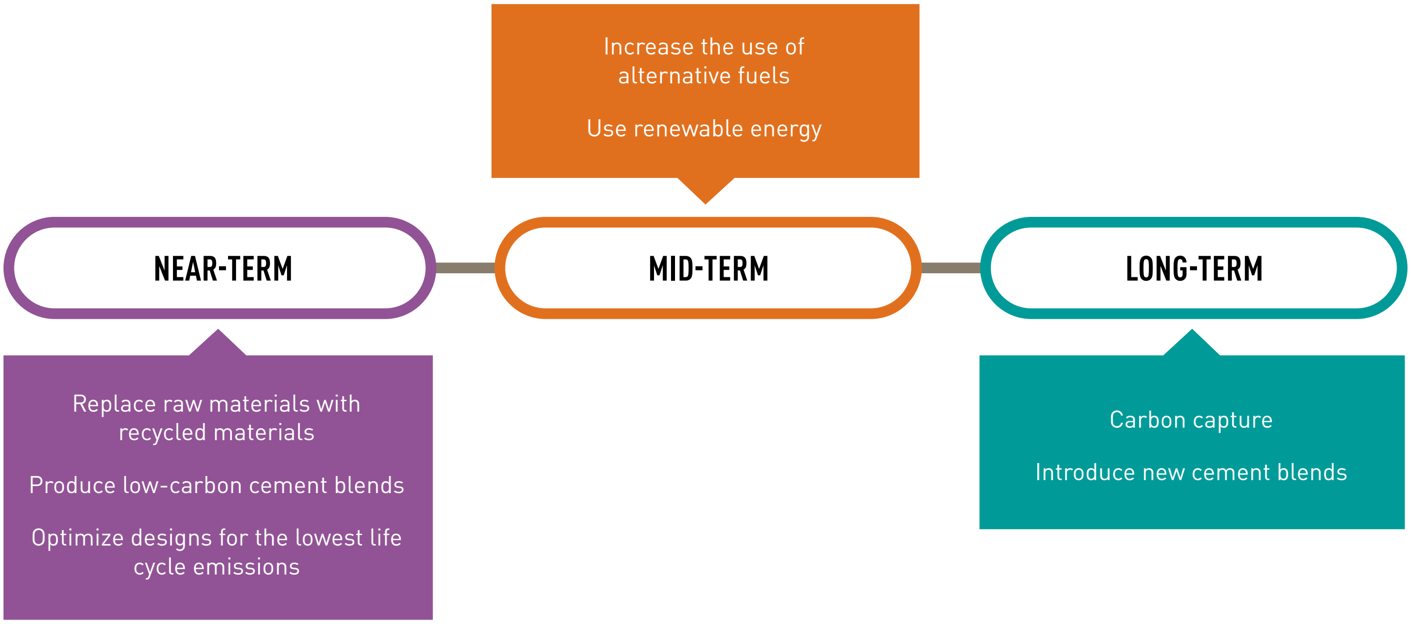
Near- and long-term solutions



NEAR-TERM

- Replace raw materials with recycled materials
- Produce low-carbon cement blends
- Optimize designs for the lowest life cycle emissions

MID-TERM

- Increase the use of alternative fuels
- Use renewable energy

LONG-TERM

- Carbon capture
- Introduce new cement blends

OUR VISION

> *"Collaboration with industry and private partners will be imperative to realize the multitude of solutions that this Roadmap outlines. The best success stories are always when we work together to solve these grand challenges."*

Michael Ireland
President & CEO, Portland Cement Association

THE IMPORTANCE OF COLLABORATING ACROSS THE INDUSTRY AND SECTOR

To reduce CO_2 emissions from all sources, including the building sector, one must recognize the way that our world is interconnected.

Concrete, made with cement, is the most used man-made product in the world. As climate concerns grow, concrete is positioned to help society meet tomorrow's challenges by delivering infrastructure that can adapt to the realities of climate change while also being produced with lower net emissions. However, stakeholders must work together up and down the value chain to ensure that the building sector is creating a built environment that is truly sustainable.

Focusing only on clinker or cement or concrete, the upstream portion of the value chain, misses the huge opportunity for reduced and avoided CO_2 emissions in construction and across the service life of buildings, structures, and pavements. Adopting whole-building life cycle-based standards in design and construction can have dramatic impacts in reducing CO_2 associated with the built environment. The initial CO_2 impact of building materials is minuscule in comparison to the CO_2 associated with heating and cooling a building, moving conditioned air, powering elevators and escalators, providing clean water, and energy for lighting, phones, computers, display screens, workstations, and dozens of other energy needs. That is especially true when considering most buildings and roadways will be around for decades.

This is why PCA member companies are embarking on a journey to carbon neutrality as a full industry and inviting others across the entire value chain to join this effort.

The cement and concrete industry cannot do this alone. PCA and member companies have been collaborating, coordinating, and cooperating with peers in the cement and concrete industry in North America and globally, along with research groups, including the Massachusetts Institute of Technology (MIT). The industry looks forward to collaborating with government agencies, non-governmental organizations, and academic institutions to help in this mission.

MEASUREMENT

The U.S. cement and concrete industry is arguably the most heavily regulated of all energy-intensive, trade-exposed industries. Cement producers report to a variety of federal and state authorities including the EPA, the Department of Labor Mine Safety and Health Administration, the U.S. Geological Survey (USGS), and many others to document the environmentally responsible and safe operation of cement facilities. In nearly all cases, emissions are monitored on a continuous basis.

Achieving carbon neutrality across the entire value chain by 2050 will require the development of an entirely new set of metrics, means, and methods to track progress. These new measurements will be developed and incorporated over time. Once established, PCA member companies are committed to the same level of transparency in reporting Roadmap progress as is currently exemplified through member companies' environmental, health, and safety reporting.

A CORNERSTONE OF THE ECONOMY

The cement and concrete industry drives economic growth in local communities and nationally:

600,000+ people

are employed by the cement and concrete products industry.

$100 billion

is contributed by the cement and concrete industry to the U.S. economy each year.

$8.8 billion+

in employee wages, in addition to hundreds of thousands of other jobs supported by the industry.

A strong infrastructure system

(drivable roads, safe bridges, resilient structures) enable all facets of our economy to continue to run smoothly.

OPPORTUNITIES AND IMPACT

THE INDUSTRY ROADMAP TO CARBON NEUTRALITY

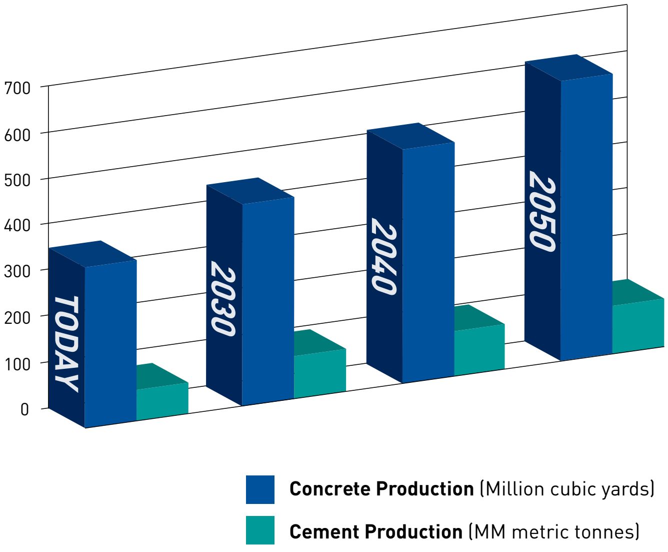
America's cement manufacturers are key to producing the second most consumed material in the world – concrete. While member companies have a clear path for reducing emissions when producing cement, they are also committed to influencing partners and stakeholders to optimize how they use cement, further driving down emissions.

To quote MIT, "to make the most sustainable design decisions, whole-building life cycle assessments (LCAs) that include impacts from material production, construction, operation, and end-of-life should be used by architects and engineers."

This Roadmap examines the full cement-concrete-construction value chain. Clear levers that can be activated through technology, regulation, and mindset changes are outlined along five critical phases in the cement-concrete life cycle: clinker, cement, concrete, construction, and carbonation (concrete as a carbon sink).

In many cases, institutional inertia is preventing progress. There are many solutions available today that simply require shifting mindsets and optimizing existing processes and approaches. The industry cannot do this alone. To succeed, it is essential to have collaboration with producers, suppliers, consumers, legislators, regulators, design professionals, trade unions, builders, contractors, and communities, among others.

Importantly, while many near-term measures noted in this Roadmap are available today, additional innovation, investment, and research will be needed to achieve the long-term mission. These solutions include innovative materials, elevating baseline standards and specifications, increasing the use of optimization techniques, and technologies that are, and have been, tested. There are many options and opportunities to dramatically reduce CO_2 emissions along the value chain.



GROWING CITIES MEANS THE DEMAND FOR CEMENT AND CONCRETE CONTINUES AND INCREASES OVER TIME

SIGNIFICANTLY REDUCING EMISSIONS ALONG THE CEMENT AND CONCRETE VALUE CHAIN, NOW AND IN THE NEAR FUTURE

PRODUCTION: AT THE CEMENT PLANT	
Replace raw materials with decarbonated materials	Using decarbonated materials eliminates CO_2 emissions from processing traditional raw materials, like limestone.
Use alternative fuels	Replacing traditional fossil fuels with biomass and waste-derived fuels lowers GHG emissions and keeps materials out of landfills.
Continue efficiency improvements	Increasing energy efficiency reduces the amount of CO_2 emitted for each ton of product.
Implement carbon capture, utilization, and storage (CCUS) technology	CCUS directly avoids a significant portion of cement manufacturing emissions.
Promote new cement mixes	Creating new cements using existing and even alternative materials reduces emissions from mining for new materials, while optimizing the amount of clinker used ensures emissions correspond to necessary production.
Increase use of portland-limestone cement (PLC)	As an existing lower-carbon blend, universal acceptance of PLC will reduce clinker consumption and decrease emissions.
CONSTRUCTION: DESIGNING AND BUILDING	
Optimize concrete mixes	Considering the specific needs of the construction project and using only the materials necessary, avoiding excess emissions.
Use renewable fuels	Switching to solar, wind and other renewable sources of energy directly reduces emissions from other energy sources.
Increase the use of recycled materials	Diverting these materials from landfills.
Avoid overdesign and leverage construction technologies	Designing for the specific needs of the construction project reduces unnecessary overproduction and emissions; incorporating just-in-time deliveries.
Educate design and construction community	Improve design and specifications to be more performance oriented which will permit innovation in cement and concrete manufacturing. Encourage the use of advanced technologies to improve structural performance, energy efficiency, resiliency and carbon sequestration.
EVERYDAY: CONCRETE INFRASTRUCTURE IN USE	
Incentivize energy efficient buildings	Increasing buildings' energy efficiency can cut energy use and resulting emissions from heating and cooling.
Reduce vehicle emissions by improving fuel efficiency	Because of its rigidity, concrete pavements enhance the fuel efficiency of vehicles driving over them, reducing vehicle emissions.
Decreased maintenance	Due to their durability, concrete structures (buildings, pavements, bridges, dams, etc.) last longer and require less frequent maintenance.
Recycling	Concrete in place can be 100% recycled, limiting the use of raw materials and production emissions.
Carbonation	Every exposed concrete surface absorbs CO_2 and over the course of its service life, a building can reabsorb 10% of cement and concrete production emissions.

AT THE CEMENT PLANT

- Increase the use of decarbonated raw materials
- Decrease the use of traditional fossil fuels by 5X
- Increase the use of alternative fuels
- Push efficiency and decrease energy intensity for one metric ton of clinker
- Utilize carbon capture to avoid the release of CO_2 emissions
- Reduce clinker production emissions

The most energy intensive phase of the value chain is at the cement plant, where two critical materials are produced: clinker and cement. Cement production is a 24/7 process and is naturally energy intensive. However, there are opportunities to optimize energy use, shift away from traditional fossil fuels, and utilize carbon capture technology to avoid emissions that are otherwise a "chemical fact of life."

The first step in making cement is producing a binding ingredient called clinker.

Clinker is an intermediate product that you will never see unless you visit a cement plant, but its production is a major source of CO_2 in relation to cement. The key chemical reaction in cement manufacturing is the transformation of the calcium carbonate in limestone to calcium oxide. This is the essential step in cement manufacturing. This "chemical fact of life" is responsible for more than 60% of CO_2 emissions from cement manufacturing. There is no way around that step and there is no viable alternative that can be produced at the scale needed. To drive off the CO_2 and continue the chemical process, material temperatures of approximately 2,800 degrees Fahrenheit or about 1,500 degrees Celsius are needed. In comparison, the surface temperature of the sun is 10,000 degrees Fahrenheit. More than 60% of the CO_2 from cement manufacturing comes from that "chemical fact of life" while just under 40% of manufacturing CO_2 comes from combustion.

Optimizing clinker composition and how clinker is manufactured

Decarbonated raw materials

Clinker starts with quarried materials like limestone, clay, shale, and sand. Heating limestone releases CO_2. To reduce these emissions, manufacturers can use decarbonated raw materials as opposed to virgin raw materials. Decarbonated raw materials have already been processed, so they no longer contain CO_2. Most often, these materials end up in landfills, so in addition to avoiding processing emissions, these materials are also brought into the circular economy.

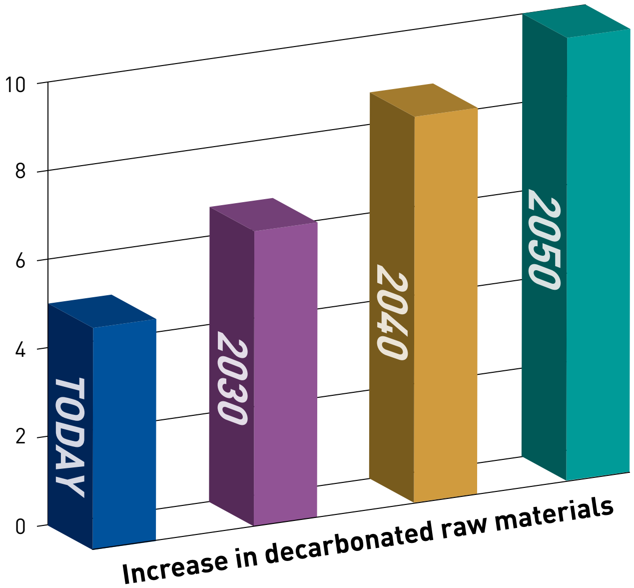
Today, these materials represent less than 5% of cement manufacturers' raw material input; tomorrow with the right policies, that could be doubled. By 2050, the industry is targeting replacing virgin raw materials with at least 10% decarbonated raw materials.

This is a simple one-to-one switch and directly reduces emissions, but it is limited by availability.

Making cement: Addressing the chemical fact of life

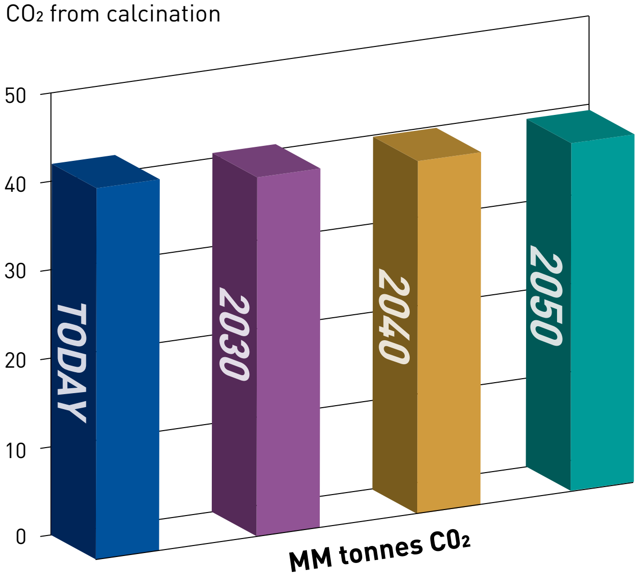
HOW WE'LL GET THERE

Percent of decarbonized raw materials



THE RESULTS

CO_2 from calcination



Fuel switching

Clinker production requires material temperatures of nearly 3,000 degrees Fahrenheit and those temperatures can only be achieved with combustion. Using alternative fuels and biomass instead of traditional fossil fuels like coal and petcoke reduces the CO_2 created in the combustion process and switching to renewable sources of electricity like wind and solar eliminates the CO_2 created from fossil fueled power plants.

Today the industry's fuel mix includes 60% coal and petcoke, and the industry wants to cut that amount by a factor of 5 with a goal of no more than 10% coal and petcoke use in 2050.

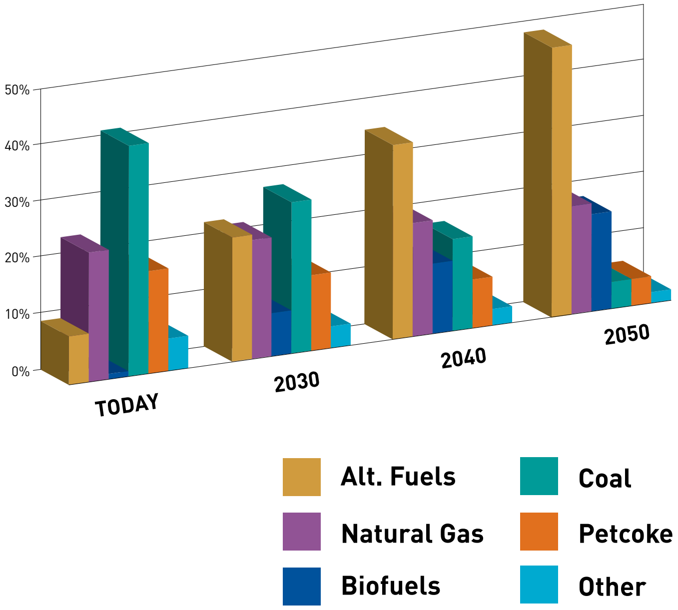
Alternative fuels are a fraction of the current fuel mix and there is an opportunity to quickly scale up use to displace traditional fossil fuels. These fuels range from cellulosic biomass to non-recycled plastics, residuals from paper and cardboard recycling, and agricultural wastes – all opportunities to give spent materials a second, productive life. Current regulations limit the use of non-hazardous secondary materials, even when those materials can be beneficially used in lieu of fossil fuels. The unintended consequence of these regulations often means materials that are fuels become waste.

Cement plants are already equipped to use alternative fuel materials, provided the supply is available. With the right policies and regulations, alternative fuels could make up 50% of the industry's fuel mix.

The industry is also advocating for the use of "transition" fuels, like natural gas, while renewable fuel sources become available at scale. Displacing traditional fossil fuels with natural gas in the near-term cuts CO_2 combustion emissions by 24%.

With the right infrastructure investment, cement producers hope to use fully renewable, non-polluting sources of energy. To leverage these renewable sources of energy investment is needed in associated infrastructure.

USING FUTURE FUELS TO LOWER CO_2



European cement manufacturers use about 60% alternative fuels in their fuel mix while in the U.S. alternative fuel use is about 14% of fuel-related energy. In fact, some European plants operate entirely on alternative fuels. With the right policies, alternative fuel use in the U.S. can increase several times over.

AT THE CEMENT PLANT

Optimizing clinker composition and how clinker is manufactured

Improving energy efficiency

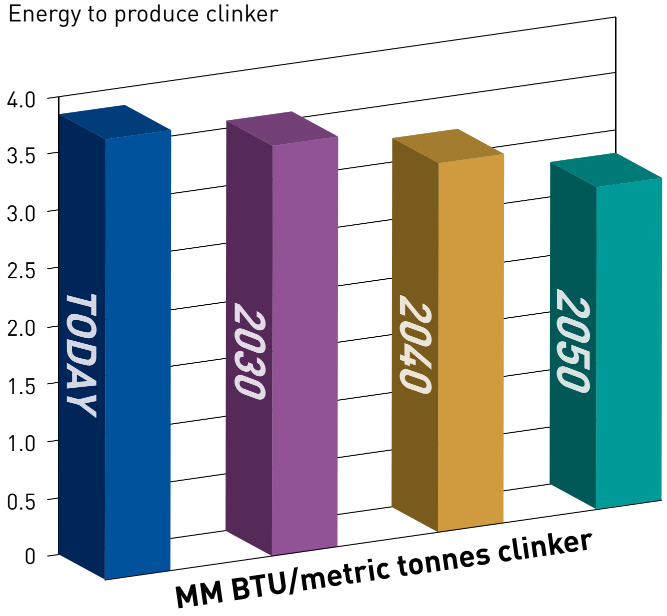
Since 1990 the cement industry has improved energy efficiency 20%. In fact, cement manufacturing is already one of the most energy efficient industrial processes – with today's technologies operating above 80% thermal efficiency. While this efficiency also makes realizing additional process efficiencies more challenging, producers are constantly looking for new opportunities to improve, and many plants are U.S. EPA ENERGY STAR certified for performing in the top quartile and PCA itself was recently recognized as ENERGY STAR Partner of the Year.

Today it takes 3.84 MM BTU of energy to produce one metric ton of clinker. Through the use of modernizations, upgrades, machine learning, and artificial intelligence the goal is to reduce that by more than 25%.

Pushing the envelope on combustion efficiency

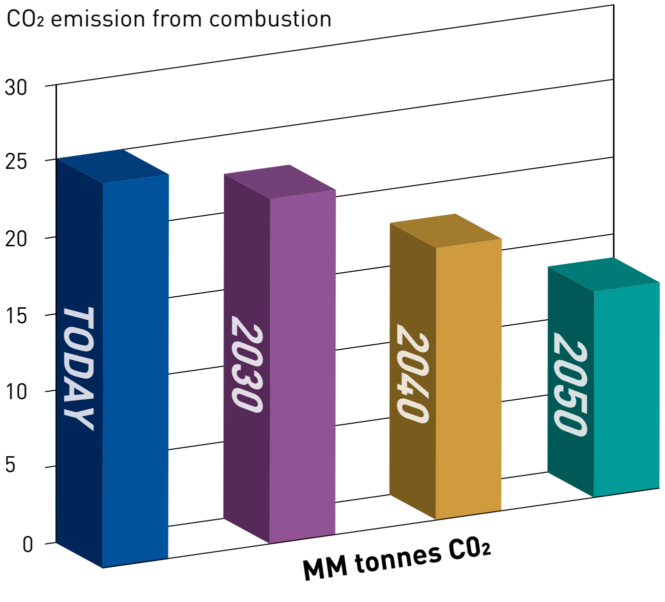
HOW WE'LL GET THERE

Energy to produce clinker



THE RESULTS

CO_2 emission from combustion



Carbon capture

CCUS is a critical part of cutting emissions in cement production. CCUS effectively captures CO_2 so it can either be used to produce new materials or be safely and permanently sequestered. Dozens of CCUS technologies are undergoing research and testing in cement plants throughout the world. In early 2021, the U.S. Department of Energy (DOE) announced two initial studies for carbon capture with cement plants in Colorado and Texas.

Capture technologies undergoing research in the cement industry include a variety of solvent, sorbent, and membrane technologies. Carbonation, mineralization, calcium (or carbonate looping), oxyfuel combustion and calcination, and algae capture are included within that research.

Today, the U.S. cement industry faces major obstacles to CCUS.

- There are no commercial scale CCUS installations at any cement plant within the U.S. To do so will require significant investments in research.
- No technology in the world can address CCUS without a clear path to siting and permitting.
- Infrastructure investment is needed to handle captured CO_2. That infrastructure will need to supply energy for those captured units. Energy for everything from scrubbers to separation units and compressors to chillers. Additionally, plants will need to compress, deliver, and distribute their captured CO_2 to its ultimate destination.

With the right policies, research, and investment carbon capture can become an integral part of any cement plant.

INNOVATIVE IDEAS

Some of the most innovative CCUS projects underway are taking place at cement plants.

CEMEX USA, in partnership with various stakeholders, was awarded a grant from the DOE to research, engineer and develop a pilot for a breakthrough carbon capture unit. The project, anchored to CEMEX's northern California cement plant, also contemplates cost-competitive solutions to completely close the loop on current carbon emissions. The goal is to significantly reduce its CO_2 footprint through technological upgrades. The specific objectives of this project also include the development, optimization, and scaleup of specific CO_2 capture process components, as well as incorporation of next-generation, non-aqueous solvents. Integration aspects of the low-cost, modular, process intensification capture technology with CEMEX's cement plant are also part of the research, together with subsequent cost evaluations and technical considerations for the transformation of captured CO_2 into new, marketable products.

Lehigh Hanson, and Silicon Valley-based materials technology company **Fortera** announced a collaboration to implement a new type of carbon capture and utilization technology in a pilot installation, with an expected 60% reduction in CO_2 emissions per ton of product. Both parties will construct and operate a small commercial plant where CO_2 will be captured from the kiln exhaust and converted into a cementitious material. The final product will be suitable for use as a new low-carbon, supplementary cementitious material in the production of high-quality concrete with a lower CO_2 footprint. The product generated within the new carbon capture process will be the first cementitious material produced commercially from CO_2 captured directly from a cement kiln.

AT THE CEMENT PLANT

Optimizing the materials used to create cement

Clinker is ground and mixed with materials like gypsum to create cement. Cement is a binder that when mixed with water and aggregates holds everything together and ultimately forms concrete.

Optimizing the ingredients in cement not only enhances the benefits of cement-based products, but it also reduces the carbon intensity of cements.

Increasing supplementary cementitious materials

Cement includes clinker and finely ground limestone, inorganic processing additions, and precisely controlled amounts of sulfate. By decreasing the amount of clinker and increasing the limestone, inorganic processing additions, and other materials, the carbon intensity of cement can be lessened and still create a product that is equally durable and resilient and continues to meet the stringent quality standards required.

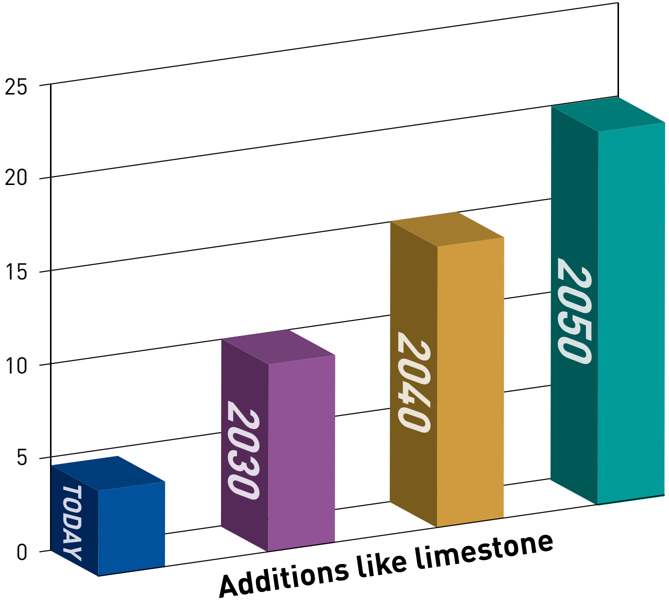
Currently, cements include less than 5% of these materials, and the industry is targeting increasing that ratio to 10% of these materials in 2030, 15% by 2040, and 20% by 2050.

Currently, cements have a clinker to cement ratio of more than 90%. The remaining material, gypsum, limestone, and processing additions can be partially replaced with supplementary cementitious materials (SCMs), which directly reduces the CO_2 that comes with clinker production – dropping the clinker amount 15% reduces the amount of CO_2 by 15%. SCMs include slag, fly ash, and silica fume. In many cases, these are industrial byproducts that would otherwise be landfilled and forgotten. Proper amounts of SCMs can improve durability and address the harmful chemical reactions caused by some aggregates.

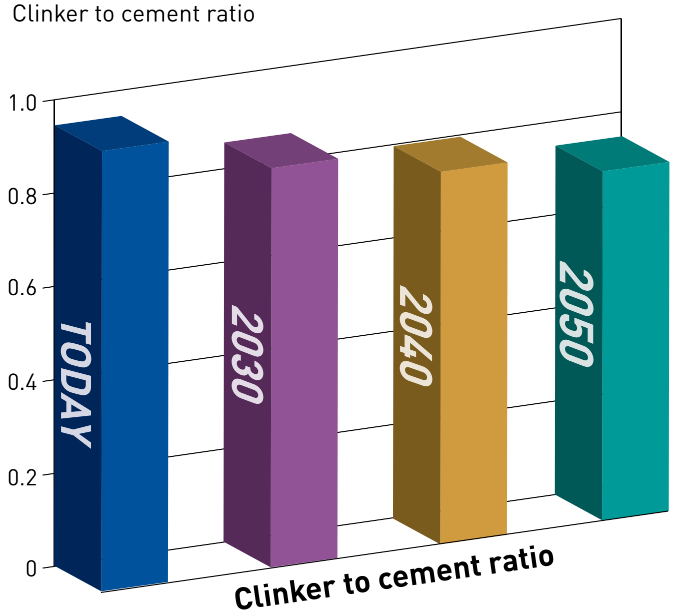
Tomorrow’s cements are targeting lower clinker to cement ratios with 0.85 by 2030, 0.80 by 2040, and 0.75 by 2050. Lowering clinker to cement ratios below 0.75 further requires consistent availability of SCMs.

Optimizing cement: Changing the composition

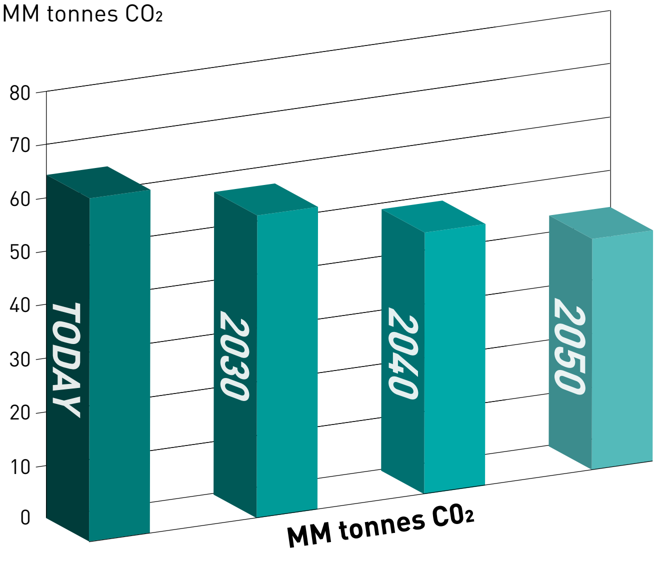
HOW WE'LL GET THERE: PART 1
Percent of non-gypsum additions



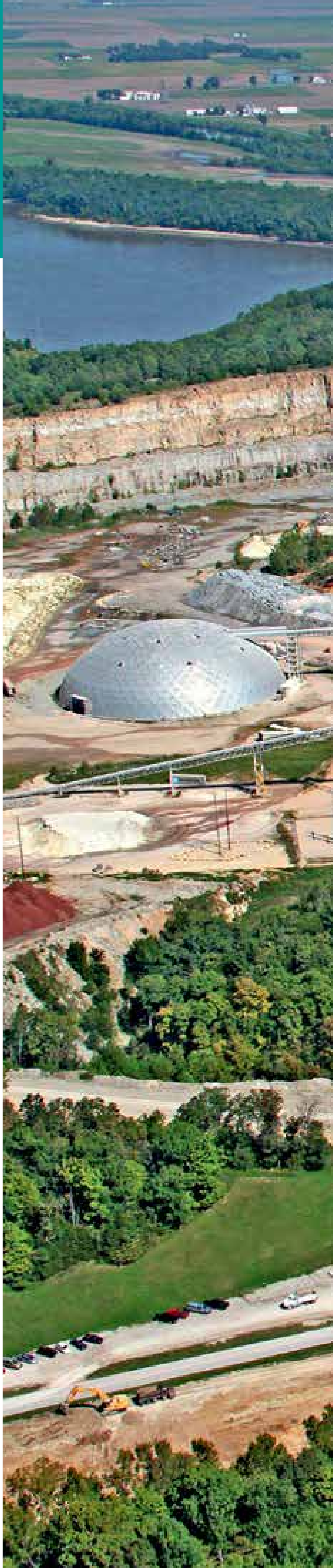
HOW WE'LL GET THERE: PART 2
Clinker to cement ratio



THE RESULTS
MM tonnes CO_2



Optimizing the materials used to create cement



Leveraging new cement blends

Portland cement specifications limit the amount of limestone that can be added in cement to just 5% and that is why PLCs were developed. PLCs allow the addition of up to 15% limestone.

Users can gain even more flexibility by specifying blended cements. These are cements blended with either limestone, fly ash, or slag. A blended cement with two of those materials is a ternary blended cement in contrast to portland cements that historically included just clinker and gypsum.

For limestone additions, fly ash, slag, silica fume, and PLCs to be more widely used there needs to be a shift from current industry approaches and mindsets.

There is opportunity to increase the use of these and other materials, but in many cases, institutional inertia presents one of the greatest obstacles to widespread use. This Roadmap is an approach to accelerating the acceptance and adoption not only of these proven materials but also the long-standing standards and specifications that provide a pathway to their use.

In general, standards provide consistency so that producers, users, and consumers are all speaking the same language. Cements are also standardized. Different cement standards provide cement users the flexibility they need. Harmonizing these unique standards provides an even greater degree of flexibility. Organizations such as ASTM International and the American Association of State Highway and Transportation Officials play a critical role in developing and updating standards and will be key in helping the cement and concrete industry achieve carbon neutrality.

It is important to educate cement users on the various options available when it comes to cements and cement-based product and the various benefits. Educating producers, users, consumers, the government, academia, contractors, the construction industry, and the general public has been a hallmark effort from PCA for more than a century.

OPTIMIZING THE DESIGN AND CONSTRUCTION OF THE BUILT ENVIRONMENT

- Lower concrete manufacturing emissions to zero at the plant
- Transition to zero emission fleets
- Optimize concrete mixes
- Reduce overdesign

The cement and concrete industry's "product" is ultimately the built environment. No matter the type of infrastructure, concrete construction provides a sustainable and resilient built environment. It is not just a significant component of GDP, it directly and indirectly supports hundreds of thousands of well-paying U.S. jobs. This is an important part of the PCA Roadmap to Carbon Neutrality.

What is commonly considered construction involves four separate phases: design, construction, use, and end-of-life. Much like earlier steps in the value chain, the carbon intensity of construction can be reduced through optimization within each of these phases.

SHIFTING MINDSETS

The industry encourages architects and engineers to shift from prescriptive specifications and move toward performance specifications. Prescriptive specifications are like a recipe while performance specifications focus on results. Performance specifications give the producer the flexibility needed to provide the best product for the application.

Performance specifications allow concrete producers to design with the application in mind rather than use the same specifications, no matter the project. For example, in some cases, the strength of a concrete sidewalk has the same strength as concrete in a modern high rise. Concrete used in a high rise needs strength and ductility that a sidewalk will never need, while a sidewalk may need to be able to withstand something like winter salting to melt ice that a high-rise building does not.

Lowering concrete manufacturing emissions

Optimizing concrete mixtures

The concrete that is poured at construction sites is formed when cement is mixed with water and other aggregates.

Manufacturing concrete today is a complex process. From everyday concrete for residential applications to ultra-high strength concrete for the tallest buildings and longest bridges in the world, concrete manufacturing requires stringent quality control and an understanding of the characteristics and properties of local materials. Along with cement, aggregate and water, most concrete today uses SCMs, admixtures and additives that improve plastic and hardened properties of concrete. There are almost a limitless number of concrete formulations. Concrete can be made for any application to meet the need of engineers, contractors, owners, and others.

This Roadmap targets improved mix designs that optimize every single component within concrete. With dozens of inputs and outputs, leveraging both conventional and machine-based tools allow producers to transition from a set menu of default mixtures to designing tailor-made mixtures using the right materials at the right time for the right application.

Through optimized concrete mixes, it is possible to avoid 10% of the CO_2 footprint of concrete by 2030, 18% by 2040, and 26% by 2050.

Improved mix design translates into avoided CO_2. A cubic yard of concrete today represents about 500 pounds of CO_2. By 2030 that same cubic yard of concrete will represent 364 pounds and in 2040 it will represent 273 pounds. By 2050, a cubic yard of concrete will represent less than 200 pounds of CO_2, a reduction in intensity of 60%. That concrete will still have the same strength and durability consumers have come to expect.

Reducing direct emissions from concrete manufacturing and transportation

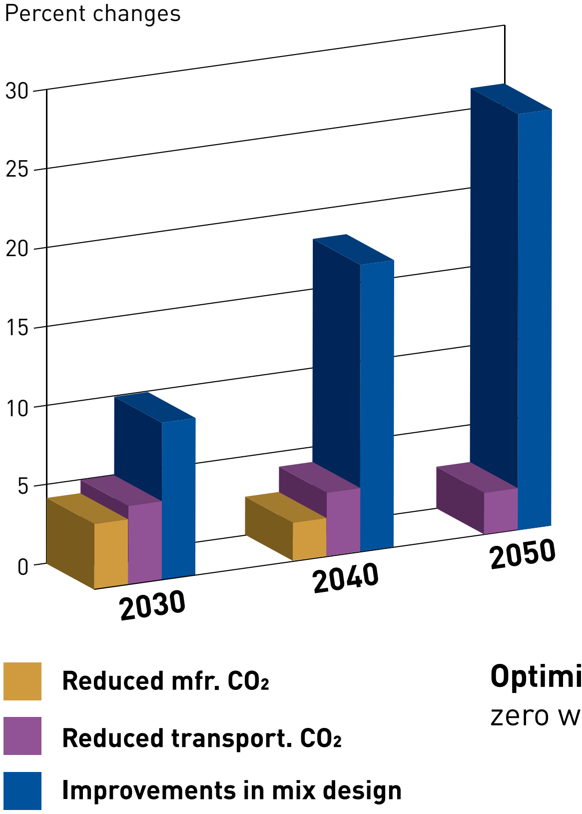
Mixing and delivering concrete requires energy. Manufacturing today's concretes accounts for about 5% of the total CO_2 footprint of concrete. By shifting the energy needs of concrete production facilities to renewable energy sources, these emissions are targeted at 4% of the total CO_2 footprint by 2030, 2% by 2040, and 0% by 2050.This ultimately results in a 100% reduction in production energy.

Concrete and concrete products are delivered and that too requires energy. Concrete manufacturers have committed to transitioning from diesel powered to zero emissions fleets. This takes time, but this is a real and steady change underway.

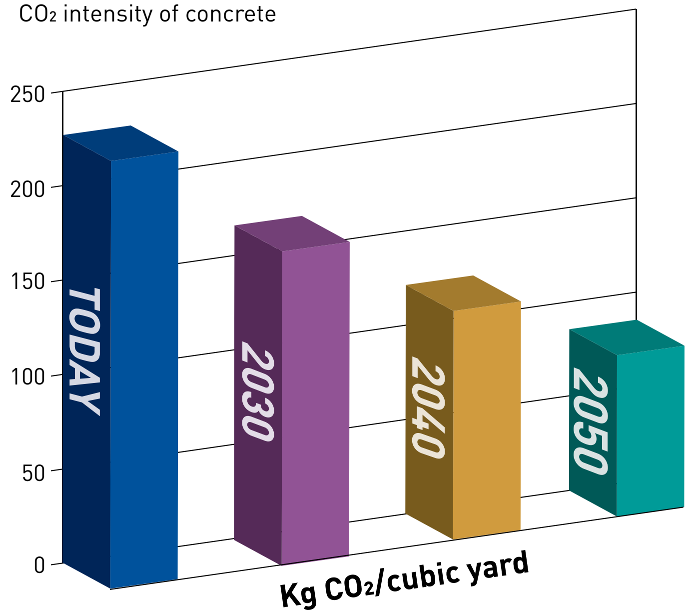
Today, transportation accounts for about 6% of the total CO_2 footprint of concrete, with targeted reductions to 5% by 2030, 4% by 2040, and 3% by 2050. This action ultimately results in a 50% reduction in delivery energy.

Optimizing concrete: Pushing performance

HOW WE'LL GET THERE
Percent changes



THE RESULTS
CO_2 intensity of concrete



Optimized concrete: Efficient manufacturing and transportation, zero waste, optimized mixtures engineered for peak performance

Optimizing design of the built environment

Avoiding overdesign

Optimization in the design phase takes a whole life building design approach that involves both an integrated design approach and an integrated team process. It is a modern take on the classic "start with the end in mind" approach. Building Information Modeling (BIM) is an example of optimized design – it is an intelligent virtual model-based process that helps designers optimize every aspect of a building through each phase of construction.

This Roadmap encourages a rational approach to eliminate unnecessary overdesign and keeping codes and standards updated with actual building performance, as well as the latest developments in research. Every structure is designed on basic principles like strength, stiffness, stability, durability, and long-term performance. Despite advances in buildings codes and design, there is still an inherent amount of overdesign in materials and structures. Some of that overdesign reflects the uncertainty of loading conditions and the inherent variation in material properties but some overdesign is unnecessary.

Structural systems can also be optimized by considering the size, shape, and spacing of structural components including how and where those components are connected to most efficiently transfer loads. One common example is the use of higher strength concretes to decrease slab depths or column sizes or to increase bay spacing. While the higher strength concrete requires higher cement contents, the overall structural system can be designed with a lower carbon footprint because the overall system has been optimized.

This Roadmap envisions that optimization in the design and construction phase can achieve construction efficiencies of 10% by 2030, 20% by 2040, and 30% by 2050.

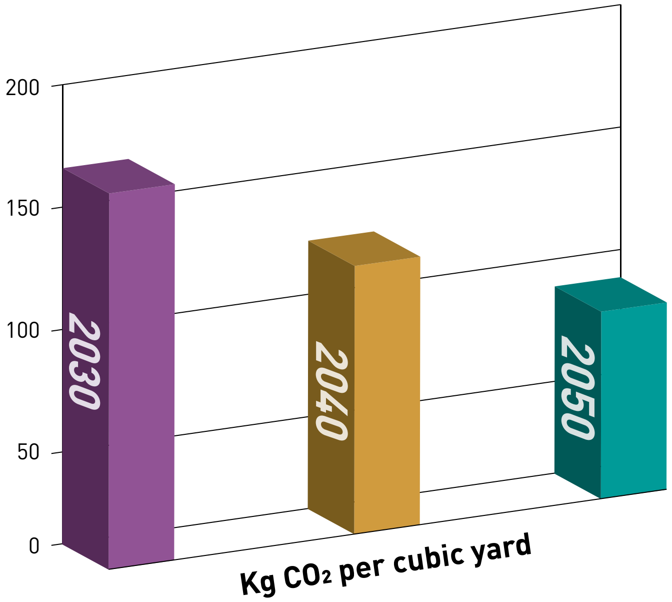
This is an approximately 1% increase in construction efficiency per year over the next thirty years. This increase in optimized construction translates into reduced CO_2 intensity similar to the avoided CO_2 in a cubic yard of concrete. It is possible to model the CO_2 avoided in construction using concrete volumes as a surrogate measurement.

Optimized construction also means zero waste on the job site and zero returned concrete.

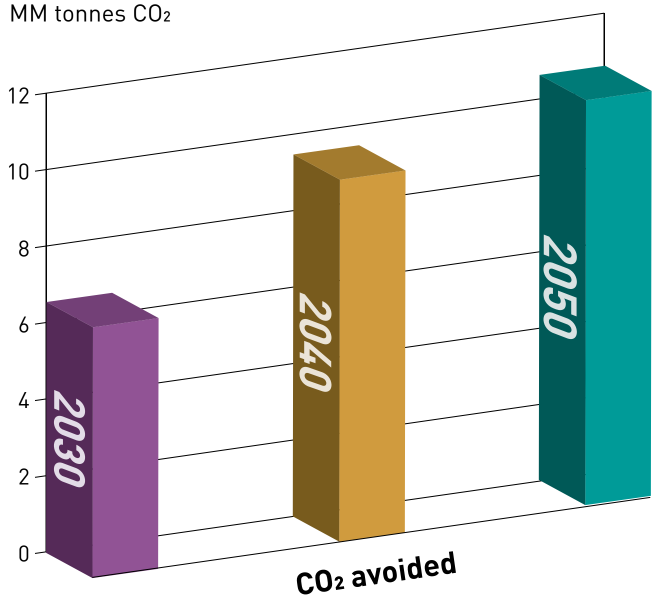
Today, more than 5% of concrete is returned from construction sites. Through more precise design, and limiting excess materials at the job site, targets for returned concrete are 4.25% by 2030, 3.25% by 2040, and 2.5% by 2050.

Optimizing construction: Solutions for the built environment

HOW WE'LL GET THERE: PART 1
Intensity of concrete construction



HOW WE'LL GET THERE: PART 2
MM tonnes CO_2



A NOTE ABOUT ENVIRONMENTAL PRODUCT DECLARATIONS

Environmental Product Declarations (EPDs) are an intermediate account of embodied CO_2 showing the upstream environmental impact sometimes referred to as the "cradle-to-gate" impact of a material. EPDs provide upstream sustainability data that designers can then use to conduct a full LCA — a cradle-to-cradle approach, of a structure to learn the best way to lower the embodied CO2 of the final product, things like a building or a road. While EPDs can be useful for comparing similar products, their limited scope means that they are not useful for full building design and material choices.

CONCRETE IN USE: THE FOUNDATION OF SUSTAINABLE CITIES

Homes with concrete walls can use up to 15% less energy than other homes

A reduction of 46.5 million metric tons of GHG emissions per year could be realized if the entire U.S. road system used concrete pavement according to the MIT Concrete Sustainability Hub (MIT CSHUB)

10% The amount of CO_2 that concrete buildings, structures, and pavements can permanently absorb from the air is 10%

Buildings use tremendous amounts of energy. The CO_2 impact of building materials is minuscule in comparison to the energy that goes into heating and cooling a building, powering elevators and escalators, providing water for bathrooms, and energy for workstations. That is especially true when considering most buildings will be around for decades.

The U.S. DOE notes that, "The buildings sector accounts for about 76% of electricity use and 40% of all U.S. primary energy use and associated GHG emissions."

Concrete is used to create some of the most energy efficient, long-lasting, and climate-adapted infrastructure. Concrete's thermal mass, its reflectivity, its strength, durability and resiliency make it part of the solution to address climate change and global warming.

Buildings constructed with concrete have thermal mass that can avoid large swings in the energy consumption related to heating and cooling. Pavements constructed with concrete are more fuel efficient and more reflective than asphalt, keeping communities cooler by avoiding the urban heat island effect. Concrete structures are resilient. They can remain in use throughout most natural disasters and can be back in service almost immediately.

THE BENEFITS OF OPTIMIZED CONSTRUCTION

The durability, resiliency, and insulating qualities of cement-related products lowers society's environmental footprint. For example:

- Studies by MIT have shown that homes with concrete walls can use 8% to 15% less energy than other homes.
- Concrete does not rust, rot, or burn, saving energy and resources needed to replace or repair damaged buildings and infrastructure.
- Concrete makes urban areas cooler as its lighter color reflects more sunlight than other, darker materials.
- Because of its durability, concrete structures will not require additional carbon release to produce additional materials used for repairs.

The U.S. General Services Administration Green Building Advisory Committee and their Embodied Carbon Task Group provides an approach for optimized construction that has direct use-phase efficiencies.

THE GUIDING PRINCIPLES

1. Employ integrated design principles
2. Optimize energy performance
3. Protect and conserve water
4. Enhance indoor environmental quality
5. Reduce environmental impact of materials
6. Assess and consider climate change risks

KEY FINDINGS

Compared to legacy stock buildings, GSA's high-performance buildings show:		Compared to industry benchmarks, GSA's high-performance buildings show:
↓ 23%	**Energy Use**	43% ↓
↓ 28%	**Water Use**	35% ↓
↓ 23%	**Building Operating Expenses**	10% ↓
↓ 9%	**Waste Landfilled**	Not Tracked
↑ 2%	**Overall Tenant Satisfaction**	1% ↑

STUDIES ACROSS THE U.S. FROM THE MIT CSHUB HAVE SHOWN THE IMPACT OF POOR PAVEMENTS:

1 billion gallons
of excess fuel was used over a five-year period according to an analysis of approximately 50,000 miles of highway in California.

1 million tons of CO_2
was the result found of a seven-year study of 5,000 miles of Virginia's interstate highways excessive fuel consumption.

When looking at 40-ton trucks (used for freight and trucking), decreasing the impacts of deflection through stiffer roads can lead to a fuel savings of up to 3%, which translates to
2 million tons of CO_2.

Driving down emissions with concrete pavements

Fuel consumption and related emissions from vehicles depend on several factors, like the size of the vehicle and the type of engine, but most drivers might be surprised to learn that the quality of the roads we drive on also impacts the amount of fuel vehicles use. On roads where surface conditions are poor, vehicles consume more fuel beyond what is needed to move, which leads to excess fuel consumption and emissions.

Every exposed concrete surface is absorbing CO_2 from the air...even at this very moment

Concrete is a carbon sink, and through carbonation, concrete permanently sequesters CO_2. Carbonation is the process that takes CO_2 and an alkaline reactant to form calcium carbonates. And in the case of concrete, it occurs naturally.

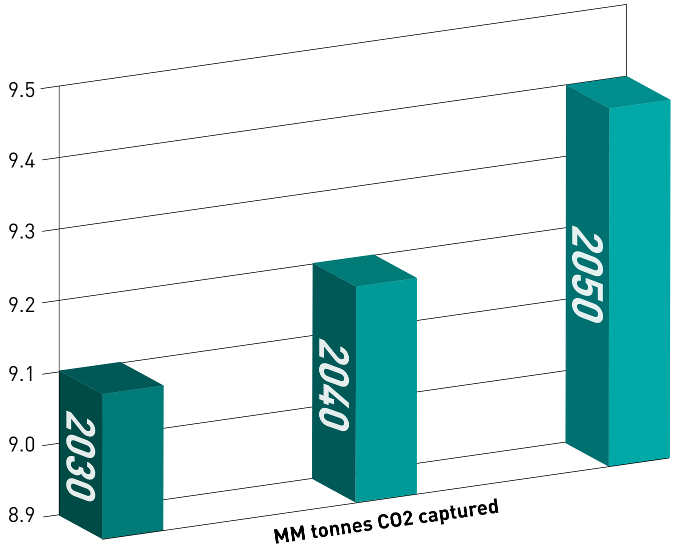
In fact, for all the concrete produced in the U.S. between 1990 and 2018, more than 300 million metric tonnes of CO_2 will be absorbed and sequestered by concrete over its service life.

How much CO_2 is sequestered depends upon the surface area of concrete that is exposed to the atmosphere and the length of exposure. This naturally occurring process can be accelerated either by heating or pressurizing the CO_2 or by pretreating the alkaline materials before they are exposed to CO_2. CO_2 can also be injected into fresh concrete or introduced under pressure in chambers containing concrete products. Again, in both cases, the CO_2 remaining in the concrete is permanently sequestered.

Research at IVL, the Swedish Environmental Research Institute, conservatively notes that 20% of the CO_2 calcination emissions can be permanently sequestered during the use phase of a concrete structure with an additional 2% of calcination emissions permanently sequestered when the concrete structure is demolished. Yet another 1% of calcination emissions are considered permanently sequestered if the demolished concrete is reused as an aggregate in new concrete. That research is now accepted as an IPCC Tier I measurement. Ongoing data collection for Tier II and Tier III will likely demonstrate even greater amounts of sequestration.

Permanently sequestering CO_2 using concrete as a carbon sink directly reduces CO_2 within the value chain. And as importantly, recycled concrete aggregate avoids the energy, emissions, and natural resource depletion that normally occurs with mining and processing natural aggregates.

Concrete as a carbon sink: Capturing CO_2

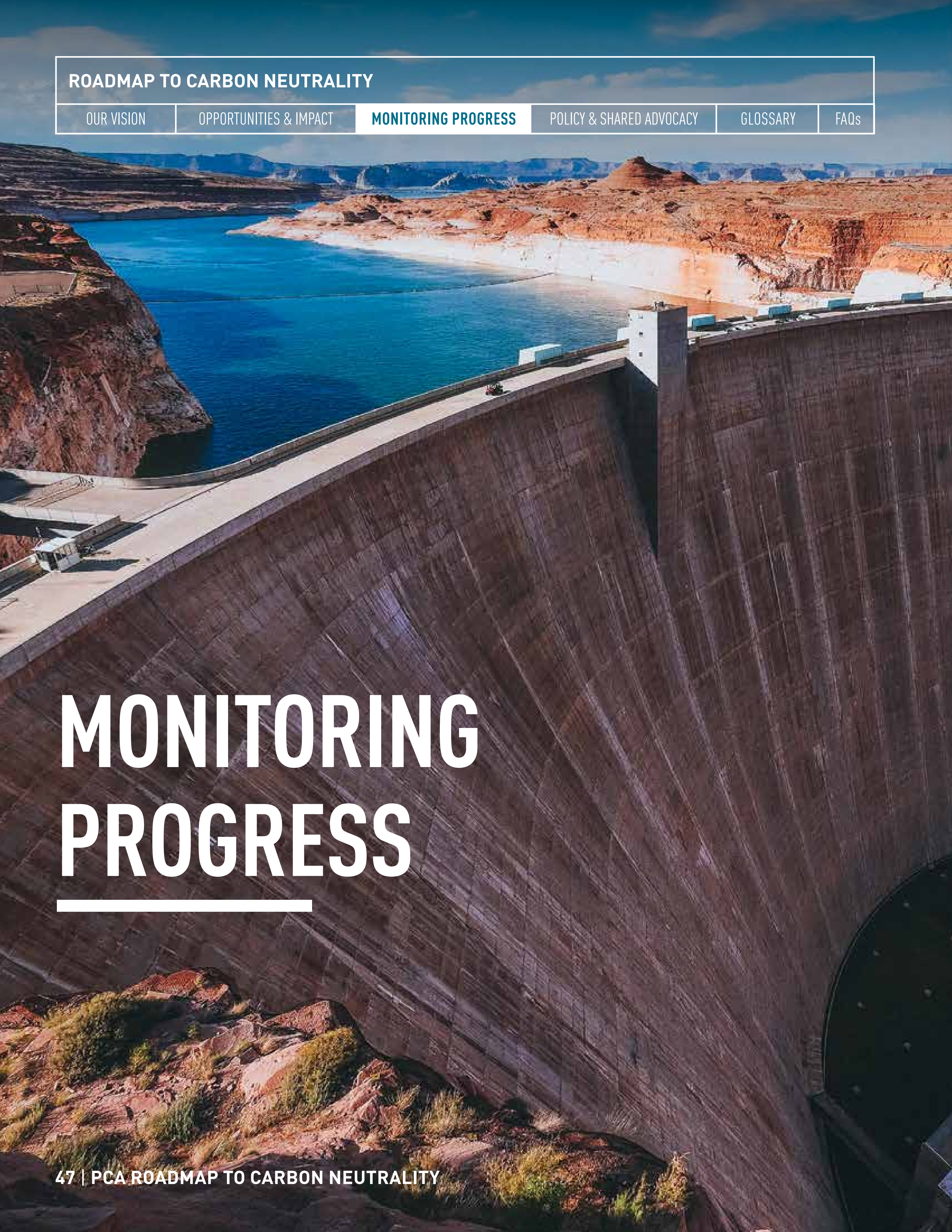


Concrete and Leadership in Energy and Environmental Design (LEED®)

Concrete's characteristics of low albedo, thermal mass, recyclability, local availability, lack of volatile organic compounds and the industry's transparency can all contribute to more-sustainable projects.

Specifically, concrete building materials contribute to a wide range of environmental strategies and LEED® credits:

- Within sustainable sites, pervious concrete paving and paver systems are used for rainwater management.
- The light color of traditional concrete contributes to a reduction in urban heat island impacts.
- Cement can be used as a solidification and stabilization medium for contaminated soils on brownfield redevelopment.
- The energy and atmosphere credits seek to reduce operational energy of the project.
- There are a variety of insulated concrete wall systems that incorporate high levels of insulation, minimize or eliminate air infiltration and provide thermal mass.
- Material and resources credits are offered for impact reductions in the construction materials from which the building is made. Concrete is very durable, lasting much longer than most building materials in similar conditions. Credits for building reuse, recycled content, and regionally available materials are supported by concrete applications.



MONITORING PROGRESS

MAPPING THE INDUSTRY'S JOURNEY

Commitment

PCA member companies have developed this Roadmap and as an industry are committed to achieving carbon neutrality by 2050 with intermediate goals for 2030 and 2040.

PCA will provide an annual report. However, this Roadmap is dynamic and designed to respond to evolving market conditions, government actions, and technology advancements. PCA will revise the Roadmap in response to those changes periodically.

Operations

Cement manufacturing is a complex and highly regulated industry, and cement manufacturers – PCA member companies – use rigorous standards and routinely work with local, state, and federal regulatory agencies to ensure member companies operate at the highest standards. Each year, member companies report emissions data to various government agencies.

Tracking progress along the value chain

In the case of actions and progress beyond the cement plant, PCA will continue to seek further analysis and studies through industry partnerships. Progress will be tracked in developing policies to support the Roadmap objectives.

POLICY AND SHARED ADVOCACY

2050 CARBON NEUTRALITY

The Roadmap to carbon neutrality is more than targets, timelines, and technologies for each link within the value chain. Each of these require significant policy support. PCA supports market-based policies and initiatives that will enable the cement and concrete industry's continued reduction of its carbon footprint responsibly and sustainably.

Federal policy should be realistic and technically feasible. It must recognize the significant technology, funding and market innovation needed for rapid decarbonization while preserving economic growth and international competitiveness. These reductions will not come easily and will require technology advancements, regulatory refinements, new ways of thinking about clean energy and industrial fuels, and increased resiliency of our buildings and infrastructure. However, the cement and concrete industry cannot achieve this goal alone and effective federal policies are needed to help reach this goal. Without effective policies, the industry cannot attain the goal of carbon neutrality by 2050.

PCA has identified ten major policy levers that can help the industry achieve its goal of carbon neutrality and they include:

1. Accelerated research, funding, and investment in manufacturing, material innovation, and CCUS technologies and associated infrastructure.
2. Streamlined regulation, siting, and permitting practices for facility and infrastructure modernization.
3. Recognition and credit for industry reduction levers.
4. Community acceptance of CCRs, alternative fuels, CCUS, and other manufacturing technologies.
5. Consideration of a market-based carbon price – preferably a cap-and-trade mechanism (see p. 58 for additional information) – consistent with core principles, including fairness, transparency, and innovation.
6. Market acceptance of low-carbon alternative cements and concrete.
7. Adoption of performance-based standards for building materials.
8. Consideration of the full product, material, and building life cycle in procurement standards and policy.
9. Investments in clean fuel, energy, transportation, and industrial infrastructure.
10. Leakage protections for domestic manufacturers competing against less regulated imports.

KEY POLICY LEVERS

2050 Carbon Neutrality Policy Levers

- Research, Development & Innovation
- Regulations, Permitting & Guidance
- Financial Incentives & Support
- Performance-Based Material Standards
- Market-Based Carbon Pricing
- Market Acceptance
- Community Acceptance
- Cradle-to-Cradle Life Cycle-Based Procurement
- Low-Carbon Infrastructure
- Level Playing Field

Achieving carbon neutrality across the cement and concrete value chain will require more than just a technical blueprint – it will require policy alignment with federal, state, and local governments and communities to drive innovation; encourage adoption of low carbon fuels, feedstocks, products, and construction practices; protect health, the environment, and communities; and promote economic growth, sustainability, and international competitiveness.

Many of these policy needs and levers are shared with other industries and sectors, and apply across multiple points in the value chain. Relevant policy levers include:

Accelerated research, funding, and investment in manufacturing, material innovation, and CCUS technologies and associated infrastructure

Over the last several decades, domestic cement and concrete manufacturers have invested hundreds of millions of dollars to increase the energy, materials, and emissions efficiency of their plants. These investments have generated significant reductions in the energy and emissions intensity of the industry, but more will be needed to achieve the industry's 2050 ambition. While there are opportunities for short-term improvement at some facilities, more research is needed to accelerate the development and deployment of innovative and cost-effective emissions technologies to support CCUS, innovative manufacturing technologies, low-carbon alternative raw materials, innovative construction methods, and new testing and analytical methods. Advancing this research at the pace needed to meet key reduction goals will require support from the federal government through government research and funding for industry and other efforts.

Streamlined regulation, siting, and permitting practices for facility and infrastructure modernization

Project permitting and facility regulations can pose significant barriers to investment and adoption of carbon reduction technologies, even where such technologies and practices are quite mature. Three common examples include EPA's New Source Review regulations, which impose onerous air permitting requirements on facility energy efficiency and modernization projects; EPA's Non-Hazardous Secondary Materials (NHSM) rule, which restricts the use of plastic, tires, and other low-carbon fuel alternatives at cement kilns; and EPA's CCR beneficial use rule, which limits storage of CCRs used as low-carbon feedstocks in clinker, cement, and concrete. For CCUS implementation, new projects will have to navigate federal and state air, water, waste, and land-use requirements, creating uncertainty as to the time and resource constraints associated with permits. Permitting rules can also discourage critical investments in infrastructure needed to switch plants from coal to natural gas and other alternative fuels, expand the use of renewable energy and storage at industrial facilities, build a national low emissions vehicle charging network, or site CCUS transportation and storage infrastructure. These limits affect major reduction pathways across the industry's Roadmap, making regulatory modernization a necessity.

Recognition and credit for industry reduction levers

Where emissions reduction options do exist for the cement and concrete industry, policymakers can expedite their adoption by formally recognizing and encouraging their use and benefits. For example, PLC and low-carbon blended cements and concretes using CCRs and other secondary cementious materials have lower embodied carbon profiles while offering comparable if not superior performance to other cement and concrete types. Non-recycled plastics, paper, fibers, and fabrics are excellent lower-carbon substitutes for coal – a fact illustrated by the higher utilization rates in European Union countries. By using these materials as fuels and feedstocks, cement plants not only reduce their products' emissions intensity, they provide valuable environmental and community benefits, diverting or recovering industrial secondary materials from land disposal and creating new markets for secondary material collection and recycling. Finished concrete and concrete aggregate act as carbon sinks over the useful life and end-of-life phases of concrete projects. These benefits are often overlooked by federal and state policy makers, reducing public awareness, skewing life cycle analyses, and discouraging short-term reduction opportunities.

Community acceptance of CCRs and alternative fuels, CCUS, and other manufacturing technologies

Misinformation and lack of awareness about the risks and benefits of cement manufacturing and materials technology can create community opposition to improvements that benefit surrounding communities through fewer environmental releases, waste diversion and reduced land-disposal, and associated public health and environmental impacts. These considerations are particularly important as policymakers assess options for promoting environmental justice and economic recovery. Policymakers and regulators can help reduce opposition resulting from misinformation through environmental justice and public education programs, as well as programs like EPA's National Recycling Strategy.

Market-based carbon pricing consistent with core principles, including fairness, transparency, and innovation – with preference for a cap-and-trade mechanism

PCA believes that market-based carbon pricing can encourage both conventional and breakthrough technologies to reduce CO_2 emissions at the lowest cost and could accelerate the path toward carbon neutrality. There are two widely recognized market-based mechanisms that impose a price on carbon – emissions trading systems – also known as cap-and-trade (C&T) – and a carbon tax. Both mechanisms, if well-designed, incentivize the private sector through financial mechanisms to reduce greenhouse gas emissions and invest in sustainable technology innovation, leading to meaningful and cost-effective carbon reduction. Of these mechanisms, a C&T system is preferable as it directly targets abatement, setting an emissions cap aligned to emission reduction goals where the cap diminishes over time. This system creates a market price which allows gradual reductions in hard to abate sectors by allowing them to take advantage of existing levers, while simultaneously investing in innovation and technologies to ensure long-term reduction solutions.

Market acceptance of low-carbon alternative cements and concrete

Government policies can pave the way for alternative raw materials, blends, admixtures, finished low-carbon building materials, and construction practices, but such advances will only pay dividends if the market accepts and adopts these innovations. In the past, institutional inertia and risk aversion have discouraged the uptake of many currently-available materials and building practices – limiting the market for both current building solutions and new innovations. Government can promote increased market acceptance by leading the way through government procurement, and by providing guidance and supporting materials that recognize and encourage the use of these alternatives.

Adoption of performance-based standards for building materials
While lower-carbon cement and concrete materials have been available for some time, the markets for these materials have been, in some cases, limited by overly restrictive or arbitrarily prescriptive procurement policies in both the private and public sector. By transitioning to performance-based material and design standards, policymakers can increase the market for currently available high-performance, lower carbon products like PLC, fly ash cement and concrete, and other SCMs and admixtures.

Consideration of the full product, material, and building life cycle in procurement standards and policies
Where policymakers adopt procurement policies to incentivize "sustainable" products and materials, they should mandate "whole-building" or "project life cycle analysis" to ensure that government purchasing also considers the impact of material selection on emissions from use, maintenance, repair, replacement, useful life, and end-of-life management of materials and structures. This distinction between the embodied carbon (cradle-to-gate) analyses contained in environmental product declarations and full life cycle (cradle-to-cradle) analysis is particularly important.

Investments in clean fuel, energy, transportation, and industrial infrastructure
Many of the most significant emissions reduction levers available to the industrial sector will require significant new investments in energy, transportation, and carbon reduction infrastructure. Switching from coal to natural gas-fueled kilns will require expanded natural gas capacity and delivery for industrial use. Increasing the use of NHSMs as fuel will require increased secondary material recovery, collection, processing, and distribution. Switching from fossil-fuel generated electricity to distributed renewable generation will require grid, transmission, and distribution upgrades and investment in battery storage. Transitioning industrial fleets to low emissions vehicles (LEVs) will require charging sites and supporting infrastructure. Implementing CCUS will require a national network of CO_2 pipelines to connect generators to use and sequestration sites, particularly outside of traditional oil and gas corridors. All of these will require government support and incentives, particularly during the initial stages of implementation while markets are developing.

Leakage protections for domestic manufacturers competing against less regulated imports
In developing a comprehensive carbon reduction strategy for the U.S. cement and concrete industry, both manufacturers and policymakers face an unfortunate reality: cement manufacturing is a highly energy intensive, trade exposed industry. Clinker and cement are commodity materials in an increasingly global marketplace. Whether price increases arise from carbon taxes or caps, new industrial or material standards, or CCUS capital and operating costs, climate policies that target domestic producers alone risk undermining the competitiveness of the U.S. cement and concrete industry. Indeed, one PCA analysis suggests that a mere $20 price on carbon could increase imports significantly if not accompanied by trade remedies to maintain a level playing field. Federal climate policies and procurement programs must take these market dynamics into account or risk destroying the U.S. cement and concrete industry and associated employment base while offshoring cement and concrete manufacturing emissions to other less regulated countries.

THE ROLE OF CARBON PRICING ON THE ROAD TO CARBON NEUTRALITY

The Roadmap does not depend on carbon pricing, but we cannot overlook the role it could potentially play on the road to carbon neutrality.

As an initial matter, *any* carbon pricing policy should be consistent with the following principles:

1. Prevent carbon leakage to support domestic industries: Prevent carbon leakage through a Carbon Border Adjustment Mechanism (CBAM) to maintain a fair and level competitive playing field across building materials and global suppliers;
2. Invest in research and sustainable infrastructure: Ensure revenue generated from carbon pricing is invested to drive and accelerate public and private research, innovation, and investment in industrial carbon reduction and avoidance technologies, CCUS, and sustainable infrastructure;
3. Clear the regulatory path to a low-carbon economy: Promptly establish clear, consistent, and common-sense regulatory policies, preempt inconsistent state and local policies, and eliminate regulatory barriers to the adoption of sustainable low-carbon technologies, fuels, feedstocks, product designs, and infrastructure; and
4. Adopt a "whole life cycle" approach for the built environment: Account for the "cradle-to-cradle" life cycle impact of regulated products and activities, including embodied emissions as well as carbon sink and carbon avoidance opportunities during manufacture, use, maintenance, and end-of-life management.

Any system should be periodically reviewed in light of technological advancements and timely incorporation of supporting policies noted in this Roadmap. This will ensure decarbonization goals and domestic competitiveness will not be undermined.

Decarbonizing the U.S. economy will require bold and creative action, innovation, and long-term investment across all sectors of the economy. When defining policy to limit carbon emissions, two main approaches exist: command-and-control and market-based mechanisms.

Traditional command-and-control regulations that impose specific limits on the level of emissions (emissions-based standards) or fixed product/technology requirements (design standards) are ill-suited to these demands, particularly for complex, energy-intensive, trade exposed industries like cement. There is no one size-fits-all regulatory standard or control solution for today's ever-evolving cement industry, and the tools and technologies in 2021 may be very different from those available in 2030 or 2050.

Market-based carbon pricing offers a more flexible alternative to traditional, rigid command-and-control regulations or facility/product standards. They incentivize behavior through financial mechanisms and the market – in the case of carbon, imposing costs on levels of emissions – and allow companies to make their own decisions about how to meet emissions obligations, incentivize long-term investment in sustainable technology innovation and encourage going beyond the

threshold, rather than just meeting it. Because of this flexibility and incentive toward net-zero, we believe that a well-designed market-based mechanism is a potential enabler for the industry's path toward carbon neutrality.

Market-based carbon pricing can take many forms, from carbon taxes and fees to emissions trading systems (ETS), also known as cap-and-trade (C&T), and hybrid approaches. Under a carbon tax (or fee), producers or consumers must pay a tax (or fee) for every ton of CO_2 emitted. Under a C&T system, policymakers set a cap on total CO_2 emissions, creating a market for companies to buy and trade emission "permits." The government can allocate free allowances for emissions to regulated companies and plants at levels consistent with the cap for that sector, which reduce over time, in recognition of the difficulty of some industries, such as cement, to decarbonize. Those exceeding their cap can buy permits at auction or on a trading market, all the while having a sector cap to ensure emissions are actually reduced. Moreover, carbon pricing can generate revenue for the government to use toward decarbonization R&D, supporting the necessary development of innovative solutions that will unlock capabilities to achieve carbon neutrality in the years to come.

Each model has strengths and limitations, depending on the scope, design, and implementation of the market system. For cement manufacturers, however, a federal, multi-sectoral C&T program offers the greatest promise.

ETS-based systems encourage an economy-wide, multi-sector life cycle perspective, encouraging industries to direct carbon reduction investments to projects with the lowest cost and highest reduction potential, with certainty in long-term decision-making and planning. This is particularly important for industries like cement manufacturing, which currently lack cost-effective, industrial scale technologies for capturing or removing chemical process emissions.

By allowing cross-sectoral trading, ETS markets can drive down emissions at the national level while accommodating unique challenges facing individual regions, states, industries, and plants, facilitating a comprehensive and synergetic move towards net-zero solutions while avoiding the potential risk of internal U.S. carbon leakage.

CAP-AND-TRADE SYSTEM

C&T sets a supply cap on carbon emissions and creates a market for companies

	Benefits
Achieving decarbonization goals	Directly aligned to emissions goals through gradually diminishing supply caps, which in turn creates a market price
Implementation feasibility	Cap-and-trade has historically more success on a larger scale, with more operational examples to point to, and has more general support from the private sector due to market freedom
The government and public sector	Because many countries are using cap-and-trade, there are more opportunities for coordination between systems at a global scale
The cement and concrete industry	Gradual reduction of allowances provides time for hard-to-abate sectors to capitalize on the achievable wins, while investing in long-term emissions reduction


TO VANDERBILT AVENUE
THE CAMPBELL APARTMENT
WEST BALCONY
WEST BALCONY
TICKET
DINING CONCOURSE
TRACKS 100 TO 117
Information
ARRIVALS

POLICY PRIORITIES ACROSS THE CEMENT AND CONCRETE VALUE CHAIN

Considering these policy drivers across the cement and concrete value chain provides another perspective on how federal, state, and local governments can drive or hinder decarbonization.

1. Policy Priorities for Clinker

Energy Efficiency

- Fund and accelerate research and development into new industrial efficiency technologies and process improvements.
- Expedite permitting for technology retrofits and process improvements.

Alternative Raw Materials

- Reduce storage and use restrictions for CCRs used in cement manufacturing.
- Incentivize diversion, recovery, and use of CCRs in clinker/cement manufacturing.
- Incentivize use of alternative raw materials through procurement policy.

Alternative Fuels

- Reduce permitting barriers to use of NHSM fuels in industrial manufacturing.
- Treat waste-to-industrial energy (WTIE) as valid recycling use.
- Build robust recycling infrastructure and markets that incentivize use of non-recycled material streams as alternative industrial fuels.
- Community education and support for use of low carbon alternative fuels.
- Increasing the use of NHSMs diverts these materials from landfills.

Carbon Capture, Use, and Sequestration

- Accelerate research, development, and commercialization of at-scale carbon capture solutions for industrial sources.
- Invest in and incentivize creation of national carbon capture, transport, use, and storage infrastructure.
- Accelerate siting and permitting of CCUS projects and infrastructure.

Healthy Competition

- Maintain a level competitive playing field between carbon-constrained domestic manufacturers and foreign importers.

2. Policy Priorities for Cement

Lower Clinker Factor

- Establish performance-based material standards for cement and concrete.
- Eliminate minimum-clinker requirements in government procurement requests.

PLC and Blended Cements

- Promote PLCs and other blended cements through performance-based procurement.
- Adopt whole life cycle approach to construction material sustainability.
- Reduce storage restrictions for coal combustion residuals and alternative raw materials.
- Promote research into the use of alternative raw materials and SCMs.

Natural Gas and Renewable Energy

- Fund research into industrial-scale renewable energy generation and storage.
- Invest in infrastructure for renewable grid capacity, natural gas distribution, and renewable energy generation and storage.
- Reduce or eliminate grid interconnection fees and expand net energy metering rules.

Low Emissions Vehicles

- Fund research and development for low emissions commercial/industrial fleets.
- Provide financial incentives for transitioning industrial fleets to LEVs.
- Expand LEV refueling and charging infrastructure for industrial use.

Healthy Competition

- Maintain a level competitive playing field between carbon-constrained domestic manufacturers and foreign importers.

3. Policy Priorities for Concrete

Optimize Performance of Concrete Materials

- Support research on mix design and zero-waste manufacturing.
- Promote development of improved testing and quality control procedures.

Increase Use of Supplementary Cementitious Materials

- Fund research into alternative low-carbon blends and admixtures.
- Adopt performance-based standards for project design and procurement.
- Adopt whole life cycle approach to sustainable construction.
- Expedite updates to codes to track material and design innovations.
- Reduce restrictions on storage and use of CCRs and other SCMs.
- Promote markets and infrastructure for SCM recovery, distribution, and use.

Reduced Energy Consumption

- Provide tax incentives and financing for plant efficiency upgrades.
- Invest in infrastructure for renewable energy generation.
- Streamlined permitting (natural gas, renewables, LEVs).

Low Emission Vehicles

- Financial incentives to promote conversion to industrial low emission fleets (LEFs).
- Build out infrastructure industrial-scale LEV charging.
- Expedite siting and permitting of renewable transmission, distribution, and industrial LEV charging stations.

Breakthrough Technologies

- Accelerated research and development (alternative feedstocks, SCMs, admixtures, others).

Healthy Competition

- Leakage protections for concrete products.

4. Policy Priorities for Construction

Performance and Construction Optimization

- Use of performance-based building/ material standards and whole life cycle analysis in government procurement, design, and construction.
- Develop improved performance testing and quality control procedures.

Life Cycle Tools and Inventory

- Develop science-based, whole-life LCA tools for material selection, project design, construction, and end-of-life materials management.
- Factor concrete's role as a carbon sink into government sustainability and procurement standards.

Reduced Energy Consumption

- Expand availability of industrial-scale natural gas, renewable energy, and LEV charging infrastructure.

Circular Economy

- Develop and expand markets and infrastructure for end-of-life reuse and recycling of concrete construction and demolition debris.

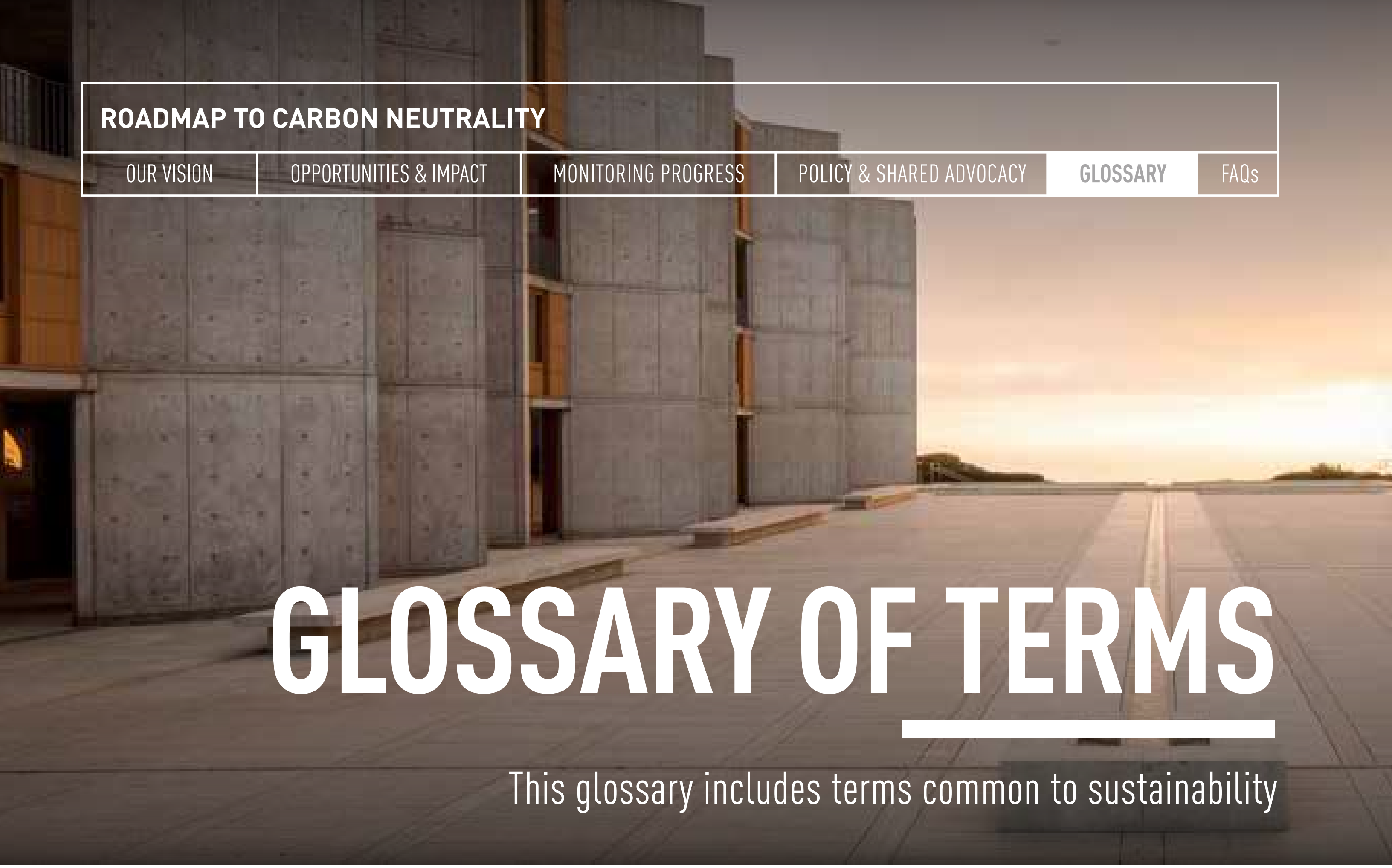
5. Policy Priorities for Carbonation

Recognition and Validation

- Establish an accepted method for calculating CO_2 uptake in building materials and construction.

Life Cycle Consideration

- Recognize and quantify carbonation in whole-life LCAs and sustainable procurement policy.
- Research the life cycle carbonation benefits of concrete materials and end-of-life demolition debris recycled into different types of buildings and infrastructure (roads, highways, base course, aggregates, rip rap, etc.).



GLOSSARY OF TERMS

This glossary includes terms common to sustainability

Absolute emissions: All CO_2 emissions generated at a plant.

Albedo: A measure of the fraction of solar energy reflected by a surface or object often expressed as a percentage. Lighter color surfaces reflect solar energy and have a high albedo, while darker surfaces absorb solar energy and have a low albedo.

Algae capture: The use of CO_2 in agricultural and aquacultural systems for the cultivation and harvesting of biomass. Algae are extremely efficient photosynthetic organisms – sometimes referred to as CO_2 eating machines.

Alternative fuels: Any fuel other than a fossil fuel, biomass, or hazardous waste fuel. Common examples include tires, agriwaste, and refuse-derived fuels.

Avoided CO_2 emissions: Emission reductions that occur outside of a product's life cycle or value chain, but as a result of the use of that product.

Bioenergy: Energy via the combustion of biologically derived material other than fossil fuels, for example wood, biosolids, or agricultural products.

Biogenic content: The amount of natural material in a fuel. For example, car tires have 17-20% and bus and truck tires have 29-30% biomass including natural rubber, rayon, and stearic acid.

Biogenic emissions: Combustion emissions generated from the biogenic content of fuel.

Biomass: Organic material like wood, agricultural waste and agricultural byproducts, ethanol, railroad ties, manure, or the methane generated from the decomposition of materials like these in a landfill. NOTE: Peat is usually excluded from the category of biomass.

Calcination: The process of thermally treating minerals to decompose carbonates from ore. Calcination is the first step in a series of complex chemical and physical changes required to make cement. Specifically, limestone is "calcined" in high-temperature cement kilns, driving off CO_2 to create the intermediate ingredient, clinker. *See also "chemical fact of life".*

Calcium (or carbonate) looping: A capture technology that captures CO_2 cement plant emissions and reacts that CO_2 with calcium oxide to form calcium carbonate (limestone). This process takes advantage of the fact that the calcination reaction is reversible.

Cap-and-trade/emissions trading system (ETS): A carbon pricing approach that caps the total level of GHG emissions and allows those industries with low emissions to sell their extra allowances to larger emitters. By creating supply and demand for emissions allowances, an ETS establishes a market price for GHG emissions. The cap helps ensure that the required emissions reductions will take place to keep the emitters (in aggregate) within their preallocated carbon budget.

Carbonation: The natural absorption of ambient CO_2 by concrete over its life cycle or the injection of CO_2 into fresh concrete. *See also "concrete as a carbon sink".*

Carbon border adjustment (mechanism): A tax on imported goods based on their carbon footprint with the aim of limiting emissions leakage and leveling the playing field for domestic industries that produce goods with lower GHG emission footprints than imports that may be cheaper but have higher GHG footprints.

Carbon leakage: A potential shift in production resulting in some of the U.S. carbon reductions being counteracted by increased production in less regulated countries. The risk of carbon leakage is particularly high in energy-intensive, trade exposed industries like cement manufacturing.

Carbon neutrality: The principle by which CO_2 emissions resulting from a product or process are offset either by direct CO_2 emissions reductions or through avoided CO_2 emissions.

Carbon tax: A carbon pricing approach that directly sets a price on carbon by defining a tax rate on GHG emissions or – more commonly – on the carbon content of fossil fuels. It is different from an ETS in that the emissions reduction outcome of a carbon tax is not predefined but the carbon price is.

Cement: Any material that binds other materials together.

Chemical fact of life: The fact that even if the industry were to eliminate all combustion emissions, the chemical process used to manufacture clinker creates a separate stream of CO_2 emissions. For example, in the U.S., 60% of the CO_2 generated by cement plants is from a chemical reaction called calcination. Calcination is the chemical fact of life in that it is the first step in a required series of complex chemical and physical changes to make cement. The chemical fact of life is also called "process emissions".

Circular economy: A circular economy is an industrial system that is restorative or regenerative by intention and design. It replaces the end-of-life concept with restoration, shifts toward the use of renewable energy, eliminates the use of toxic chemicals which impair reuse and return to the biosphere, and aims for the elimination of waste through the superior design of materials, products, systems, and business models.

Clinker: An intermediate product created during the cement manufacturing process.

Clinker factor: *See "clinker-to-cement" ratio.*

Clinker-to-cement ratio: The ratio of clinker to cement; typically expressed as a decimal value. For example, a ton of cement composed of 80% clinker would have a clinker to cement ratio of 0.80.

CO_2eq: Some gases including methane and nitrous oxide contribute to climate change and have an effect greater than that of CO_2. The impact of these gases is measured in terms of "CO_2 equivalent," or units equivalent to the effect of CO_2.

Combustion emissions: Combustion is the chemical reaction using fuel and air (or oxygen) to produce heat and/or light. The major products of fossil fuel combustion include CO_2 and water vapor along with other emissions.

Concrete: A resilient, sustainable, building material that also absorbs CO_2.

Concrete as a carbon sink: Concrete naturally absorbs CO_2 from the atmosphere. Typically, over its lifetime, concrete that is not buried will absorb about 10% of the CO_2 emissions that were generated in its production.

Cradle-to-cradle: An accounting method that considers the product life cycle from raw material extraction (or delivery) to the product's salvage/re-use as an alternative raw material thereby completing the material cycle within the circular economy.

Cradle-to-gate: An accounting method that considers the processing impacts from raw material extraction (or delivery) to final product assembly or shipment.

Cradle-to-grave: An accounting method that considers the processing impacts from raw material extraction (or delivery) to the product's final disposal/salvage/re-use.

Emissions intensity (or **greenhouse gas intensity**): A measure of the quantity of CO_2 emitted for a designated unit of energy generation or product production.

Fossil fuel: An energy source formed in the Earth's crust from decayed organic material. The common fossil fuels are petroleum, coal, and natural gas. (Ref. Energy Information Administration). Fossil fuels traditionally used in combustion include coal, coke or petcoke, and natural gas.

Gross emissions: Combustion emissions that exclude emissions contributed by biomass combustion.

Levers: A combination of tools, techniques, technologies, processes, and products that individually or in combination reduce the emissions of greenhouse gases.

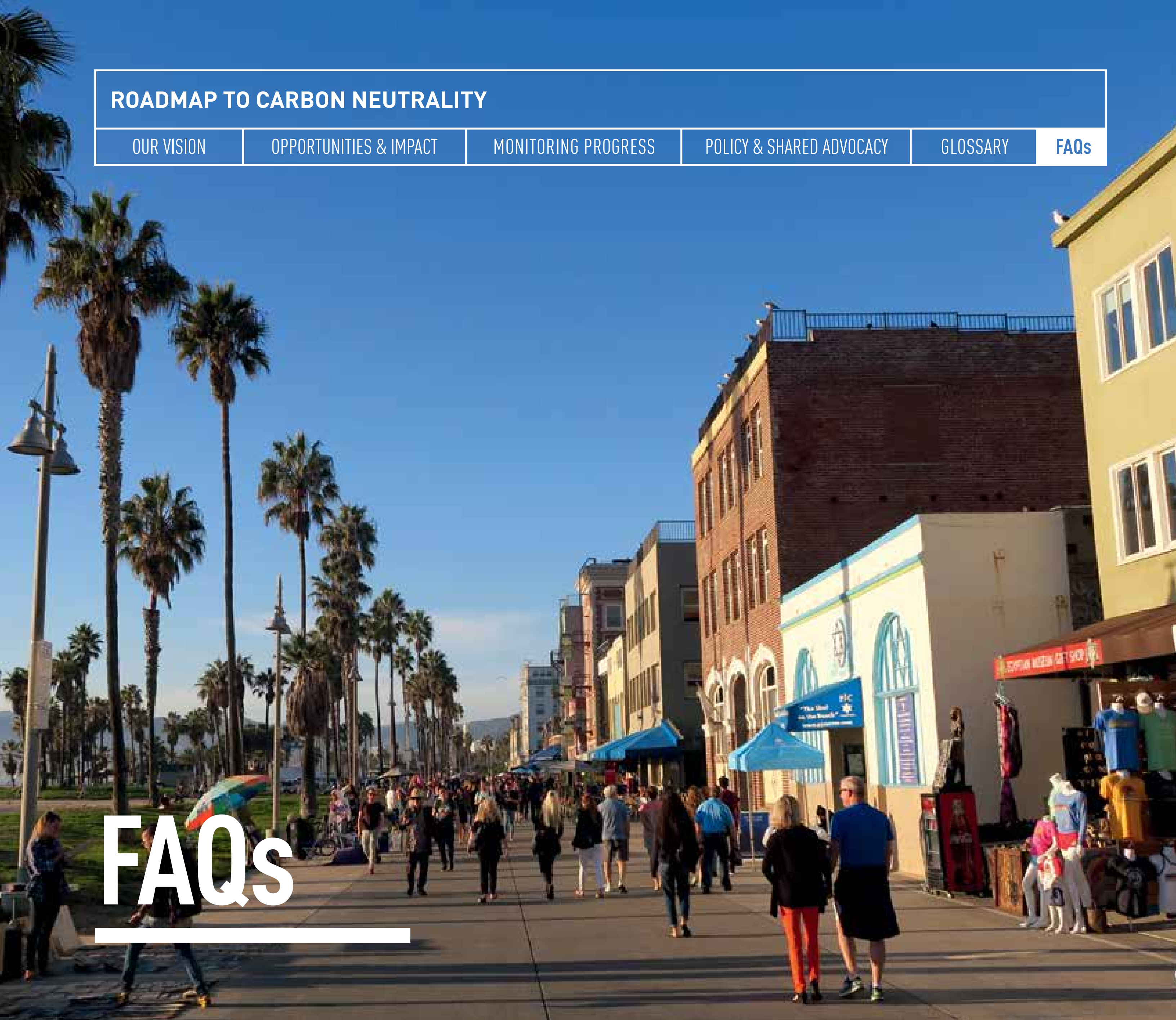
Life cycle assessment: An accounting method to evaluate the energy and environmental impacts of a product from cradle-to-grave.

Net emissions: Combustion emissions that exclude emissions contributed by biomass and alternative fuel combustion.

Oxyfuel combustion: Combustion which takes place in an atmosphere of 100% oxygen. In comparison, most other combustion takes place using air which is an atmosphere of 78% nitrogen and 21% oxygen.

Petcoke: A residue high in carbon content and low in hydrogen that is the final product of thermal decomposition in the condensation process in cracking during the oil refining process. Often used as a fuel.

Process emissions: Emissions from chemical transformation of raw materials and fugitive emissions. The chemical transformation of raw materials often releases greenhouse gases such as CO_2, methane (CH_4), and nitrogen oxide (N_2O). These processes include iron and steel production, cement production, petrochemical production, and nitric acid production, among others.



FAQs

What is the Roadmap?
The Roadmap is the documentation of the path that the U.S. cement industry will use in reaching carbon neutrality throughout the value chain by 2050.

What is in the Roadmap?
The Roadmap is a document that includes the targets, the timeframes, the technologies, and the policy needs along each step of the value chain that will get the cement industry to carbon neutrality by 2050.

What is carbon neutrality for concrete?
Carbon neutrality occurs when CO_2 emissions from the production of concrete are offset by at least an equal amount of CO_2 reductions.

Why 2050? Why not sooner?
While the cement and concrete industry has made consistent progress in reducing the carbon intensity of its products across the value chain, reaching carbon neutrality will require significant advances in technology, policy, infrastructure, and markets. With full support in these areas, the industry can reach carbon neutrality sooner. Without those policies and support, it will take the industry more time and possibly jeopardize reaching the goal.

What kind of policies and support?
Reaching carbon neutrality requires support in a wide variety of areas including funding research and development, regulation and permitting, credit for carbon reduction levers, community acceptance, market acceptance, performance-based standards, procurement based on cradle-to-grave life cycle analysis, low-carbon infrastructure, and a secure and level playing field.

How will the cement and concrete industry get all of this done?
The cement industry cannot do it alone. The industry is asking everyone involved throughout the value chain to help reach this goal by re-thinking their role, by setting their own bar higher, by pushing their own envelope further, and by helping advocate for the policies the cement and concrete industry need to reach carbon neutrality. The industry is asking everyone involved throughout the value chain to help advocate for the policies needed to reach carbon neutrality. Everyone has a role to play. The academic, the architect, the builder, the contractor, the engineer, our government, the homeowner, the material scientist, the manufacturer, the owner, the policy maker, and the researcher, will all be at the forefront but there are hundreds of others that can support these efforts.

What is the value chain?
The value chain includes clinker, cement, concrete, construction, and the use of concrete as a carbon sink. The value chain is a microcosm of a circular economy. Clinker, the first step in the value chain, is an intermediate product within the cement manufacturing process. Cement, the second step, is a blended mixture of clinker and gypsum along with potentially many other materials like limestone and other processing additions. Concrete, the third step, is a mixture of cement, water, fine and coarse aggregates, and chemical and mineral admixtures. Concretes today also commonly include, fly ash, slag, and other materials. Construction, the fourth step, is the built environment. Concrete construction includes airports, buildings, bridges, runways, streets, sidewalks, tunnels, and many more structures. The fifth and final step in the value chain is the use of concrete as a carbon sink. Concrete absorbs CO_2 throughout its lifetime and even after it is demolished.

How much CO_2 is generated by the cement industry?
The U.S. cement industry contributes 0.17% CO_2eq to the global production of CO_2. The EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks notes current (2019) total U.S. emissions of 6.6 GtCO_2eq. Using the same calculation procedure, the U.S. cement industry contribution to U.S. CO_2eq emissions is 1.25%.

Where does this CO_2 come from?
The manufacture of cement relies upon the transformation of calcium carbonate into calcium oxide. That reaction produces CO_2 and without that reaction, there can be no clinker, hence no portland cement. In the U.S. more than 60% of the CO_2 emissions from cement manufacturing are generated by this chemical reaction called calcination. PCA and the industry calls this calcination reaction the industry's "chemical fact of life". In addition, the chemical reactions to produce clinker require material temperatures of nearly 2,800 degrees Fahrenheit or 1,500 degrees Celsius. (For comparison, the surface temperature of the sun is 10,000 degrees Fahrenheit or 5,500 degrees Celsius.) The only way to achieve those high temperatures is through fuel combustion. In the U.S., just under 40% of the CO_2 emissions from cement manufacturing are generated from fuel combustion.

How can CO_2 be reduced or avoided at the clinker stage?
The CO_2 generated from combustion can be reduced through the transition from traditional fossil fuels like coal, petcoke, and natural gas to alternative fuels including biomass, secondary materials, and renewable energy sources and also from increased fuel efficiency in the manufacturing process. PCA also anticipates that hydrogen and other transformative fuels and transformative technologies will play a role. The CO_2 generated from the chemical reaction or chemical fact of life can be reduced by incorporating decarbonated raw materials, including slag and fly ash, as feedstocks. These are materials that have already been processed and no longer contain CO_2. Additionally, increasing the use of recycled materials diverts these materials from landfills.

How can CO_2 be reduced or avoided at the cement stage?
The CO_2 associated from cement can be reduced or avoided by replacing a portion of the clinker with limestone, inorganic processing additions, supplementary cementitious materials, and by manufacturing and transporting cements using zero emission rail and truck transport. PLCs have been available for decades and can reduce the CO_2 footprint of today's cements by up to 10%. Blended cements using fly ash and slag can also reduce CO_2. Shifting from prescriptive specifications to performance-based specifications provides designers more flexibility also reduces or avoids CO_2.

How can CO_2 be reduced or avoided at the concrete stage?
The CO_2 associated from concrete and concrete production can be reduced or avoided using PLCs and other low-carbon blended cements, supplementary cementitious materials, admixtures to optimize concrete mixtures, and by manufacturing and transporting concrete and concrete products using zero-emissions electricity, rail, and truck transport.

What does it mean to optimize a concrete mixture?
Concrete mixtures can be optimized by increasing the use of SCMs and using machine learning algorithms and artificial intelligence to discover the optimal mix design for specific applications and to identify the optimal sequencing, scheduling, and delivery of concrete and concrete products. Optimized concrete mixtures and concrete products provide the best strength and durability performance requirements and the most sustainable performance for specific individual applications. Quality assurance and acceptance testing of fresh concrete can also be optimized. Optimization ultimately provides better performance with less variability.

What exactly is concrete optimization?
Optimization is about "shifting the curve" and "shaping the curve" regarding performance. Shifting the curve means bringing the slow adopters and less than average performers into the median or average range, bringing the median or average adopters and performers into the above average range, and allowing the above average performers to push the envelope even further through innovation and discovery. In many cases this means simply removing the obstacles that slow adopters and average performers face. Shaping the curve means bringing the below average and average adopters much closer to and always chasing the above average adopters and performers. It is about setting the bar higher and pushing the envelope further.

How can CO_2 be reduced or avoided in the design phase of construction?
Using building construction as an example, optimization in the design phase is exemplified by the Whole Building Design Guide developed by the National Institute of Building Sciences. Optimized construction envisions the use of Building Information Modeling (BIM) and full-life cycle analysis techniques that incorporate energy efficiency, resource efficiency, resiliency, project-life, indoor air quality, and adaptability into the circular economy. The guiding principles for high-performance buildings and infrastructure include employment of integrated design principles, optimization of energy performance, protection and conservation of water, enhancement of indoor air quality, reduction of the environmental impact of materials, and the assessment and consideration of climate change risks. Each of these principles can be met through concrete construction. Design optimization considers the initial structure use as a starting point while providing the flexibility to adapt to the structure's future uses. Strength, stiffness, stability, slab depth, column size and spacing, and framing considerations can all be optimized for future adaptability.

How can CO_2 be reduced or avoided in the construction phase?
The CO_2 associated with the construction phase can be reduced or avoided through life cycle-based procurement policies, zero-waste materials management, and end-of-life reuse and recycling of concrete materials.

What does it mean to optimize construction?
Construction can be optimized using innovative construction techniques like additive manufacturing, a zero-waste construction site, advanced sequencing and scheduling, zero-emission deliveries and zero-emission construction material handling equipment, on-site robotics, and the use of drones. These and many other innovations can all reduce the carbon footprint in the construction phase.

Why is it so important to consider the use phase of concrete structures during design and construction?
The use phase of a building accounts for 88-98% of the life cycle global warming potential. Research by MIT indicates that using concrete lowers the use phase global warming potential impacts up to 10% and lowers the life cycle global warming potential impacts up to 8% in comparison to buildings that are not concrete.

How can the end-of-life phase of concrete be optimized?
Crushed concrete can be recycled and re-used as aggregate in new concrete mixtures thereby saving the energy required to quarry and process virgin aggregate. Further, over time recycled concrete continues to absorb and sequester CO_2 (see discussion about concrete as a carbon sink).

How can CO_2 be reduced or avoided using concrete as a carbon sink?

Concrete and live growing trees share something in common; they both absorb CO_2. Trees and plants use CO_2 to produce the food they need through photosynthesis. Concrete absorbs CO_2 from the moment that it sets throughout its entire life through a process called carbonation. Air contains about 0.04% or 400 ppm of CO_2. That CO_2 naturally diffuses into concrete and reacts with the calcium hydroxide and other hydration products in concrete to form calcium carbonate. This reaction is irreversible

How much CO_2 can concrete absorb?

The absorption of CO_2 by concrete depends primarily on the concrete surface area exposed to the atmosphere, the amount of water and moisture available, the permeability of the concrete, and the length of exposure. For example, an above grade concrete wall will slowly absorb CO_2 throughout its life. If that concrete wall is removed, reduced into smaller aggregate-sized particles, and exposed to the atmosphere in a stockpile, it will absorb CO_2 more quickly due to the higher surface area. The crushed concrete can then often be recycled as aggregate. Various models using the compressive strength of the concrete, the type of structure, the type of exposure (exposed to rain vs. sheltered from rain, indoor vs. outdoor, with or without cover, in ground or out of the ground) have been developed to calculate the degree of carbonation. The U.S. EPA is currently evaluating what is known as the Tier I model for incorporation into the National Inventory Report. Current estimates indicate that approximately 10% of the CO_2 generated during the manufacture of cement and concrete can ultimately be absorbed over the life of a concrete structure.

What is CCUS?

CCUS (carbon capture, utilization, and storage) is an integral part of the Roadmap and includes a range of technologies that capture CO_2 as the first step and then either transforms the CO_2 into a useful product or sequesters (permanently store) the CO_2. While some commercial scale projects are being implemented in other industries and countries, the use of CCUS in the cement industry, like other industries, is still in the research and development stage. The cement industry is currently evaluating the use of solvents, sorbents, membranes, oxyfuel combustion, oxyfuel calcination, calcium or carbonate looping, algae capture, direct separation reactor technology, and other carbon capture and related technologies in cement plants worldwide.

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