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State of Innovation 2024: **Paving the Way for Low-Carbon Cement and Concrete**

Ana Aday, Katie Richardson, Danielle France, Jonathan Olavarria, Joshua Schaidle, and Trish Cozart

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Executive Summary

Concrete production in the U.S. accounted for nearly 393 million cubic yards in 2023, with $38.8 billion in revenue. While cement, the key ingredient in concrete, is only 10%-15% of concrete's mixture by mass, 8% of total global emissions come from the production of cement. A significant challenge lies in the fact that roughly 51% of concrete emissions stem from the material calcination process of cement production.

Stakeholders ranging from cement producers to government agencies are beginning to take measures to significantly reduce concrete emissions by 2050 and are seeking novel technologies from the startup community. Strategies to lower carbon emissions include reducing quantities of cement in concrete formulas; optimizing digital and automated production; lower temperature processing; carbon capture, utilization, and durable storage; and other cost-saving approaches to energy and material efficiencies. New materials based on carbon mineralization and novel cement chemistries hold the potential to reach net-zero or even carbon-negative concrete production; however, there is presently no readily available substitute that can replicate concrete's unique properties and versatility at the volume demanded by construction worldwide. The nature of concrete's raw materials, diverse applications, and scale of demand means that complete decarbonization will rely on a combination of innovative production methods and novel cement chemistries. Low-carbon solutions will need to compete economically with traditional concrete to become viable in a high-volume commodity market, although consumer demand and regulation will play important roles.

Despite these challenges, this analysis reveals in Part 1 that venture capital (VC) investments in low-carbon concrete reflect a growing awareness of the decarbonized cement market opportunity. Between 2022 and 2023 emerging low-carbon technologies garnered more than $700 million in VC investments, representing a growing share of investment in the built environment. An investment gap appears after Series A for technology solutions, demonstrating the sector's potential, as well as the need for additional performance assurance and technology incubation.

In Part 2, perspectives from both concrete contractors and building owners reveal a coordinated readiness for implementing low-carbon innovations, while startups are benefiting from technology validation from the National Renewable Energy Laboratory (NREL). Active engagement of diverse and complex perspectives from the concrete ecosystem is necessary to accelerate low-emissions solutions to the marketplace.

Part 3 highlights the convening power and technical de-risking capabilities of NREL, a U.S. Department of Energy (DOE) laboratory. In 2023 and 2024 NREL held workshops inviting building owners, contractors, investors, and innovators to a facilitated dialogue. The conversation uncovered industry needs and explored ways NREL can accelerate the deployment of low-carbon concrete. Researchers use these multi-stakeholder inputs as a signpost on the path to eliminating concrete emissions, keeping research efforts strongly aligned with the current state of the industry and marketplace while informing stakeholders about new opportunities and validating emerging solutions.

In the last two years, 61 different low-carbon cement and concrete technology companies have recruited more than $729 million from over 100 unique investors

1. Progress: Growing Venture Capital Investments and Startup Activity in Low-Carbon Concrete

Demand for low-carbon concrete has been expressed by industry leaders and regulators alike, and entrepreneurs are answering with a range of technology solutions. Investors likewise see low-carbon concrete as a central component in decarbonizing the built environment, as well as a massive market opportunity, and have begun seeding the sector with early-stage capital.

A Surge in Investments

In the last two years, 61 different low-carbon cement and concrete technology companies have recruited more than $729 million from over 100 unique investors, comprising 75 VC deals and 25 grants.[1] These numbers reflect approximately 9% of the funding and 12% of the active startups recorded by PitchBook for the built environment sector[2] during this period (Table 1). All deal data, including total VC and grant dollars and number of active startups, are from PitchBook, which provides comprehensive data on private market transactions around the world.[3]

Table 1: Low-Carbon Concrete (LCC) Is a Growing Share of Built Environment (BE) Activity[1,2]

Years	LCC Funding (Millions)	BE Funding (Millions)	LCC Number of Active Startups	BE Number of Active Startups	LCC Share of BE Active Startups
2016-2017	$46	$950	15	195	7.7%
2018-2019	$182	$1,685	31	298	10.4%
2020-2021	$436	$4,603	48	432	11.1%
2022-2023	$729	$8,441	61	508	12.0%

The trend of investment from both dilutive and nondilutive deals recorded by PitchBook since 2016 shows robust growth and reveals how investments in low-carbon concrete track closely with the built environment (Figure 1). The number of active startups in the low-embodied carbon space has

1 NREL's curated low-carbon concrete list started with Sightline Climate's list of green concrete companies (https://platform.sightlineclimate.com/ > Sector Compass > Cement. Accessed January 31, 2024) and was refined by NREL authors to a total of 79 companies. Companies making the final list are involved in the reduction of concrete emissions as a primary business activity; for instance, companies providing low-carbon heat sources to a range of industries like concrete were not included. Eighteen of the 79 companies did not have sufficient funding data in Pitchbook to include in graphical analysis.

2 "Built environment" includes all companies classified within PitchBook's curated built environment technology vertical, as well as all companies in NREL's curated low-carbon concrete list (which makes low-carbon concrete a subset of the built environment vertical). The inclusive built environment list contains 681 companies in total.

3 PitchBook (https://pitchbook.com/about). Accessed May 22, 2024.

quadrupled in the last seven years, while attracting 16 times the investment. Given the capital necessary to develop new materials technologies and establish demonstration at scale, the increase in funding is promising. Moreover, low-carbon concrete is becoming a more important proportion of the built environment sector. Low-carbon concrete startups have grown from 7.7% of the built environment companies in 2016 to 12% today. Funding for low-carbon startups has grown similarly, from less than 4.8% to 8.6% of investments into the built environment in the same period. This performance is even more commanding considering the 9-fold growth of the parent sector itself, which has realized $15.7 billion invested in built environment technologies since 2016.

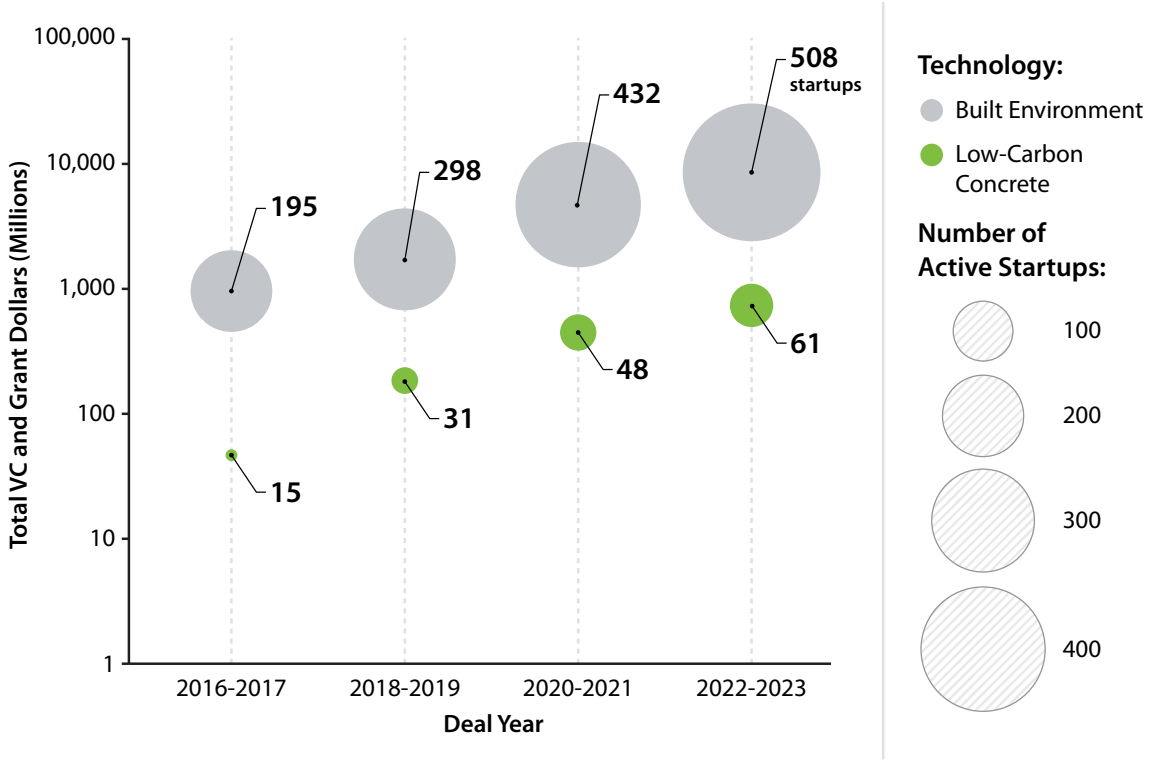

Figure 1: Low-carbon cement and concrete, as well as built environment startup investments, increased over the last eight years[4]

Movement Toward Commercialization

A closer look at the funding deals that have catalyzed low-carbon concrete company growth shows that the field is still relatively immature, with only one in seven companies to date progressing past Series A funding to push toward commercialization at scale. Figure 2 shows how long companies have been raising capital and the stage of their last funding round, which serves as a proxy for progression toward market adoption.

4 The authors sorted the same low-carbon concrete companies listed in Figure 1 into four technology categories, using initial characterizations assigned by Sightline VC as a starting point. Each company was assigned to a startup stage based on their latest VC raise. The Series C+ category was used as a catchall category for companies that surpassed the Series C funding round but had not yet exited or reached growth stage. For each company, dilutive and non-dilutive deals were summed to obtain the total funding attribute. The figure labels the top 10 companies by total funding, plus the Series C+ company Brickeye.

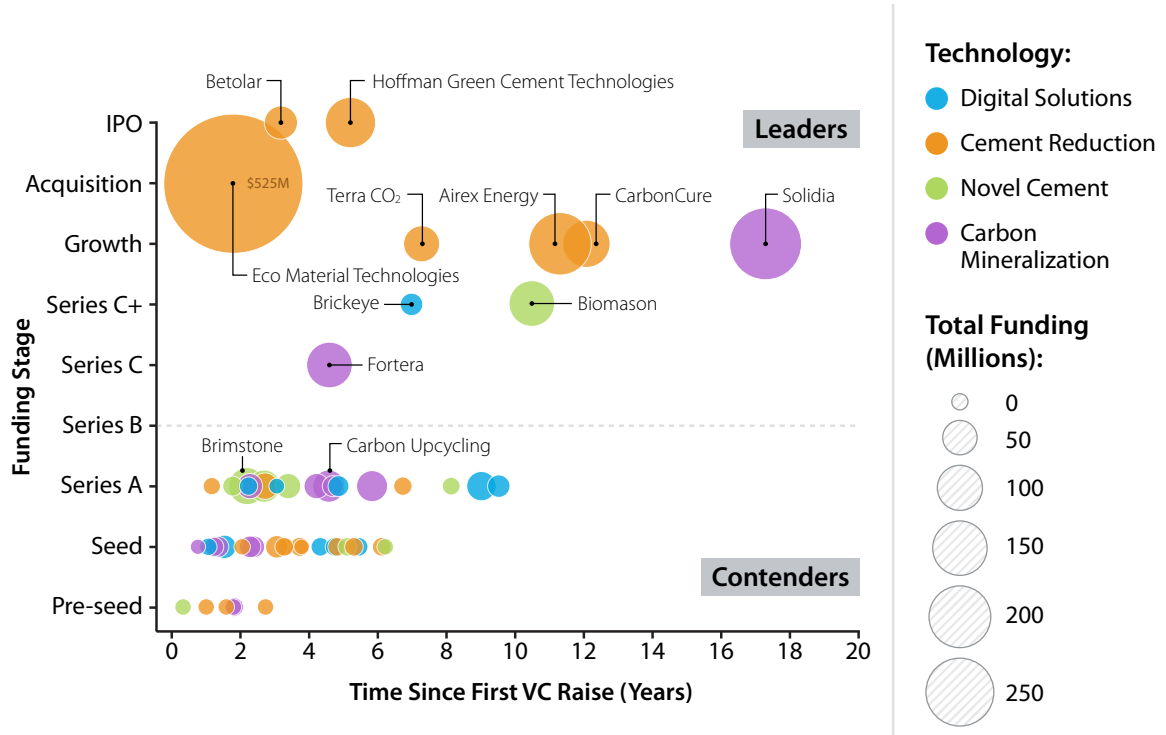

Figure 2: The low-carbon cement and concrete startup investment landscape[5]

There is a clear breaking point in the dataset between companies that have raised Series A or earlier capital and those that have crossed the capitalization gap to later-stage funding. While the capitalization gap following Series A is not unique to the low-carbon concrete industry, other more sector-specific factors can impact growth, such as the entrenched nature of existing procurement and concrete production strategies. For this sector, more mature companies tend to specialize in cement-reduction technologies, which are generally easier to adopt and scale. Saving money through efficiency in a commodity market, the currently favored strategy, does not ultimately deliver zero emissions for the sector. Significant leaders breaking that mold include Solidia[6] and Biomason, despite steep capital requirements.

However, many early-stage companies are focused on the novel cement and carbon mineralization technologies needed to achieve zero emissions (Figure 3). The lineup of companies that have raised Series A funding on the cusp of early commercialization will be key to bringing net-zero-carbon concrete to market. Current leaders in low-carbon concrete have bridged capitalization gaps with early revenue and partnerships with incumbent industry players. These companies will benefit as performance standards are updated to accommodate novel materials. Nevertheless, companies looking to scale past Series A funding face challenges in both sourcing capital and attaining widescale market acceptance.

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6 Note that since the time of preparing this figure, Solidia has licensed its intellectual property to CalPortland.

The recent announcement of catalytic funding from the Industrial Demonstrations Program of DOE's Office of Clean Energy Demonstrations (OCED) makes a cluster of early-stage contenders particularly interesting to watch.[7] Brimstone and Sublime plan to construct first-of-a-kind demonstration plants that also engage skilled local workforces. The OCED grants recognize that capital needs to be significant and patient to bring transformational low-carbon concrete technologies to market, filling the gap between the early-stage VC funding typical for innovative new approaches and the infrastructure investment funds required to scale proven technologies. In parallel, OCED has awarded industry incumbents funding to develop calcined clay as a cement replacement (Summit Materials and Roanoke Cement Company) and to build new plants with carbon capture and sequestration (Heidelberg Materials and National Cement Company of California).

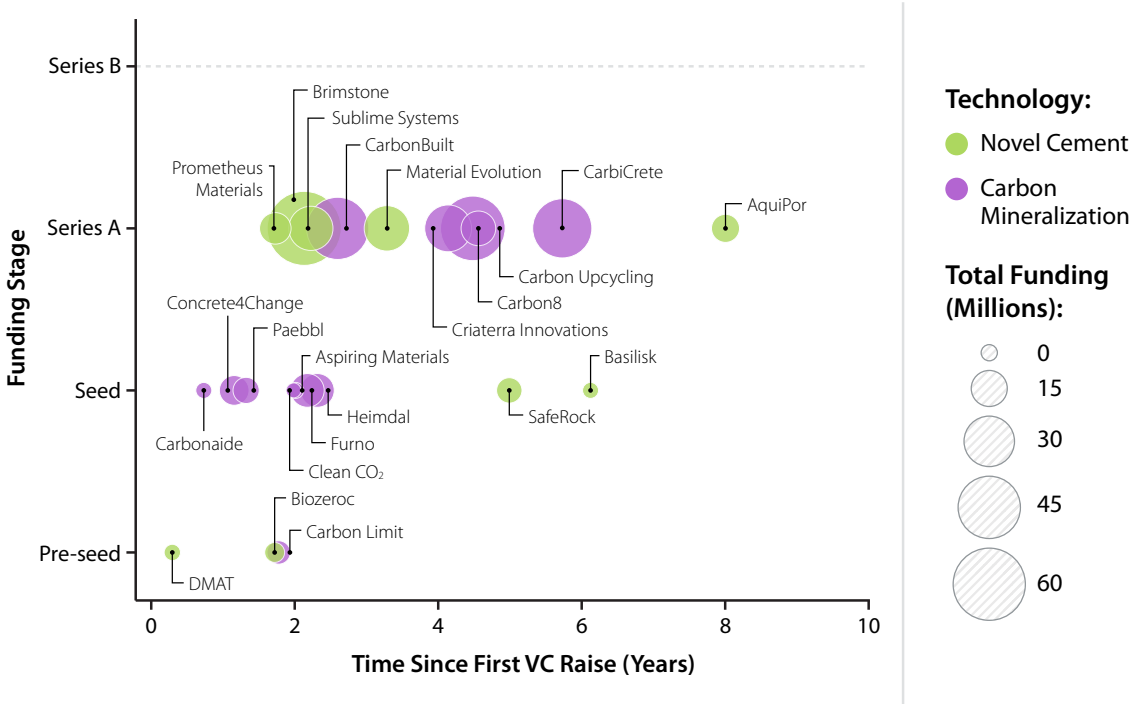

Figure 3: Contenders for market impact in novel cement and carbon mineralization approaches to low-carbon concrete[8]

2. Perspectives on Market Growth and Regulatory Support

In late 2023 the U.S. General Services Administration (GSA) announced it would spend $767 million to procure lower-embodied carbon (LEC) concrete as part of a larger $2 billion investment in 150 LEC construction projects.[9] The GSA contracts represent just a small portion of the significant market opportunities emerging for cement and concrete manufacturers who can

7 OCED funds are not included in the datasets of this analysis. Industrial Demonstrations Program Selections for Award Negotiations: Cement and Concrete. https://www.energy.gov/oced/industrial-demonstrations-program-selections-award-negotiations-cement-and-concrete. Accessed June 24, 2024.

8 An enlarged version of Figure 2 showing all novel cement or carbon mineralization companies that have yet to reach Series B funding. Figure 3 uses the same underlying data as Figure 2.

9 "GSA Announces $2 Billion Investment in Projects Using Lower-Embodied Carbon Construction Materials." https://www.cement.org/2023/11/07/gsa-announces-2-billion-investment-in-projects-using-lower-embodied-carbon-construction-materials/. *PCA (Portland Cement Association) Daily*. November 7, 2023.

offer products with a reduced carbon footprint. For instance, DOE has allocated $1.2 billion through the Inflation Reduction Act (IRA) and the Buy Clean program to accelerate the adoption of these sustainable materials at the state and local level. One specific example is the Carbon Utilization Procurement Grants (UPGrants), which help offset 50% of the costs to procure and use products developed through the conversion of captured carbon dioxide, including carbon-cured concrete and synthetic aggregates.[10] At the state level, measures such as New Jersey's Low-Embodied Carbon Concrete Leadership Act offer concrete suppliers on government projects tax credits in return for demonstrating quantifiable reductions in embodied carbon. In New York, Executive Order 22 (EO 22) in 2022 featured a range of procurement commitments, as well as guidelines for climate and environmental priorities that include embodied-carbon reductions in new construction.[11] Marin County in California successfully codified requirements for embodied carbon in 2020, requiring LEC concrete with global-warming potential limits per concrete strength or performance.[12] Internationally, the European Union's market-based mechanisms for carbon pricing have provided an approach to reducing the emissions from the cement industry. Pricing carbon creates a financial incentive to not only reduce emissions but increase adoption of low-carbon concrete. These carbon markets could raise money to finance low-carbon concrete materials.[13]

Furthermore, the increased adoption of third-party-certified environmental product declarations and product category rules is improving transparency surrounding the carbon footprint of cement and concrete products to enable more informed decision-making.[14]

The construction industry is becoming more familiar and comfortable with using sustainable materials, accelerating their mainstream acceptance. In turn, the increasing availability and adoption of novel technologies is driving further advancements and economies of scale. NREL Industrial Cement and Concrete Decarbonization Strategic Workshop attendees reported that costs are coming down as manufacturers ramp up production capacity.

Building Owner Perspective

Hines is a global real estate investment management firm that invests in low-carbon developments, and Kelsey Rose is leading their embodied-carbon strategy. "We hear from our investors a consistent interest in decarbonization, especially in European markets where the topic has historically garnered more focus. It is unclear at this point, however, whether investors are willing to pay a premium for this decarbonization. As carbon-focused regulations come online, like CALGreen in the U.S., we expect investors to start considering the risks associated with not addressing both operational and embodied carbon in a changing legislative environment. A key component to this for embodied carbon is the decarbonization of cement and concrete."

In addition to this investor demand, Rose shared that tenants want buildings aligned with environmental goals, and they may turn away from buildings that do not address these priorities. "Establishing decarbonization costs as part of the projected whole-building cost, rather than attempting to overcome green premiums during procurement, will reduce risks for project investors and tenants alike," said Rose. "Gathering all the stakeholders as early as possible during the project development will help significantly to build the right team from the start."

Rose's recommendation to low-carbon cement startups is to be prepared to answer the following questions for building owners:

- Does your product achieve cost parity with conventional products? If not, what is the premium?
- When will your product be available at the scale needed to serve a commercial development?
- What data are available to prove the environmental performance?
- Can you prove the environmental performance?

10 https://netl.doe.gov/upgrants

11 https:/www.nrdc.org/bio/sasha-stashwick/ny-and-nj-centers-action-low-carbon-concrete-buying

12 https://www.ashrae.org/file%20library/about/embodied-carbon-codes-and-policies-summary---final.pdf

13 https://www.dgs.ca.gov/BSC/CALGreen

14 https://gccassociation.org/concretefuture/carbon-pricing/

Contractor Perspective: Adapting Operationally

Mike Eads, a concrete operations manager with GH Phipps Construction Companies, believes the ability to work with low-carbon products gives his company a competitive edge. Eads said that the GH Phipps advantage over the competition has been hard-won by working with new products and building field confidence that a product can be pumped, placed, and finished reliably. New materials must meet schedule requirements for contractors to deliver on projects and win bids in the first place. As an end user, Eads is working to educate field craft about the expectation for working with these new materials. "The proper cement-to-water ratio might go against 20 years of instincts. More water is now needed to produce higher strengths, which is the opposite of what our industry has always known," Eads said.

Eads creates mockups and field prototypes to demonstrate the products' use to superintendents and project managers, who in turn teach foremen and carpenters how to work with lower-carbon materials. Regionality is another key component. "Every state's materials are different, which is another reason why it benefits owners and the industry to bring everyone into the conversation at a very early stage of discussion. This is about changing a culture and all team members need to be involved at all levels of the process."

Eads said of the July 2024 Cement and Concrete Decarbonization Meeting at NREL, which convened stakeholders from across the ecosystem, "We are all seeing the same priorities. We can't all be wrong when there are so many decades of experience in the room. We are all here to try to do a better job."

3. Resources To Accelerate Innovation and Market Acceptance

Reducing Technical Risks and Cultivating Collaboration

In the context of technical, economic, regulatory, and market forces, NREL's expertise can play an important role in overcoming the challenges that lie ahead. The laboratory gives industry partners access to the knowledge, research facilities, and networks needed to increase confidence in emerging low-carbon concrete technology solutions and investments.

NREL has a strong track record of collaborating with industry leaders to identify their most pressing needs. The laboratory's deep and extensive network of companies and investors informs new R&D with a real-world understanding of the concrete and built environment industries and the associated regulatory landscape. Working in concert with researchers in laboratory-hosted forums, stakeholders can identify and coalesce around the most promising cutting-edge technologies aligned with market pull.

As an objective research laboratory unencumbered by commercial bias, NREL provides decision-makers with scientific data to make the best choices for a successful transition to low-carbon concrete solutions. Industry can further leverage NREL expertise to verify credible field trial performance, ensure long-term durability, and diminish the risk involved in quickly deploying decarbonization technologies. NREL's ability to share data and lessons learned across aligned stakeholders, while safeguarding any proprietary intelligence, can help map a shorter path to adoption of low-carbon cement and concrete solutions.

Researching Solutions for Industry

NREL provides technology development, deployment, and accounting capabilities to help companies across the concrete value chain navigate this transition. Currently, NREL is partnering with industry and communities on three key projects that focus on the production of carbon-negative cement and concrete. These projects represent collaborations with partners across the ecosystem, from early-stage startups to large industry.

The Rapid Electrochemical Mineralization to Form Dolomite project is actively developing technologies for accelerated mineralization of mine tailings to produce carbon-negative aggregate.[15] An ARPA-E Harnessing Emissions into Structures Taking Inputs from the Atmosphere (HESTIA) project, High-Performing Carbon-Negative Concrete Using Low-Value Byproducts from Biofuels Production (LignoCrete), recently placed the first carbon-negative concrete slab at NREL.[16] Another project is informing deployment and enabling robust accounting by standardizing monitoring, reporting, and verification approaches for multiple low-carbon technologies designed to advance CO_2 curing, mineralization, and alternative supplementary cementitious materials.[17]

Advancing Startup Solutions

NREL's Innovation and Entrepreneurship Center (IEC) has more than a decade of experience working with partners to source, select, and advance startup solutions while addressing addressing market challenges.

Through technology accelerators, convened networks, and stakeholder events, the IEC is driving some of the most promising climate technology solutions from the laboratory to the market—ultimately leading to a positive impact on the environment. Key assistance to startups comes in the form of funded NREL research that advances a startup's technology readiness and reduces risk of investment and adoption. This support also establishes a route for future technology piloting at the lab, leveraging its research assets within platforms such as our Advanced Research on Integrated Energy Systems platform. The IEC creates customized programs for partners and consortia to exchange information among research, industry, and investment experts. These programs catalyze IEC relationships with startup accelerators and incubators across the country to identify emerging technology solutions.

Fundraising metrics show the strength of leveraging the DOE's $18 billion investment in NREL's facilities and expertise for de-risking startup technologies. The longest-running IEC program, the Wells Fargo Innovation Incubator ("IN^2")[18], has seen more than 80 startups complete projects at the lab. By the time these companies have exited the program in two years, they are raising more than three times the amount of funding as their non-selected peer applicants, and within six years they have raised four times more. The catalytic $250,000 in lab assistance received in IN^2 helps to unlock an average of $28 million in capital per company in six years. The IEC investor network is just as critical to this success as the lab assistance. IEC hosts events that include the Industry Growth Forum to connect investable startups with climate tech VCs from pre-seed to growth stage and beyond.

15 https://www.nrel.gov/news/program/2023/turning-mining-waste-into-sustainable-concrete-replacement.html

16 https://arpa-e.energy.gov/technologies/projects/high-performing-carbon-negative-concrete-using-low-value-byproducts-biofuels

17 https://www.nrel.gov/news/program/2024/nrel-collaborates-on-15-million-dollar-multilaboratory-efforts-to-advance-commercialization-of-carbon-dioxide-removal.html

18 https://in2ecosystem.com

Startup Perspectives: Working With NREL

Ryan Bourns, Co-Founder of Carbon Upcycling

"Carbon Upcycling has worked with NREL to progress our CO_2 capture and SCM beneficiation technology. NREL's deep technical knowledge, lab testing and validation capabilities, and network of partners has provided us with valuable validation from a trusted partner, while also giving us the opportunity to collaborate in new areas of research.

In an industry that is as driven by specifications and standards as the cement/concrete industry, NREL provides objective third-party results that meet comprehensive requirements. We look forward to continuing to work with NREL and use their expertise to validate new pathways to decarbonize the cement and concrete industry."

John Mead, CEO of Solid Carbon

"We sent two material candidates to NREL to do a full suite of analytical tests. This testing provided us phenomenal scientific backup to our approach and a deeper understanding of the nature of our materials." Solid Carbon is now working to partner with NREL on follow-on federal funding opportunities as they pursue a seed round of VC investment.

Mead says it's an exciting time to be involved in the low-carbon concrete industry. Discussions with homeowners, building owners, architects, and structural engineers indicate that there is a market hunger for these products. "A shift in the marketplace is occurring now, and historically there is an opportunity for new enterprises to grab market share. That's why we are hearing interest from strategic investors and industry partners."

Conclusion: Demand, Early Investments, and Technology De-Risking Aim to Reshape the Concrete Industry

Growing recognition of the need to reduce greenhouse gas emissions alongside the concrete industry's share of those emissions has set the stage for re-inventing how this globally dominant building material is deployed. With the expectation that end user demand will continue to grow, supported by both continuing policy support and public sentiment, industry visionaries have already adopted some emissions-reduction technologies.

Disruptive startups working toward net-zero concrete have sourced early-stage investments from the venture capital world at a rate exceeding the growth of investments in the sustainable built environment overall. While significant time, money, and development are still needed to displace all concrete emissions, NREL stands as a trusted partner and resource for developing solutions to deployment obstacles.

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