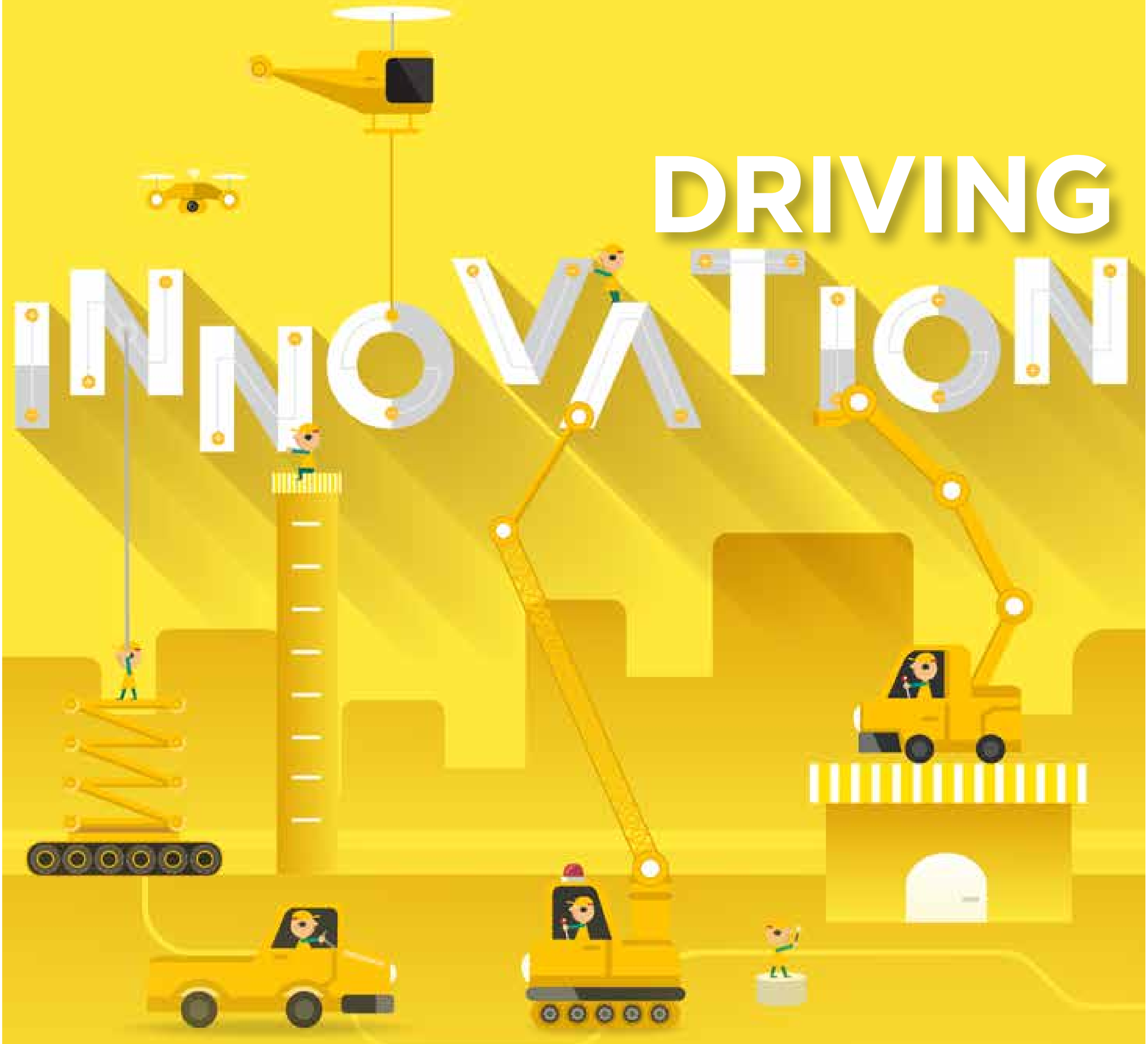
NICHOLAS DECRISTOFARO, PH.D., AND VAHIT ATAKAN, PH.D., SOLIDIA TECHNOLOGIES®, USA, DISCUSS THE TRANSFORMATION OF CO_2 INTO A PROFITABLE SOLUTION FOR THE CEMENT AND CONCRETE INDUSTRY.

DRIVING INNOVATION



Introduction

Concrete made with Portland cement is the most widely used manmade material in the world. The cement industry is the second largest emitter of CO_2 in the world. Cement manufacturers have committed to reducing their carbon footprint but are often constrained by their assets and chemistry.

The Cement Sustainability Initiative of the World Business Council for Sustainable Development set 2050 CO_2 reduction targets for the global cement industry. To this end, cement companies worldwide have followed the International Energy Agency roadmap for long-term sustainability efforts.[1] For example, Lafarge has reduced CO_2 emissions in its plants by 20% over the 2001 – 2010 period, but seeks an additional 33% reduction by 2020.

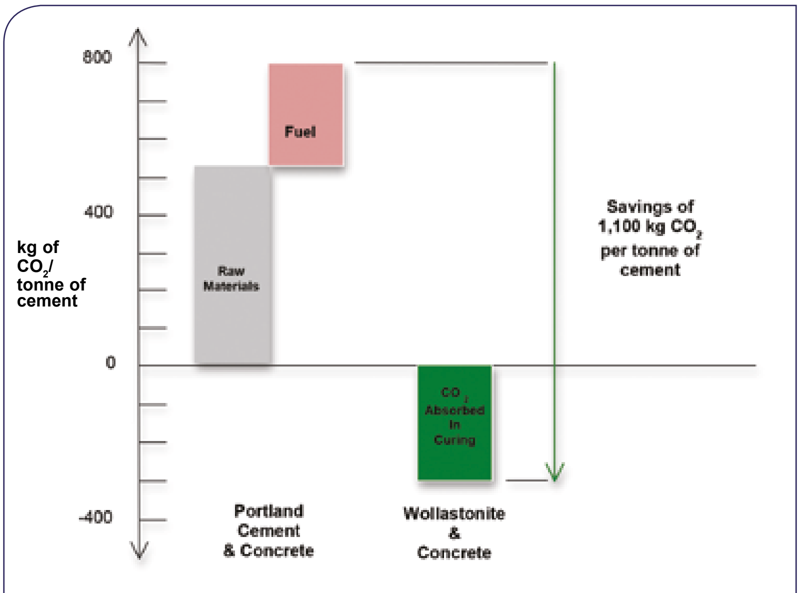


Figure 1. Raw material and fuel consumption produce CO_2 in the Portland cement and concrete case (~800 kg/t). If Portland cement is replaced with Wollastonite in concrete-based building materials, this CO_2 production is avoided and the curing reaction involving Wollastonite consumes CO_2 (~300 kg/t). The net CO_2 saved is ~1100 kg/t of Portland cement replaced with Wollastonite.

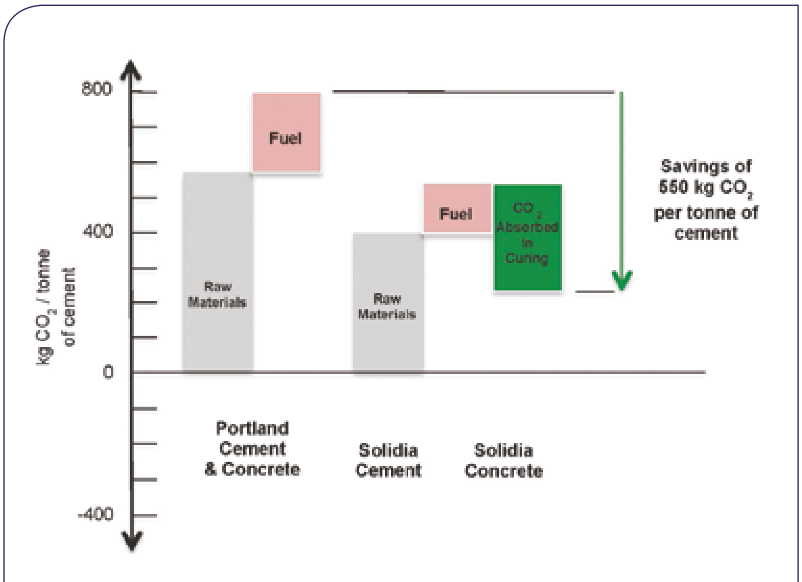


Figure 2. Raw material and fuel consumption produce CO_2 in both the Portland cement case (~800 kg/t) and the Solidia cement case (~550 kg/t). The curing reaction in the Solidia cement case consumes CO_2 (~300 kg/t) to give a net savings of ~550 kg/t.

During this same period, venture capital firms have become interested in global warming as an investment opportunity, eyeing technologies that could offer alternatives to greenhouse gas-emitting practices. Sustainable building materials such as concrete were an attractive target market because of their immense scope. However, bringing a sustainable innovation to a 2000-year-old industry is no short order; the last time the concrete industry embraced a major product innovation was close to 200 years ago with the invention of Portland cement.[2] The challenge facing innovators is not only inventing sustainable technologies, but making it possible for an established industry to economically and logistically adopt them.

While start-ups can shoulder levels of risk too destabilising to large corporations, they usually fail by running out of time. Solidia Technologies, with its novel approach to cement and concrete, has attracted a number of investors committed to sustainable innovation for their promising returns, but also as a societal imperative. These investors include Kleiner Perkins Caufield & Byers, Bright Capital, BASF, BP, Lafarge, Total Energy Ventures, Bill Joy and other private individuals. But time is still a key commodity for the start-up. Product development needs to be quickly focused and directed by market insights and hard data. Therefore, a critical element in the path to commercialisation is finding partners who can help shorten the learning curve, provide market insight, open doors and accelerate implementation.

Transforming a problem into a solution

For over 50 years, scientists have tried to cure concrete with CO_2, knowing the resulting product would be stronger and more durable. Solidia Technologies has developed processes that make this possible.

The initial concept was to bypass conventional cement manufacture altogether. Rather than making cement in a rotary kiln, the company's original strategy was to develop a mineral replacement for cement that could be used in a CO_2-cured product, with the goal of producing a carbon-negative concrete. Like many disruptive technologies, Solidia's formative concepts were generated outside the target industry, and the approach stemmed from a discipline outside the industry's traditional technology base. The original concept for Solidia came from Rutgers, the State University of New Jersey, rather than from a cement or concrete company, and the approach was developed in a Materials Science department.

The mineral Wollastonite was chosen for the initial proof-of-concept, as it occurs geologically in deposits that do not require expensive purification. It is similar in chemistry to Portland cement: both Wollastonite and Portland cement are composed primarily of calcium, silicon and oxygen, albeit in different ratios. The use of Wollastonite as a cementitious material avoids the need to manufacture ordinary Portland cement, the most energy-intensive and polluting component of conventional concrete.

To create Portland cement, one must decompose limestone to produce CaO, mix the CaO with a source of SiO_2 (such as sand, shale or clay), and then fire the CaO/SiO_2 mixture at an elevated temperature. The decomposition of limestone liberates about 550 kg of CO_2/t of cement produced. Decomposing the limestone and heating the CaO/SiO_2 mixture to its reaction temperature requires the burning of fossil fuels, which emits an additional 250 kg of CO_2/t of cement produced. Thus, the production of Portland cement emits approximately 800 kg of CO_2/t of end product.

Using one tonne of Wollastonite as a cementitious material in place of one tonne of Portland cement thereby avoids the generation of 800 kg of CO_2. CO_2-curing this Wollastonite to harden a concrete product will capture up to 300 kg of CO_2. Thus, when compared to conventional concrete, the new concrete offers the potential to reduce airborne CO_2 by 1100 kg/t of cementitious material used (Figure 1).

Figure 3. Solidia Concrete hollow core slab being removed from the extrusion bed after a 24 hour CO_2-cure.

Figure 4. Vibration casting of Solidia Concrete in a railroad sleeper ('tie') mold.

A new generation of cement

Meeting the industry's goals to reduce CO_2 emissions can only be accomplished by a new generation of cement. The research, however, unveiled practical limitations to the approach described above, such as the supply, logistics and cost of Wollastonite.

While Portland cement concrete is the most widely used building material in the world, both the concrete and cement industries are intrinsically local in nature. Concrete and cement are relatively inexpensive materials (~US$0.05/lb). The cost of transporting these materials even over short distances is prohibitive. As a result, Portland cement is made from locally available raw materials, and is rarely shipped more than 250 miles by truck or more than 1500 miles by boat. Concrete is typically made from local gravel, local sand, and locally produced Portland cement. Most concrete is hardened at the site where it is used, and, like cement, is rarely transported very far.

Wollastonite is significantly more expensive than Portland cement (>US$0.15/lb). It is also less ubiquitous. Known reserves are not necessarily located near the many points of demand for cement and concrete. In North America, for example, Wollastonite is only mined in New York State and in Mexico. Portland cement is produced at over 100 locations continent-wide.

Additionally, Wollastonite reserves are not sufficiently abundant for this mineral to be considered as a potential Portland cement alternative. Approximately 10^5 t of Wollastonite is mined and sold annually in North America. By comparison, approximately 10^8 t of Portland cement is manufactured and used each year in North America. If all of the Wollastonite mined in North America were used to replace Portland cement in the production of a new building material, the total reduction in airborne CO_2 would be limited to 1.1 x 10^5 tpy (10^5 t of Wollastonite available x 1.1 t of CO_2).

Figure 5. Cross-section of a CO_2-cured Solidia Concrete railroad sleeper.

For Solidia to have a significant global impact on lowering CO_2 emissions, it is necessary to develop an alternative cementitious material that has chemical characteristics similar to those of Wollastonite, but which can be made and consumed locally.

Working with Lafarge, Solidia has demonstrated that standard cement kilns and raw materials can be used to produce Solidia Cement™ simply by adjusting the relative amounts of the raw materials that are fed into the kiln and operating the kiln at lower reaction temperatures. While this approach does not completely avoid the decomposition of limestone and the high temperature reaction of CaO and SiO_2 associated with Portland cement manufacturing, it reduces the amount of limestone decomposed and energy consumed by 30%. This reduces the amount of CO_2 emitted from a cement plant by ~250 kg/t of cement produced. When coupled with the 300 kg of CO_2 captured during curing, the production and use of one tonne of Solidia Cement will reduce airborne CO_2 by 550 kg when compared to the production and use of one tonne of Portland cement (Figure 2).

Although the CO_2 savings associated with the use of one tonne of Solidia Cement is half that claimed for the Wollastonite example, Solidia Cement can potentially replace all of the Portland cement currently in use, as it can be made everywhere that Portland cement is made. With the broad replacement of Portland cement with Solidia Cement in North America, airborne CO_2 can theoretically be reduced by 5.5 x 10^7 tpy (10^8 t of OPC x 0.55 t of CO_2). This represents a 500x increase when compared to the Wollastonite vs the Portland cement example.

In making the shift from Wollastonite to Solidia Cement, the start-up traded the hope for carbon negativity on a small-scale (building materials made and used in close proximity to Wollastonite mines) for a 70% reduction in the CO_2 footprint of a truly large-scale application (the entire Portland cement concrete industry).

Shifting from theory to application

Solidia has engaged an array of partners to help shift a fundamental discovery from theory to application. These third party, collaborative efforts include applied research, materials testing and characterisation, manufacturing logistics and general marketing.

Lafarge Precast

Lafarge has proven to be an influential partner from both the cement and precast concrete perspectives. In addition to the cement activities described above, Lafarge Western Canada Precast operations will be an important test bed for the demonstration of Solidia Concrete™ manufacturing and performance. Much of this work is financially supported by the Alberta-based Climate Change and Emissions Management Corporation (CCEMC).

Linde

The manufacture of Solidia Concrete is accomplished primarily with the same basic raw materials used for conventional concrete, i.e., water, sand, aggregate and Solidia Cement as a direct replacement for Portland cement. The only new ingredient in Solidia Concrete is gaseous CO_2. Thus, a CO_2 supply chain to concrete manufacturers must be established and managed. The Linde Group, a global leader in the international gases market, has become a critical partner to Solidia by extending its CO_2 supply and delivery expertise to the commercialisation of Solidia Concrete.

US Department of Energy – National Energy Technology Laboratory

The US Department of Energy's National Energy Technology Laboratory has co-funded a four-year research and development project as part of its CO_2 Storage Program. That research has focused in part on improving the understanding of water distribution in Solidia Concrete during the drying and CO_2-curing process. The research demonstrated that Solidia Concrete can achieve full hardness in a time comparable to that in which Portland cement-based concrete reaches its initial hardness in a controlled curing environment. In every application studied, Solidia Concrete fully cures in less than 24 hours as compared to the curing time of 28 days required for Portland cement-based concrete to achieve final hardness. At every stage of curing, Solidia Concrete parts match or exceed the strength of comparable products made with Portland cement-based concrete.

US Environmental Protection Agency

Results of research conducted under Phase I of the Small Business Innovation Research Program of the US Environmental Protection Agency confirmed that the incorporation of supplementary cementitious materials can further reduce the carbon footprint associated with the production and use of Solidia Cement. This research demonstrated that waste materials such as ground flyash and blastfurnace slag can be used to replace Solidia Cement by as much as 40% in concrete formulations.

US Department of Transportation

The US Department of Transportation's Federal Highway Administration, through a Cooperative Research and Development Agreement, is examining transportation infrastructure applications for Solidia Concrete. This work, conducted at the Turner-Fairbank Highway Research Center, has demonstrated the basic mechanical strength and durability of Solidia Concrete. ASTM/AASHTO certified testing laboratories such as the CTL Group, formerly the R&D laboratory of the Portland Cement Association, have provided third party verification of these Solidia Concrete characteristics.

Purdue University, Ohio University and the University of South Florida

Academic partners have helped to better characterise and understand the behaviour of Solidia Concrete in actual service environments. A team led by Professors Jan Olek and Jason Weiss at the Purdue School of Engineering report Solidia Concrete's outstanding performance in freeze-thaw, freeze-thaw with deicing salts and sulfate environments. Prof. Alberto A. Sagüés heads a University of South Florida, Civil and Environmental Engineering team aimed at characterising the corrosion of steel rebar embedded in Solidia Concrete in a variety of service environments. At Ohio University's Institute for Corrosion and Multiphase Technology (ICMT), Profs. Yoon-Seok Choi, Ph.D. and Srdjan Nesic, Ph.D. are leading a group of scientists examining methods to better passivate the surface of steel rebar.

Rutgers, the State University of New Jersey

One of the last challenges for Solidia is the development of practical cast-in-place technologies for its concrete products. Long-term research addressing this topic continues at Rutgers University, under the direction of Solidia's founder, Prof. Richard Riman.

Conclusion

Solidia's R&D partnerships lend academic and industrial perspectives based on their understanding of how to address scientific issues and 'real world' demands. Driven by the company philosophy, 'It can't just be green; it has to be better,' Solidia's diverse array of R&D collaborators is helping to speed the start-up towards its vision of 'a world where CO_2 means green and sustainability is an engine for profitability and growth.'

References

1. WBSCD Cement Roadmap Targets 2010.
2. *History of Portland Cement*, Portland Cement Association.