Recognising the need to lower both its carbon and energy footprints, the cement industry actively participates in the World Business Council for Sustainable Development (WBCSD) Cement Sustainability Initiative (CSI). The WBCSD-CSI has identified four practices that can help reduce the industry’s carbon footprint:
1. improvement of energy efficiency in cement production
2. alternative fuel usage
3. substitution of clinker in the cement
4. carbon capture and storage.

Clinker substitution benefits
The cement and concrete industry has adapted clinker substitution technologies as a strategic approach to meeting its CO$_2$ reduction goals and the conservation of energy and natural resources. Using low-clinker cements can help:
• save energy
• cut pollutants
• reduce raw materials consumption
• enable the utilisation of waste products that are otherwise detrimental to the environment.

Lower CO$_2$ emissions
In recent decades the cement industry has substituted clinker with various supplementary cementitious materials (SCMs), such as fly ash, slag, silica fume, natural pozzolanic materials and fillers such as limestone. Even with these clinker substitutions, the WBCSD predicts the CO$_2$ reduction generated by producing low-clinker cements will reach only 10 per cent of the industry’s 2050 CO$_2$ reduction target.

To help the cement industry achieve its goals of energy conservation and pollutant reduction, USA-based Solidia Technologies® has developed patented processes. Produced with a non-hydraulic, lower-energy and lower-emission chemistry, Solidia Cement™ is more sustainable than ordinary Portland cement (OPC). Solidia Concrete™ is made with Solidia Cement and cures with CO$_2$ instead of water. In addition to helping meet CO$_2$ reduction goals, Solidia Concrete performs better, is more durable and cost-effective than traditional concretes, and typically cures in one day. Adaptable to the full range of concrete mix specifications, Solidia Cement also has the ability to save on the consumption of raw materials.

How is Solidia cement made?
Solidia’s patented cement chemistry and curing processes offer the building materials and construction industries the ability to manufacture cement and concrete products within existing plants and using traditional design specifications, with minimal requirements for new supply chains and capital investment. Solidia Cement is composed of a family of ‘green’, low-lime calcium silicate phases that are similar, but not identical, to the chemistry of Portland cement. As a result, it can be produced in existing cement kilns using the same raw materials that are used to make OPC, albeit in different proportions.

Carbon cure?
For concretes made with Solidia Cement, curing is achieved by a reaction between the low-lime calcium silicate compounds CaSiO$_3$ and Ca$_3$Si$_2$O$_7$, and gaseous CO$_2$ within a moist environment. Unlike its OPC-based counterparts, CO$_2$-cured Solidia Concrete does not react with water. On average, 70-80 per cent of the water used in the Solidia Concrete formulation can be recovered during the CO$_2$-curing process. The remainder of the water is retained in the concrete and can be recovered if needed.¹

Solidia Concrete derives its strength from the formation of CaCO$_3$ (calcite) and SiO$_2$ (silica gel), as given below in Equations 1 and 2. The overall curing
reaction is succinctly written as:

\[ \text{Eq 1} \quad \text{CaSiO}_3 (s) + \text{CO}_2 (g) \rightarrow \text{CaCO}_3 (s) + \text{SiO}_2 (s). \]

\[ \text{Eq 2} \quad \text{Ca}_2\text{SiO}_3 (s) + 3\text{CO}_2 (g) \rightarrow 2\text{CaCO}_3 (s) + 2\text{SiO}_2 (s). \]

No water is consumed in either reaction. The curing reaction is exothermic and releases -87kJ/mole of heat. The heat generated during the reaction is dissipated by the evaporation of water. The curing process is controlled by counter diffusion of CO₂ and H₂O molecules.

The ability of Solidia Cement to avoid hydration and cure via a reaction with gaseous CO₂ opens the possibility for the permanent sequestration of CO₂ in the cured concrete structure. The curing process described in Equations 1 and 2 enables Solidia Concrete products to sequester between 250-300kg of CO₂/t of Solidia Cement used in the concrete formulation. Depending on the specific ratios of fine and coarse aggregate and Solidia Cement used in the concrete mix, the final Solidia Concrete part may contain between about 3-7 weight per cent of sequestered CO₂.

Working with Lafarge as an R&D partner, 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 a lower reaction temperatures. While this approach does not completely avoid the decomposition of limestone and the high-temperature reaction of CaO and SiO₂ associated with Portland cement manufacturing, it reduces the amount of limestone decomposed and energy consumed. In combination with the capture of 300kg of CO₂ during curing, the production and use of 1t of Solidia Cement will reduce airborne CO₂ by 550kg when compared to the production and use of 1t of OPC (see Figure 1). This CO₂ saving is equivalent to a clinker factor of between 0.33-0.39 in a Portland cement-based system.

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 alone, airborne CO₂ can theoretically be reduced by 55Mta (1bt of OPC x 0.55t of CO₂).

The inclusion of all the SCMs, namely fly ash, bottom ash and slag, led to improvements in the workability of Solidia Cement mortars, especially when class F fly ash was used, suggesting a reduction in the overall water demand in the mixtures thereby allowing for more rapid curing. Solidia Cement can be partially replaced with slag, class F and class C fly ash. The amount of replacement depends on the product and can be as high as 40 weight per cent.

**Linking sustainability and performance**

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 SCMs can further reduce the carbon footprint associated with the production and use of Solidia Cement. The research demonstrated that waste materials such as fly ash and ground granulated blast furnace slag can be used to replace Solidia Cement by as much as 40 per cent in concrete formulations. When the ability to replace Solidia Cement clinker with moderate amounts of fly ash and blast furnace slag are considered, the total CO₂ savings associated with Solidia Cement production and use can be further reduced, resulting in further reduction in clinker factor. That Solidia Concrete also performs better, is more durable and cost-effective than traditional concretes, opens the potential to added value beyond that of low-clinker cements. Also, depending on the product, Solidia Concrete typically cures in one day, as opposed to the up to 28 days required for curing traditional concretes. The time saving in the curing process translates into costs saving for the producers.

This new, alternative process offers cement and concrete manufacturers another sustainable and potentially-profitable route to achieve the IEA’s CO₂ emissions reduction goal.

**References**

1. Water Savings in Concrete Made from Solidia Cement™, April 2014.
2. Use of Supplementary Cementitious Materials in High Performance, CO₂ Sequestering Construction Material, EPA Extramural Research Contract Number