

ECOConcrete – Reducing the Carbon Footprint of Concrete Based Coastal and Marine Infrastructure

Technical Memo #0817

In Short

A concrete Problem

Scientists claim that at least 5% of humanity's carbon footprint comes from the concrete industry, both from energy use and the carbon dioxide byproduct from the production of cement, one of concrete's principal components.



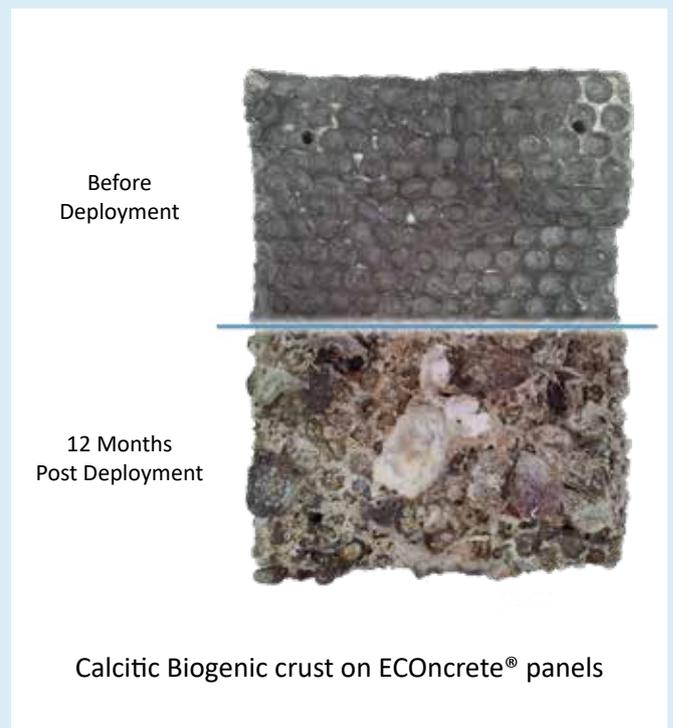
Concrete is the main construction material globally, accounting for over 70% of Coastal and Marine Infrastructure (CMI) such as ports, coastal defence structures and waterfronts. Standard Portland cement based concrete CMI support low biological diversity and are typically dominated by nuisance and invasive species.



100% Cover of invasive Zebra mussel on coastal infrastructure in the Great Lakes

ECOConcrete® Low Carbon Solution

ECOConcrete®'s bio-enhancing concrete products have a reduced carbon footprint compared to Standard Portland cement based concrete, due to a combination of proprietary admix integrating by-products and recycled materials, and unique ability to enhance biological processes such as biocalcification and photosynthesis which facilitate CO₂ assimilation.



A Concrete Problem

With nearly 60% of the human population living along coastlines^[1], coastal development, and increasing coastal urbanization are inevitable. Concrete is the main construction material globally, accounting for over 70% of Coastal and Marine Infrastructure (CMI)^[2]. Nonetheless, it is a poor substrate for biological recruitment, and is considered toxic to many marine organisms mainly due to its unique surface chemistry which impairs the settlement of various marine larvae^[3-6]. Subsequently, concrete based CMI commonly attract low diversity biological communities which are primarily dominated by invasive species and very different to those typical in natural habitats^[7,8].

Concrete's carbon footprint is fairly large due to two factors^[9]:

- 1) The use of fossil fuels in the burning process to heat limestone (CaCO_3) in kilns to form CaO , one of the major components in concrete cement.
- 2) The large quantities of carbon

dioxide released during calcination, the conversion of limestone to CaO proceeds.

According to the most recent survey of Portland Cement Association (PCA), an average of 927 kg (2044 lb) of CO_2 are emitted for every 1000 kg (2205 lb) of Portland cement produced in the U.S.^[10].

Low Carbon Solution

ECOcrete® offers science based solutions that reduce the ecological footprint of CMI, through a suite of high performance environmentally sensitive concrete technologies that enhance the biological and ecological value of CMI, while increasing their strength and durability.

An innovative combination of bio-enhancing concrete admixtures, increased micro and macro surface roughness, and unique 3D designs, enhance the growth of diverse marine plants and animals on ECOcrete® products. These organisms provide a wide array of biological and ecological advantages, including high biodiversity, enhanced

ecosystem services, improved aesthetics, and Bioprotection due to the biological communities encrusting the concrete^[11,12].

A significant environmental advantage of ECOcrete® technologies is a substantial reduction of carbon footprint in all of the company's products. This is due to two main pathways: 1) the unique properties of ECOcrete's admix, which integrates by-products and recycled materials, 2) biological processes including calcification by organisms such as oysters, corals and tube worms and the primary production by photosynthetic organisms through marine flora.

Reduced Carbon Footprint through ECOcrete® Admix:

While the terms cement and concrete are often used interchangeably, cement is an ingredient of concrete that, when mixed with water, sand and gravel, forms concrete. Concrete has a high carbon footprint mostly due to high

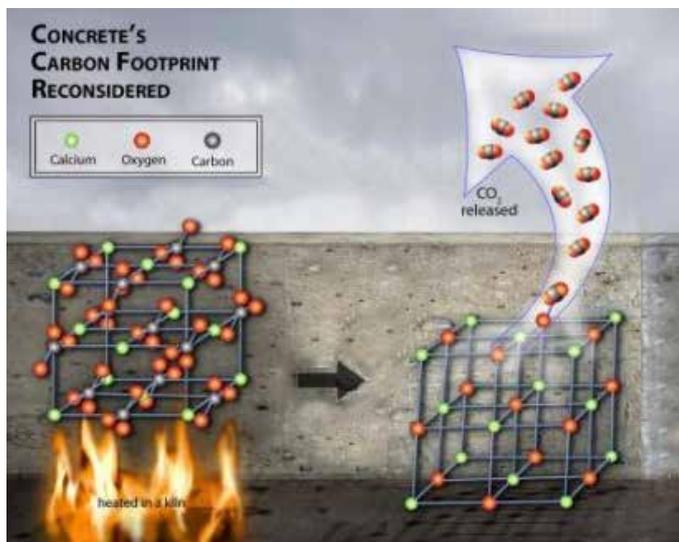
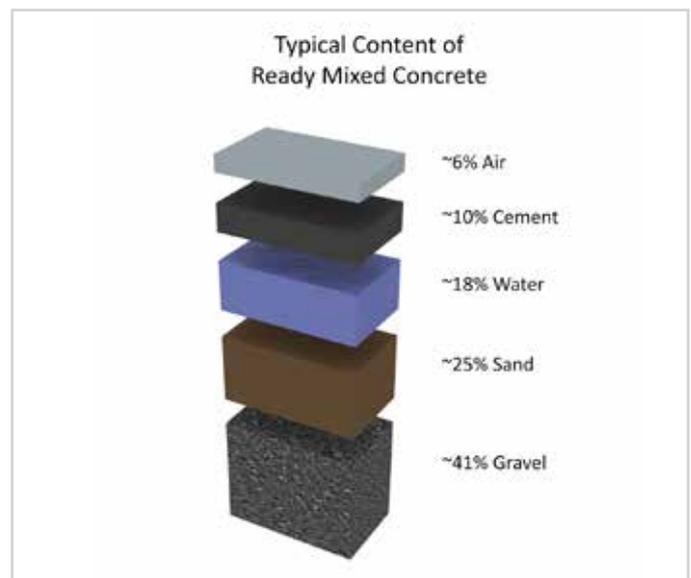


Figure 1 Credit: Zina Deretsky, National Science Foundation^[9].



content of Portland cement within it. Between 50%-60% of the CO₂ emitted during the production of cement is a result of calcination of calcium carbonate's raw materials, the remaining CO₂ emitted result of the burning of fossil fuels^[13].

ECONcrete® addresses the global need for reducing the carbon footprint of CMI by significantly reducing the amount of Portland cement in the mix compared to standard marine grade concrete. This is achieved by replacing portions of the cement with supplementary cementitious materials (SCMs). The use of SCMs in concrete work in combination with Portland cement is performed to improve strength and durability, in addition to reducing the CO₂ embodied in concrete by as much as 70%, with typical values ranging between 15 and 40%^[13]. The SCMs utilized in ECONcrete® products are various calcium carbonate based pozzolans, mostly, industrial byproducts which would otherwise end up in landfills.

Moreover, all of ECONcrete®'s products are manufactured using slag cement (containing ground granulated blast-furnace slag - GGBS) further reducing the products' CO₂ footprint. Slag cement is commonly used as a partial substitute for Portland cement in concrete at a replacement level of up to 50%. When slag cement replaces 50% of the Portland cement, greenhouse gas emissions per cubic yard of concrete are reduced by 45%^[14]. For example, while an average of 931 kg of CO₂ are emitted for every 1000 kg of ordinary Portland cement, GGB emits only 26.5 kg^[15].



ECONcrete® Tide Pool blooming with green algae

As ECONcrete® admix uses innovative combinations of slag cement with SCM, we are able to produce concrete products that have as much as 80% less carbon footprint compared to standard Portland cement based concrete products.

Carbon Footprint Reduction through Biological Processes

The oceans are a significant sink for atmospheric CO₂, removing approximately 30% of current anthropogenic CO₂ emissions^[16]. In addition, certain biological processes facilitate carbon assimilation and uptake.



ECONcrete® armor unit showing high oyster coverage.

Carbon is assimilated into skeletons of marine organisms like oysters,

corals, tube worms, coralline algae, and barnacles, in a process called biocalcification^[17]. As an integral part of the organism's growth, it produces a calcitic skeleton. As evident from the chemical equation of the process:

- (1) CO_{2(g)} ↔ CO_{2(aq)}
- (2) CO_{2(aq)} + H₂O ↔ H₂CO₃
- (3) H₂CO₃ ↔ HCO₃⁻ + H⁺
- (4) 2HCO₃⁻ + Ca²⁺ ↔ CaCO₃ + H₂O + CO₂

Two CO₂ molecules are used for generating CaCO₃. Of which, one is assimilated into the CaCO₃ and the other is released as CO₂. The bottom line is that for each unit of CaCO₃ produced, Dissolve Inorganic Carbon (DIC) is reduced by one unit and alkalinity by two units.

While clearly for every mole CaCO₃ formed, one mole of CO₂ is produced, yet another CO₂ is embedded into the CaCO₃ formed. Frankignoulle Pichon^[18] notes that due to the buffering capacity of the seawater, the ratio between CO₂ released and CaCO₃ participated is about 0.6. Nonetheless, the released CO₂ is mainly converted to HCO₃^[19], and In the short term (hours to days), some or all of the CO₂ liberated during carbonate deposition may be absorbed by biological processes on the reef^[20].

The potential carbon storage in calcitic skeletons of marine organisms is vast. One Calcium carbonate molecule (composed of 1 Calcium atom [40.078 g/mole], 1 Carbon atom [12.011 g/mole] and 3 Oxygen atoms [47.997 g/mole]) have a molecular weight of 100.086 g/mole. Thus, in every 1000 g of CaCO₃, 120 g of Carbon are stored.

For example, in crushed whelk shells CaCO₃ accounts for 95% of the shell material^[21]. With one gram of CaCO₃ containing 0.119 g carbon (by division of molecular weights), it was estimated that for each tone of shell material there is 0.091 tone of avoided CO₂ emissions^[22]. Similarly, Ware and Smith^[20] assessed a reasonable regional average for gross CaCO₃ production of reef provinces (as defined in Smith^[23]) is approximately 1.5 [±0.5]kg CaCO₃ m⁻²y⁻¹ corresponds to 180 [± 60]g C m⁻²y⁻¹.

Sella and Perkol-Finkel^[24] demonstrate that ECOcrete® units enhance growth of engineering species such as oysters, serpulid worms, bryozoans and coralline algae significantly more than control Portland cement units. These engineering species (oysters, serpulid worms, barnacles and corals) deposit CaCO₃ skeletons onto hard surfaces thus creating valuable habitat to various organisms^[25] while also contributing to the structures' strength, stability and durability^[11].



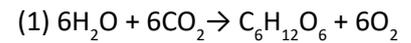
Calcitic growth on ECOcrete® units

According to Perkol-Finkel and Sella^[3] biocalcification onto ECOcrete®'s M4 bio-enhanced units averaged at 659.51 g m⁻²y⁻¹ in temperate Mediterranean Sea environment, and 249.72 g m⁻²y⁻¹ in a tropical Red Sea environments, with maximal values reaching 1000 g m⁻²y⁻¹. This rate corresponds to **maximal storage of 120 g of Carbon for every square meter of ECOcrete® infrastructure yearly.**

Notably, in the same study, values of biocalcification on control Portland cement based concrete units were significantly lower, averaging 334.48 g m⁻²y⁻¹ in temperate, and 168.68 g m⁻²y⁻¹ in a tropical environments.

Obviously the amount of CaCO₃ produced varies from one ecosystem to another, and depending on community structure. For example, Hily^[17] calculated the CaCO₃ production of various calcified species along the rocky shores of Brittany, France, and found that in sheltered sites, oyster CaCO₃ production rates were 2390 g CaCO₃ m⁻² y⁻¹. Values for coralline algae vary from 10 to 10,000g CaCO₃ m⁻²y⁻¹ in tropical areas^[26], and remain lower in temperate waters (876g CaCO₃ m⁻² y⁻¹)^[27].

Photosynthesis performed in the marine environment mostly through macro and micro-algae, seagrasses and via symbiotic algae such as the ones residing in coral tissue, acts as a CO₂ sink, through the formation of organic matter:



Photosynthesis also removes CO₂ from shallow ocean waters, and downward flux of the organic compounds generated through the process can effectively store CO₂ in the deep ocean for hundreds of years^[28].

According to Perkol-Finkel and Sella (2014) ECOcrete®'s bio-enhanced units had a significantly higher Chlorophyll a content compared control Portland cement based concrete units, which is indicative to enhanced primary production through photosynthesis. This was true for both temperate and tropical environments. Thus, **ECOcrete® has the potential to enhance photosynthesis compared to "gray" concrete, thus further reducing the structures' carbon footprint by harnessing natural processes.**

1 km ECOcrete seawall* = 2 ton CO₂/ Year = **400 trees****

* For a 7 m tall seawall
** Average 20kg/Year CO2 absorbed per adult tree <http://urbanforestrynetwork.org>

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