Cost Benefit Analysis for NJ's Low-Carbon Concrete Bill A5223/S3732

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Revised August 3, 2021

Prepared at the request of Sen. Bob Smith, Environment & Energy Committee Chair

The benefits of low-carbon concrete include reduced CO_2 emissions, jobs from making new materials, and reduction of wastes like glass and biosolids. Most of this document addresses CO_2 emissions reduction. An example bidding process is included in section 5 (p. 6).

Sourcing materials locally reduces transportation emissions and cost and also creates jobs. Currently, the concrete industry sources cement, fly ash, and steel slag from out of state as there are no cement, coal, or steel plants in NJ. New low-carbon concrete materials are either made in NJ or could be, if anticipated demand drives new plant construction here. For example, Aries Clean Energy, which makes a bio-based fly ash from biosolids, has a plant in Linden and has plans for 4-5 more in NJ (100 construction jobs and 20-25 permanent jobs per plant). Carbon Upcycling Technologies, which mineralizes CO_2 onto fly ash, natural pozzolans, and post-consumer glass, received funding from NYSERDA to add their equipment to a plant in NYS in the next year (50 construction jobs and 4 permanent jobs). Urban Mining CT makes ground glass pozzolan from post-consumer glass at their new plant in CT (12 permanent jobs). Let's get plants built in NJ!

One low-carbon concrete company, Solidia, is based in New Jersey. Solidia employs 70 people and is expected to grow. (It currently has 3 job openings.) It licenses its technology to cement and precast concrete companies as a replacement for existing equipment. Solidia collaborates with Rutgers for R&D and relies on ancillary services in the community such as testing labs.

CO_2 emissions reduction

In putting together this analysis, I gathered what information I could from low-carbon concrete vendors and an early adopter customer in NJ (Clayton Concrete). In some cases, information is not available because the products are not on the market yet. The numbers I gathered are not standardized and should be taken as rough estimates. The numbers are expected to change over time as technologies mature. Perhaps the most telling information is from Port Authority and the Netherlands, which both indicate that 30% emissions reductions are achievable for no additional cost.

Total lifecycle cost depends on more than just the materials - it also depends on the strength and durability of the concrete. Many materials substituted for cement to reduce emissions also increase strength and durability. Stronger concrete means less material is needed, which reduces short-term cost and emissions. More durable concrete means it needs to be repaired or replaced less often, decreasing long-term cost and emissions. Some low-carbon concrete vendors, such as Solidia customer EP Henry and ground-glass pozzolan vendor Urban Mining CT, report that their products are more resistant to de-icing salt, which is concrete's primary durability challenge. Transportation costs are also a factor, so local plants for materials are preferable. Numbers below reflect increased strength where indicated but do not reflect increased durability.

Emissions and cost depend on the specific mix of concrete. For the calculations below, I'm assuming:

- 400 kg CO2 is emitted per cubic yard (cy) of traditional concrete (p. 23) (strength 4001-5000 PSI)
- Concrete costs $125/cy.
- Ordinary Portland cement (OPC) accounts for 88% of the average traditional concrete mix's emissions, or 352 kg CO2/cy concrete.
- 922 kg is CO2 emitted per tonne of OPC.
- OPC costs $124/tonne
- A typical concrete block, or concrete masonry unit (CMU), costs $1.75 and has associated emissions of 2 kg.

When I needed to refer to a mix design, I used the left Blue Planet example for 5000 PSI strength at the end of this document. Specifically, this adds the following assumption:

- 404 kg cement/cy concrete

Tonne refers to a metric ton. **SCM** stands for supplementary cementitious material (cement substitute). **CCUS** stands for carbon capture, utilization, and storage.

1. Organizations Already Incentivizing or Mandating Low-carbon Concrete

Organization	Cement CO2 reduction	Concrete cost impact	Cost/tonne CO2 reduced	comment	reference
Port Authority of NY/NJ requires at least 30%	30%+	none	none	>= 30% SCM required since mid-1990s; working with academia to analyze innovative	Colin Reed[1], Manager of Physical Testing and

[1] "According to local suppliers, the market varies for slag and fly ash, but both are still less than the cost of cement. Slag might be a little more expensive than fly ash right now. Some suppliers may charge by the Design compressive strength, which would vary the cost for different mixes." 6/16/21

SCM				mixes/new materials as part of their Clean Construction Program, expected by end of 2021	Dorian Bailey, Senior Environmental Project Manager, PANYNJ
The Netherlands' CO2 Performance Ladder		none	none	Has had up to 10% discount since 2009	Maude Vastbinder, Program Administrator, SKAO

2. Reduced emissions, without CCUS - up to a 5% bidding discount

Material	Cement CO2 reduction	Concrete cost impact	Cost/tonne CO2 reduced	comment	reference
Fly ash	Up to 80%, but typically under 50%	none	none	Reduced future availability due to coal plant closures, increased cost if taken from landfills and cleaned	Casey Clayton, Clayton Concrete; MIT CSHub Figure 2
25% steel slag	Up to 25%	up to 5%	$71	Maximizes the discount; % slag could go up but cost impact would be higher than discount; cost impact accounts for improved strength	Casey Clayton, Clayton Concrete
Portland limestone cement (PLC)	10-15%	2%	$47-71	Recently approved by NJDOT; can be used with SCMs	Dan Schaffer, Sales Manager, Lehigh Cement Co. in PA
Metakaolin clay	Up to 10%			High price, rarely used	Casey Clayton, Clayton Concrete

Silica fume	Up to 10%			High price, rarely used	Casey Clayton, Clayton Concrete; SE Solutions
Ground glass pozzolan (GGP) - new material	Up to 50% (gross)	Up to 2%	$15	CT plant; GGP costs 10% more than cement; includes emissions from grinding glass	Patrick Grasso, owner, Urban Mining CT (maker of Pozzotive)
Biochar fly ash - new material	Up to 29%	Up to 2%	$46-62	Aries has 1 NJ plant, want 4-5 more; assumes up to 35% cement replacement and and 160 kg emissions per tonne biochar	Joel Thornton, Business Development Manager, Aries Clean Energy

3. Reduced emissions with CCUS for ready-mix - Mineralizing CO2 into the concrete qualifies for an additional discount of up to 3%, for an 8% maximum total bidding discount

company	Cement CO2 reduction	Concrete cost impact	Cost/tonne CO2 reduced	comment	reference
Carbon Upcycling Technologies' enhanced fly ash - new material	25% (includes 20% less cement and 5% CCUS)	+-5%	$71 savings to $71 cost/tonne	mineralized fly ash; 40% stronger; cost varies with regional market	Madison Savilow, Chief of Staff, Carbon Upcycling Technologies
CarbonCure	5%	<2% more	<$142 asked for $100/tonne in Stripe application	CO2 injected during mixing; can be used in combination with SCMs; accounts for increased strength;	Eric Dunford, Dir. of Sustainability, CarbonCure; Stripe application

				installed in 2 NJ plants through equipment leasing	
Blue Planet - new material	100% or more (carbon negative)	Not available yet	Not available yet	mineralized aggregates negate cement's emissions; 776 lbs (352 kg) CO_2 uptake/cy concrete; pilot plant operational by end of 2021	Brent Constanz, CEO and Laura Berland-Shane, VP Government Affairs, Blue Planet; Matthew Kamine, KDC Ag (NJ partner)
Carbon8 - new material	Up to 68%			mineralized biochar fly ash and industrial wastes to form aggregates, with up to 34% uptake by mass; <600 lbs (272 kg) CO_2 uptake/cy concrete	Carbon8 information sheet and Blue Planet mix example

4. Reduced emissions with CCUS for pre-cast blocks and pavers - maximum 8% bidding discount, also qualifies for tax incentives under A4933/S3091

The following options need to be cured with CO_2 in a controlled environment (pre-cast) so they do not work for ready-mix concrete, which is poured on-site and represents the bulk of the concrete market. These companies license their technology, so they do not have direct control over pricing. Their customers have both capital and operating expenses.

CMU stands for concrete masonry unit, or concrete block.

company	CO2 reduction	CMU cost impact	Cost/tonne CO2 reduced	comment	reference
Solidia - new material	30% less emissions from the cement kiln and 21% uptake of CO2 by weight from curing	Not available	Not available	in NJ; alternative cement; licenses their technology	Devin Patten, Director, Technology Deployment, Solidia
Carbicrete - new material	150% (carbon negative); 2 kg abatement + up to 1 kg CO2 mineralized (stored) per block; 2.5-3 kg net per CMU	5-10% higher for blocks; none for pavers; 10-20% lower materials cost; cost expected to be up to 30% lower in the future as cement costs rise and their technology matures; equipment purchase and licensing fee	$29-58	Pilot project is underway; carbonated steel slag replaces cement; fast curing; up to 30% stronger; licenses their technology; Carbicrete planning to sell carbon offsets	Chris Stern, CEO, Carbicrete; concrete makers web page and datasheet
CarbonBuilt - new material	60-80% due to new concrete formulation (~50%) and curing with flue gas (~20%); reduces OPC by 60-80%, adds 30-40% portlandite plus slag/ash	10-20% lower materials cost, 7-15% operating cost reduction; allows use of low-quality (cheaper) fly ash; capital expenditures balanced by savings; potential for increased profit margin	Expected to be none	Early phase business with two demonstration plants; working to improve process efficiency; asked Stripe for $260/tonne	Rahul Shendure, CEO, CarbonBuilt; technology web page, Stripe application (contains detailed forward-looking pricing information on p. 14)

5. Hypothetical bidding process

The following illustrates a hypothetical bidding process for 100 cubic yards of ready-mix concrete with 35% SCM, based on the numbers provided above. The discount percentage is proportional to the GWP reduction from 400 kg/cy.

Bid #	CO2 reduction method	$ bid	GWP kg/cy	Discount %	Discounted bid
1	35% fly ash	$12,500	277	3.5	$12,039
2	35% fly ash with CarbonCure (CCUS)	$12,750	259	7.2	$11,831
3	35% biochar fly ash	$12,750	298	2.9	$12,361
4	PLC with 35% fly ash	$12,750	233	5	$12,113
5	35% GGP	$12,938	286	3.4	$12,241
6	none	$12,500	400	0	$12,500

The discount percentage was calculated along a linear scale from 233 to 400 GWP. Bid 2 was given the full 3% CCUS discount on top of a 4.2% GWP discount. (The exact method of determining the discounts is controlled by the Treasurer and DEP. The bill only states the maximums of 5% and 3%.) The winning bid is bid #2 with fly ash and CarbonCure, which is a $250 or 2% price increase. (It needed at least a 1.6% CCUS discount to win the bid.)

If the CCUS discount were changed to be a more general breakthrough technology discount (as in the NYS version of this bill), bids #3 and #5 would also qualify for up to 3% additional discount. Assuming that they receive the same additional discount as bid #2, bid #2 still wins. Bid #3 (biochar) needs an additional discount of 2.6% to beat bid #1, and bid #5 (GGP) needs a 1.7% additional discount to beat bid #1.

6. Example mix design

The slide below shows the Blue Planet example referred to previously, showing carbon-negative concrete with Blue Planet aggregates on the left and CO2 injection (assumed to be CarbonCure) on the right. It is from a presentation given by Blue Planet's CEO, Brent Constanz. I used the mix design on the left for the biochar fly ash and Carbon8 calculations. (On April 1, 2021, the Canadian Standards Association released CarbonStar technical specifications for measuring and verifying concrete carbon intensity. See carbonstar.org for more info.)

Mix Design Examples

CONCRETE PROPERTIES		100% Replacement of Coarse and Fines		
Mix Details		Design (lb/cy)	Volume (cf)	CS Rating
Coarse Agg.	GM Pumice LWA	0	0	0
Coarse Agg.	$CaCO_3$-Aggregate (100% CaCO3)	706	7.34	-310
Fine Agg.	$CaCO_3$-Mixed Sand (100% CaCO3)	1058	9.05	-466
Cement	Hanson Type II/IV*	890	4.53	596
Water		295	4.73	0
Target Compressive Strength (psi)		5000		
Target Slump (in.)		5-6		
CARBONSTAR (lb CO_2/cy)		-180		

CONCRETE PROPERTIES		CO2 Injection (7% Cement Replacement)		
Mix Details		Design (lb/cy)	Volume (cf)	CS Rating
Coarse Agg.	GM Pumice LWA	604	6.24	0
Fine Agg.	Orca Sand	1480	9.05	0
Cement	Hanson Type II/IV*	828	4.28	554
Additive	CO2 Injection	62	0.25	-62
Water		295	4.73	0
Target Compressive Strength (psi)		5000		
Target Slump (in.)		5-6		
CARBONSTAR (lb CO_2/cy)		488		

*Assumed cement plant efficiency: 0.67 lb CO2/lb cement

Blue Planet