Site-Specific Carbon Uptake Estimation of Crushed Concrete at End-of-Life

MIT CSHub Research Brief
Gwyneth Margaux Tangog, Pranav Pradeep Kumar,* Randolph Kirchain, Hessam AzariJafari
*Corresponding Author, pranavpk@mit.edu

MIT CONCRETE SUSTAINABILITY HUB

This research brief builds on the models described in the brief "Towards Accurate End-of-Life Carbon Uptake Modeling: Impacts of Crushed Concrete Gradings on Cement Paste Content and Degree of Carbonation", which is recommended to be read first.

Need for a context-specific model for crushed concrete uptake

Crushed concrete rapidly sequesters CO_2 from the atmosphere due to its large surface area. As such, firms that properly manage crushed concrete can receive financial incentives (carbon credits) for their operations. Over the last year carbon credits have averaged $80-120 per ton of CO_2 [1–3] in the United States.

The amount of **carbon uptake**[a] that occurs in crushed concrete at **end-of-life** (EOL) is influenced by several factors, including the binder system (e.g., cement type, use of supplementary cementitious materials (SCMs)) and binder content, time (or stockpiling period), space (or stockpiling area), particle size, and exposure conditions. While there are existing models that estimate EOL uptake [4], a holistic approach to consider the critical aspects of crushed concrete stockpiling, including **stockpiling period**, **stockpile geometry**, **particle size**, and **exposure conditions**, is needed.

To address this gap, the MIT Concrete Sustainability Hub has developed a detailed, context-specific approach to estimate the carbon uptake of a concrete recycling operation. This brief describes the findings from applying that model to assess the impacts of changes in time (stockpiling period), space (stockpile size and geometry), and particle size of crushed concrete. Each of these changes can add costs to a concrete recycling operation. As such, our question is how these changes can increase CO_2 sequestration and, therefore, potential carbon revenues. These results highlight the value of investing in at least one of the three factors (time, space, or particle size) during the stockpiling period to help neutralize a portion of concrete's carbon emissions and maximize financial returns for an operation.

Modeling EOL carbon uptake of crushed concrete

Figure 1 on the following page shows a schematic of the methodology used to model EOL carbon uptake. According to Stripple et. al. (2021) [4], only the outer 30 cm of a crushed concrete stockpile reacts with CO_2. To obtain the volume of this outer 30 cm, stockpiles were modeled as a stylized truncated cone. This was followed by a gradation analysis to evaluate the paste percentages and carbonation levels expected at different particle sizes. For visualization purposes, this schematic shows only three particle sizes.

However, in the analysis, 10 particle sizes from the site-specific gradation report were used to maximize accuracy. The cement content based on

Key Takeaways:

- The method described here can be used to optimize the carbon revenues from stockpiling crushed concrete by investing in holding time, space, and/or finer crushing.
- Modeling the end-of-life carbon uptake of a case study of recycled aggregate production shows that increasing the stockpiling period from 0.5 months to 1 month can increase the carbon uptake by 41%.
- Reducing the maximum crushed concrete size from 2 inches to 1 inch increases carbon uptake by 28%.
- Spreading crushed concrete to achieve a maximum stockpile height of 1 m can increase carbon uptake from 1.2 to 5.3 $kgCO_2/m^3$ over 0.5 months.

Demolished concrete structures generate large volumes of crushed concrete, which are often reused or recycled in new construction as part of a circular economy. Due to the large surface area to volume ratio of crushed concrete, it can sequester a significant amount of atmospheric carbon dioxide. The CSHub has developed a model examining the impacts of crushed concrete grading on cement paste content and degree of carbonation. We highlight the value of investing in the factors that influence CO_2 sequestration to earn more potential revenue from carbon credits

Image Source: Iowa Department of Transportation the **paste percentage**, along with the **degree of carbonation**, is used to calculate the total carbon uptake per particle size, which is summed to determine the total carbon uptake using the model described in Pradeep Kumar et al. (2025) [5].

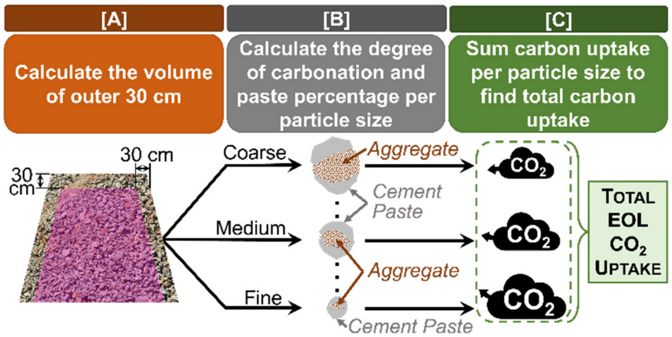


Figure 1: Schematic representation of the methodology with the three steps: [A] Calculating the outer 30 cm (unshaded) volumes of the stockpiles. [B] Calculating the degree of carbonation and the paste percentage per particle size. [C] Summing all carbon uptake values to find the overall carbon uptake rate per stockpile.

Implementing the methodology to estimate site-specific EOL carbon uptake

The framework described above is used to determine the EOL carbon-uptake potential of the stockpiles shown in Figure 2 below. The impacts of time, space, and particle size are evaluated, and the findings are presented below. The binder system is assumed to consist solely of cement. The following results represent the total uptake across all of the stockpiles shown in Figure 2.

Figure 2. Plant site with stockpiles that were used for this study. The carbon uptake of concrete is highest at the end-of-life phase, when it is crushed and the surface area is maximized. A model is developed to measure the carbon uptake of concrete at end-of-life, accounting for time, space, and particle size.

1. Effect of Time

Figure 3 on the right shows the effect of the duration of stockpiling from 0.5 months to 12 months on EOL carbon uptake. Under current practice, crushed concrete is typically stockpiled for less than a month. Increasing the stockpiling period from 0.5 months to 1 month can increase uptake by 41% (i.e., from 18 to 25 metric tons CO_2).

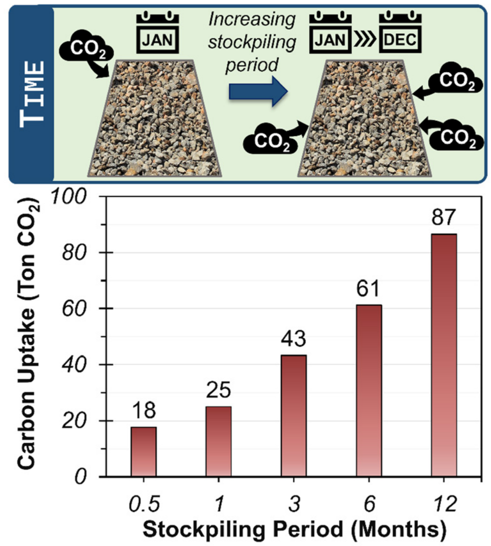


Figure 3. Effect of stockpiling time on the carbon uptake of the stockpiles in Figure 2.

2. Effect of Particle Size

To study the impact of grading on uptake, we vary the maximum particle size from 0.5 inches to 3 inches. Figure 4 below shows the effect of particle size on EOL carbon uptake. Reducing the maximum particle size increases carbon uptake. Reducing the maximum particle size from the standard 2 inches to 0.5 inches increases carbon uptake by 54%, i.e., from 25 to 38 tons of CO_2 over a one-month stockpiling period.

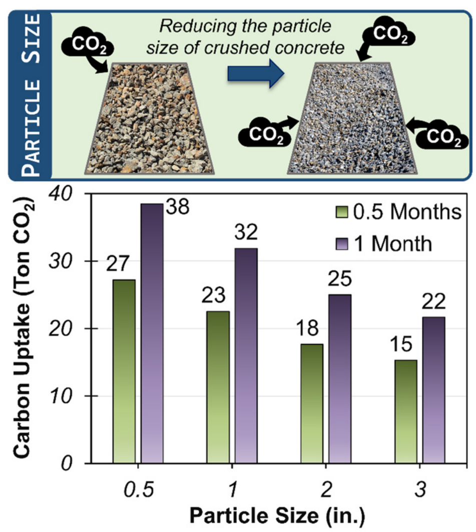


Figure 4. Effect of particle size on the carbon uptake of the stockpiles in Figure 2.

3. Effect of Space

To study the impact of increasing available stockpiling space, the stockpile height for each stockpile shown in Figure 2 is reduced from their actual height (this varied between 1.1-7.7 m at the time of this study) to a height of 1 meter. To maintain the same volume of material, this requires spreading the stockpile over a greater area. Figure 5 on the next page shows the effect of reducing stockpile height and, therefore, spreading the crushed concrete stockpile. Spreading the material and lowering the stockpile height increases carbon uptake per unit volume. Specifically, spreading the crushed concrete can increase the uptake by 340% in 0.5 months, i.e., from 1.2 to 5.3 kg CO_2/m^3. As the stockpiling period increases, the change is more drastic. While the relative increase is still 340%, in 12 months, the change is from 5.9 to 26 kg CO_2/m^3.

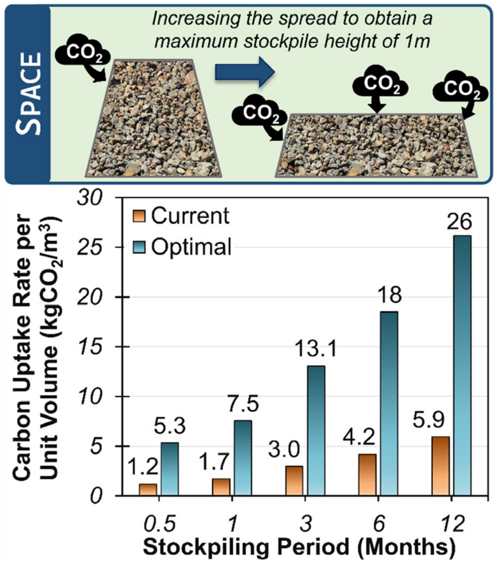


Figure 5. Effect of space on the carbon uptake rates per unit volume of the stockpiles in Figure 2.

Discussion and Broader Impacts

The context-specific approach for estimating carbon uptake underscores the importance of investing in time, space, and grain crushing to optimize EOL carbon uptake. **Changing from current practices can significantly increase the carbon credits that stakeholders can generate.** These results, and the approach that underlies them, can be used by stakeholders to develop a strategy that balances the increased costs associated with crushing, real estate, and holding time against the potential carbon credit revenue.

Table 1 presents the results of a comparative study evaluating EOL carbon uptake between a reference and an improved stockpile configuration. In the reference case, the crushed concrete had coarser particles (7.5 cm), with a stockpile height of 4 m and a stockpiling period of only 0.5 months. Under these conditions, the total EOL carbon uptake was estimated at 630 kg CO_2. In contrast, the improved case featured finer particles (0.5 inch), a lower stockpile height of 2 m, and an extended stockpiling period of 3 months, resulting in uptake of 4,610 kg CO_2 – an increase of more than 7 times.

The outcomes of this case study demonstrate the critical role of particle size, stockpile geometry, and exposure time in improving uptake. From an economic standpoint, the improved case could yield carbon credits valued at $0.35 to $0.52 per ton of crushed concrete, compared to just $0.04 to $0.06 per ton of crushed concrete in the reference case (assumptions for the carbon credit are $200-300[b] per ton CO_2 sequestered [6]). Crushed concrete often sells for $5 to $15 per ton [7]. For firms that properly manage their stockpiles, **carbon credits could add up to 10% to the revenue for this product** without significantly adding to processing costs. These results highlight environmental and financial benefits from optimizing crushed concrete stockpile conditions, reinforcing the case for integrating EOL carbon uptake strategies into sustainable demolition and recycling practices.

Acknowledgement

The authors would like to thank CEMEX for sharing the site-specific stockpile data that enabled the end-of-life carbon uptake study. The data shared was indispensable to the analyses and interpretations presented.

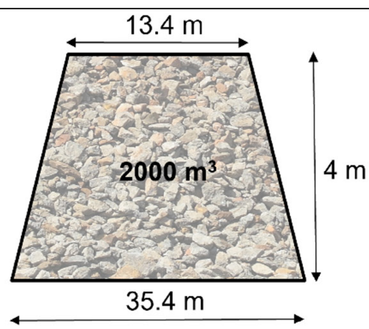
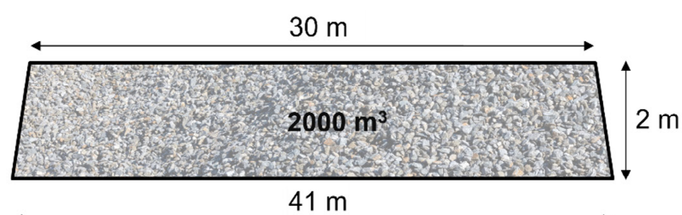
	Reference Case	Improved Case
Stockpile Geometry		
Particle Size	3 in.	0.5 in.
Stockpiling Period	0.5 months	6 months
EOL Uptake	630 kg CO_2	6,520 kg CO_2
Carbon Credits	$126 - $189	$1,304 - $1,956

Table 1. Comparison of EOL carbon uptake between reference and improved stockpile configurations.

Endnotes

[a] Carbon uptake is the natural process by which carbon dioxide reacts with components in cement to form different types of calcium carbonate. This permanently neutralizes some carbon dioxide from the atmosphere.

[b] Values have been running around $50-$180 per ton of CO_2, but most experts believe that a $200-$300 price is likely as firms tighten carbon emissions.

References

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Citation

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