Life Cycle Carbon Uptake of the United States Pavement Network

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Concrete Pavements: A Carbon Sink

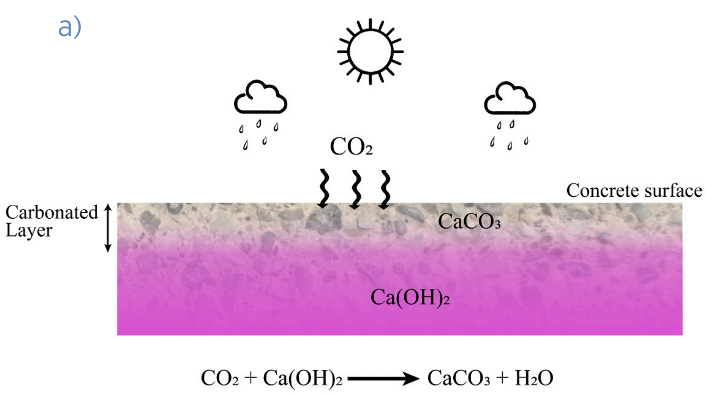
Carbon uptake in concrete occurs in a process known as carbonation, in which atmospheric CO_2 reacts with a portion of CaO in concrete binders and results in the formation of calcium carbonate. Concrete has, therefore, received attention as a potential carbon sink, especially in pavements, whose substantial exposed surface areas can maximize carbon uptake.

While carbonation rates in concrete pavements depend on many competing mechanisms, such as surface condition, concrete constituents, and climate conditions (Andersson, Stripple et al. 2019), three mechanisms, in particular, have not received adequate consideration in prior research on network-level carbon uptake. These three mechanisms are pavement design and network characterization, variation in binders and their chemical properties, and the influence of shape, cost, and timeframe of concrete stockpiling on end-of-life uptake.

This study takes a bottom-up approach using state-level data to estimate the carbon uptake of U.S. pavements and its associated cost with particular attention paid to variations in pavement networks and design, binders, and end-of-life uptake.

Key Takeaways:

- The U.S. pavement network can absorb 5.8 million tons CO_2 (around 5.5% of emitted CO2 from the cement used in pavements) over the next 30 years.
- The carbon uptake proportion of the use and end-of-life phase are in the same order.
- End of life abatement could be more cost-effective than carbon capture, use, and sequestration, with median costs ranging from \$25–100/ton CO_2 in the U.S.



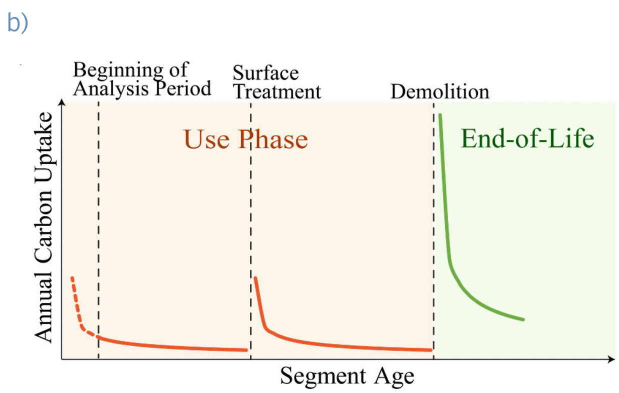


Figure 1. Schematic of a) the carbonation process and b) the annual uptake variation for a segment of a pavement network.

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Methodology

To estimate the carbon uptake of the U.S. pavement network, we first developed and incorporated a pavement management system (PMS) model. In this model, the pavement treatment actions are scheduled according to the segment condition and the performance of the segment surface condition is predicted to feed the budget allocation model and treatment decision trees.

In this study, the US pavement network, comprising more than three million miles of pavement, was divided into 10-mile segments. We predicted the timing of maintenance and repair schedules as well as the performance of pavements using the locally practiced decision-making trees and data science approaches. We either adopted or inferred required input data for the PMS model from FHWA databases (FHWA 2013, Schwartz, Elkins et al. 2015, FHWA 2020). In the second step, we adapted a carbon uptake model from the Annex BB of European standard EN 16757 (BSI 2017) to calculate the total concrete carbon uptake. Then, we developed and applied a material flow analysis framework to link the cost associated with the end-of-life carbon uptake. Uncertainty related to the material constituents and properties, climate condition, and geometry of end-of-life stockpile were propagated using 5000 Monte Carlo simulations. Figure 1b shows an overview of the methodology and the steps for the calculation of the use phase and end-of-life carbon uptake.

Evaluating Carbon Uptake

The probabilistic results of carbon uptake in the use and end-of-life stages of the U.S. pavement network are presented in Figure 2. The median results show that from 2020 to 2050, around 2.8 Mt CO2 uptake is expected from the nationwide network of concrete pavements during the use stage of their life cycle (see figure 2a). Considering a two-year stockpiling period for the demolished materials after treatment actions, a 3.0 Mt

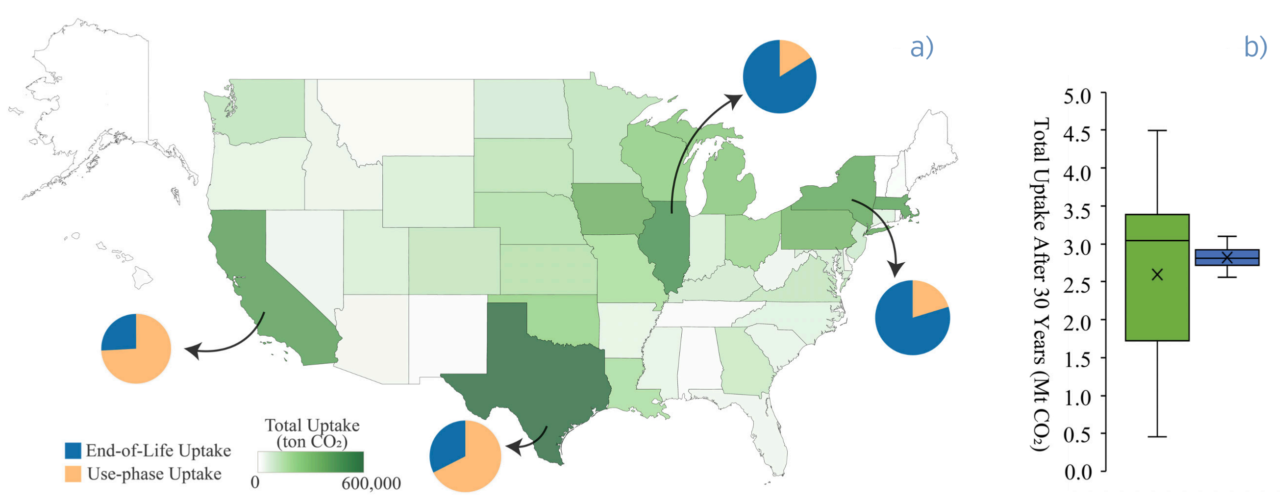

Figure 2. a) State-level carbon uptake of the U.S. pavements in use and end-of-life phases for the 30-year analysis period and b) Cumulative carbon uptake in the use (Blue) and end-of-life (green) stages. In the box whisker plots, the ends of the box are the 25th and 75th percentiles, the median is marked by a horizontal line inside the box, the mean is marked by an "x", and the whiskers are the two lines outside the box that extend to the minimum and maximum values.

CO2 can be sequestered by the demolished concrete rubble (Figure 2b).

Hence, the median of the total carbon uptake of the U.S. pavement network is 5.8 Mt. This uptake value is equivalent to 5.5% of the GHG emissions associated with the cement consumed for these pavements during this 30-year period.

Figure 3 presents the variation in end-of-life uptake and cost over the 30-year analysis period. Figure 3a shows the probabilistic uptake amount and Figure 3b shows the associated stockpiling cost as a function of time stockpiled. Over the analysis period, end-of-life uptake would total 11.8 Mt CO2 while the median abatement cost could start at $25/ton CO2 and stay under $100/ton CO2 until 17 landfilling years.

It should be noted that if the demolished concrete is processed and stockpiled at a recycling plant, there may not be any additional cost for the deposit. However, depending on the context, there might be certain costs associated with the stockpiling. For example, municipalities can charge $12 per ton of concrete deposited in a landfill (Salt Lake County 2020). Regardless, the median costs of stockpiling currently make carbonation more cost-effective than carbon capture, use, and sequestration.

a) b)

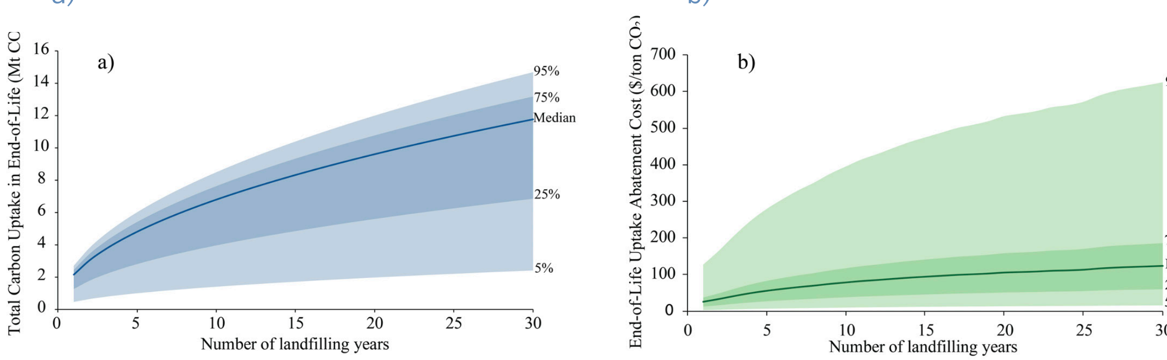

Figure 3. Effect of stockpiling time on a) total sequestered carbon and b) carbon abatement (stockpiling) cost during a 30-year analysis period. Dark and light-shaded areas represent the 25-75% and 5-95% interpercentile range, respectively, and continuous curves represent the median results.

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