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Carbon Sequestration of Concrete Masonry Products

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Agenda:

- Embodied carbon and reducing Carbon Footprint
- Carbon Sequestration Cycle
- Carbonation Potential of Cement
- Measuring the Rate of Carbonation of CMU
- Carbon Sequestration Research
- Future Research Plans / Summary

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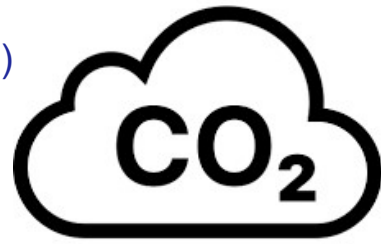
What is Embodied Carbon?

…aka carbon footprint
…aka carbon dioxide emissions (CO_2)
…aka carbon dioxide equivalent emissions (CO_2e)
…aka greenhouse gases
…aka global warming potential (GWP)
…aka ……



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What is Embodied Carbon?

Embodied carbon (measured in kg CO_2e) is the Carbon dioxide equivalent emissions associated with:

- Extraction and manufacturing of materials and products
- In-use maintenance and replacement
- End-of-life demolition, disassembly and disposal
- Including transportation relating to all stages

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Concrete is Everywhere

- Concrete is the ***most used material*** on the planet (besides water)
  - 10X more than any other construction material
- ***Modern society depends*** on its flexibility and ***versatility*** to build:
  - Durable Structures
  - Roads and Bridges
  - Other infrastructure (water and sewer systems, etc.)
- ***Cement*** is the ***key ingredient*** that makes concrete work

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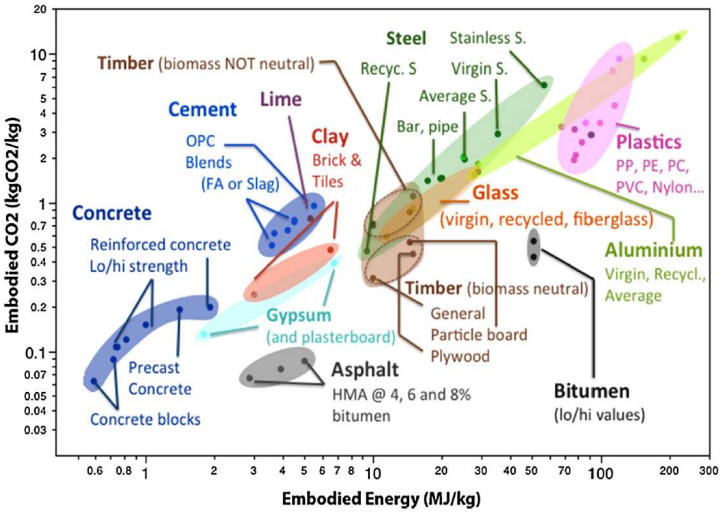
Concrete is Everywhere

- ***Concrete*** has the ***lowest embodied CO_2*** and energy of all construction materials
- Because concrete is the ***most used*** construction material it has a ***significant impact*** on the ***world's overall carbon footprint***
- ***80 to 85%*** of the ***carbon footprint of CMU*** is due to the ***cement***



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Cement and CO_2

- The cement industry produces about 1.25% of U.S. and 5 to 8% of global man-made CO2 emissions, of which 50% is from the chemical process, and 40% from burning fuel.
- The amount of CO2 emitted by the cement industry is nearly 90 lb of CO2 for every 100 lb of cement produced.
- Manufacturing industries across the world are finding new ways to reduce their carbon footprints. For their part, cement manufacturers are committed to reach carbon neutrality by 2050
- Because of the large amount of cement used worldwide, even a small reduction in the CO2 footprint will have a major impact on overall carbon emissions

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Carbon Sequestration Cycle

- Yes, CO_2 is released during cement production…but some of that ***CO_2 is reabsorbed*** by the concrete once placed in service
- This reabsorption of CO_2 is called ***Carbon Sequestration*** or ***Carbon Uptake***

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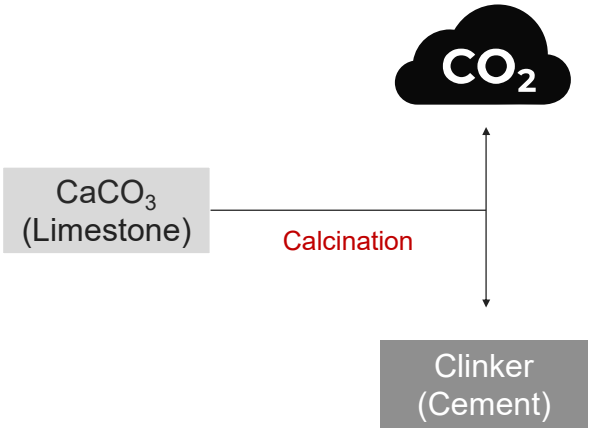
Cement production releases CO_2



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Clinker image - https://commons.wikimedia.org/wiki/File:کلینکر_سیمان.JPG

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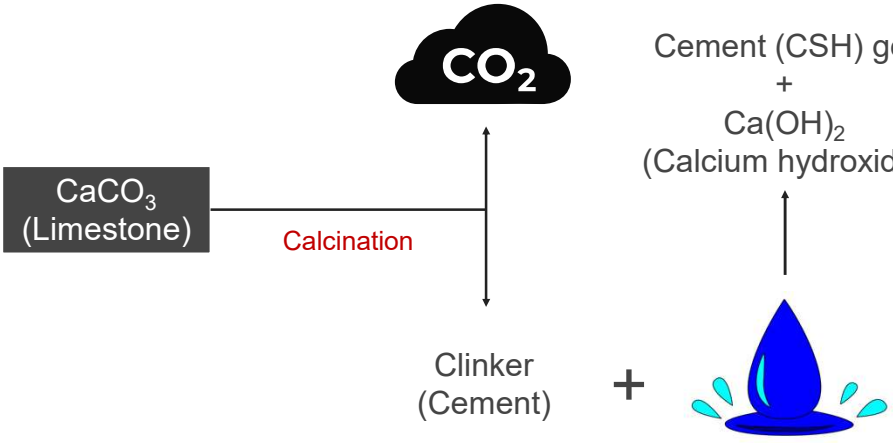
Carbon Sequestration – Cement hydration reabsorbs CO_2



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Droplet image - https://commons.wikimedia.org/wiki/File:Water_Droplet.svg

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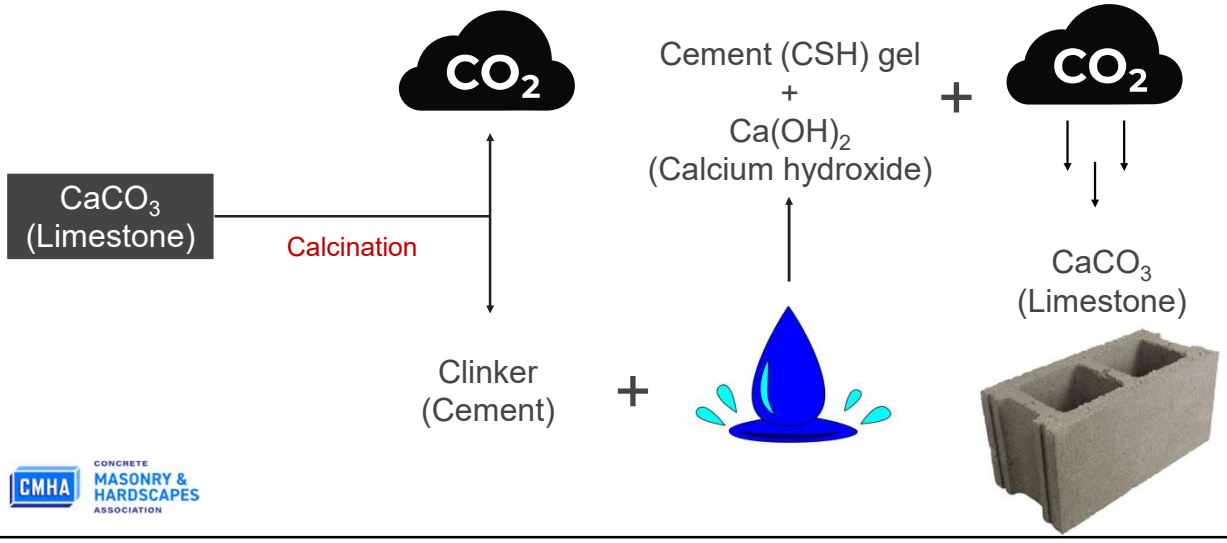
Carbon Sequestration –
Cement hydration reabsorbs CO_2



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Carbon Sequestration –
Determining the natural carbonation rate of CMU

- While it was well known that **concrete carbonates**, we didn't have a good baseline for ***natural*** dry-cast concrete carbonation
- To generate the baseline, we needed to determine the ***Carbonation Potential*** of the cement and measure the ***Rate of Carbonation*** of CMU over time

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Carbon Sequestration – Calculating the Carbonation Potential of Cement

- The ***Carbonation Potential*** is the total amount of CO_2 that the cement could reabsorb if all of the calcium hydroxide and cement (CSH) gel fully reacted with the CO_2
- This potential will depend on the **particular chemistry** of the cement but can be theoretically ***calculated for any cement***

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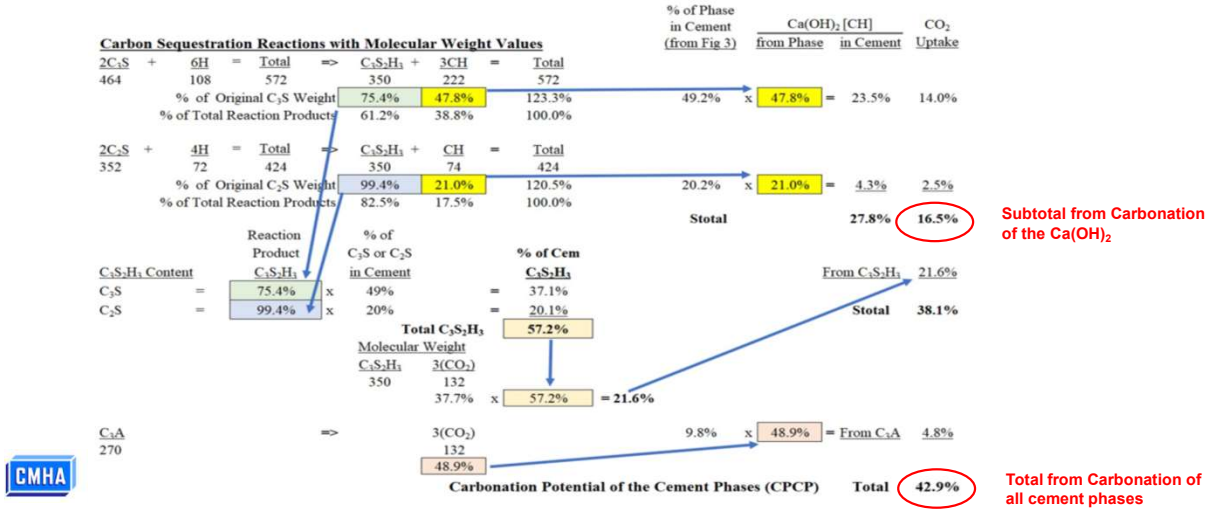
Carbon Sequestration – Calculating the Carbonation Potential of Cement



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Carbon Sequestration –
Measuring the Rate of Carbonation of CMU

- The ***Rate of Carbonation*** of 'regular' ***wet-cast concrete*** has been widely studied. The rate is ***generally fairly slow (1 to 5 mm/year)*** depending on a number of factors including composition, curing, and permeability of the concrete.
- The ***Rate of Carbonation*** of ***dry-cast concrete*** has ***not*** been widely studied
- NCMA (CMHA) undertook research starting in 2020 and presented the results at a ***2022 ASTM Masonry Symposium***

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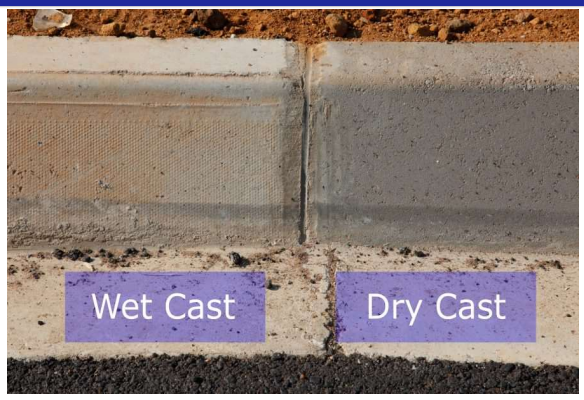
Carbon Sequestration –
Dry-Cast vs. Wet-Cast Concrete

The ***assumption*** was that ***dry-cast and wet-cast*** concrete ***carbonate*** at ***roughly the same rate*** and therefore sequester about the same amount of CO_2



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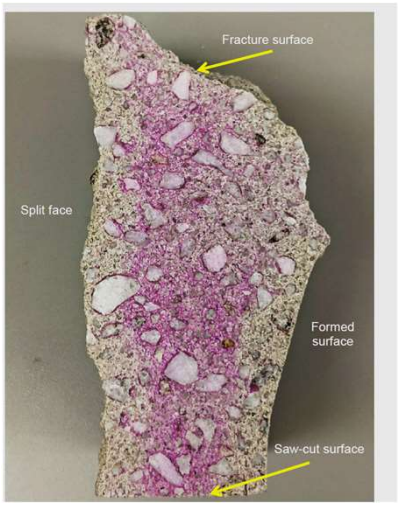
Carbon Sequestration –
Dry-Cast vs. Wet-Cast Concrete

- In ***reality***, ***wet-cast and dry-cast*** concrete ***carbonate*** at ***vastly different rates***



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Carbon Sequestration –
Dry-Cast vs. Wet-Cast Concrete

- NCMA (CMHA) research also focused to quantify the ***rate and amount of CO_2*** a concrete block ***naturally sequesters*** when exposed to the atmosphere

Set 6 4 Week | Set 6 13 Week | Set 6 26 Week

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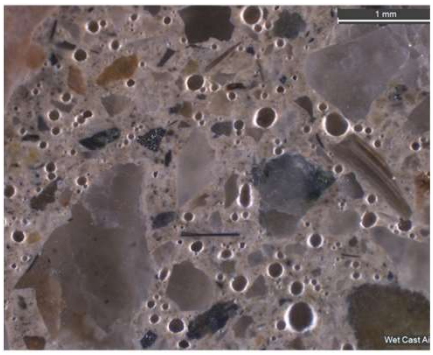
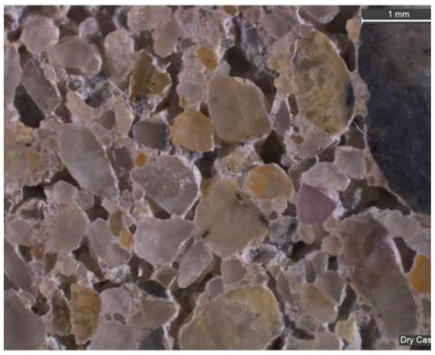
Carbon Sequestration –
Dry-Cast vs. Wet-Cast Concrete

Results are showing ***dry-cast CMU sequester substantially more CO_2*** compared to wet-cast concrete…largely attributed to the ***interconnected void structure*** of dry-cast concrete



Wet-Cast



Dry-Cast

Photos courtesy of ACM Chemistries

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Carbon Sequestration Research
Measuring the Rate of Carbonation of CMU

- During the research initiated by NCMA (CMHA) ***CMU*** were collected from producers ***across North America*** along with the ***raw materials (cement and aggregate)*** and the mix designs used in the CMU
- An analytical method call ***Thermogravimetric Analysis (TGA)*** was used to determine the amount of ***CO_2*** that was ***bound in the concrete***
- After correcting for the CO_2 that was initially bound in the raw materials – this yielded the amount of ***CO_2 that was reabsorbed*** due to ***carbon sequestration***

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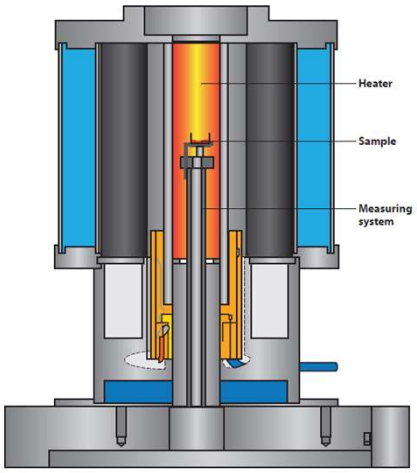
Carbon Sequestration Research
TGA – Thermogravimetric Analysis

- Essentially, a ***microbalance*** surrounded by a ***programable furnace***
- A small sample is heated to ***very high temperatures***
- The sample ***weight loss*** increases as different components are 'burned off'



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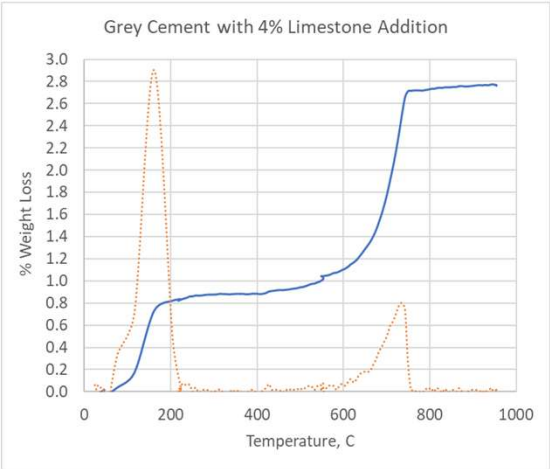
Carbon Sequestration Research
TGA – Thermogravimetric Analysis

- Commonly used to ***characterize portland cement***
- Temperature is ramped between plateaus at 45, 220, 550 and 950 °C
- ***CO_2 off-gassing*** occurs between ***550 and 950 °C***
  - Used to quantify the purity and amount of limestone added to the cement



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Carbon Sequestration Research
CMU Sample Preparation

- ***CMU stored*** in the exterior yard at ***NCMA lab***
- ***Nine sets*** were included in the study
- ***Face Shell Coupons*** were harvested at ***various ages*** (4, 13, 26 weeks plus 1 & 2 years [after paper was written])
- Coupons were ***vacuum-sealed*** to stop further carbonation

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Carbon Sequestration Research
CMU Sample Preparation / TGA – Analysis

- A ***3 to 5-mm slice*** was cut from the center of each coupon, dried at 45 °C, ground and ***analyzed by TGA***
- ***Results*** are ***'corrected'*** to account for the ***background CO_2*** in the ***raw materials*** and proportions of those materials in the mix design
- The end objective is to measure and report the ***net CO_2 sequestered***…not the latent CO_2 in the samples.

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Carbon Sequestration Research
Raw Material Background Determination

Mix Design	NW		CO_2 Loss from TGA 550 - 950 °C, %	
Mix Design				
	lb/batch	% of Total Weight	Gross in Raw Material	CMU Matrix
Conc Sand	3920	62.8%	0.664	0.417
Pea Stone	1825	29.3%	1.201	0.351
Cement	494	7.9%	1.484	0.118
Total	6239	100.0%		**0.886**

← Total Background CO_2 Loss due to Raw Materials in CMU Matrix

	% of Total Sample Weight (550 C - 950 °C Loss)		
Gross CO_2 Loss of CMU	4 Week	13 Week	26 Week
Gross % of Total Weight	1.697	2.087	2.538
Net CO_2 Loss of CMU			
% of Total Weight	0.81	1.20	1.65

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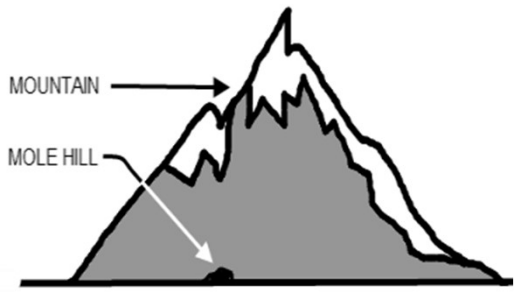
Carbon Sequestration Research
Raw Material Background Determination

TGA Limitations – Limestone Aggregate:

- ***TGA won't work*** well if the CMU contains ***limestone aggregates***
- This is because the amount of ***CO_2 in the limestone aggregate***, 40+% (the 'mountain'), ***overwhelms and drowns out the signal*** from the CO_2 sequestered by the CMU, 1 to 3% (the 'molehill')
- Nonetheless, ***CMU with limestone aggregates still sequester CO_2*** – we just can't use TGA to measure it



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Carbon Sequestration Research
Results – Equivalent Expressions

	% of Total Sample Weight (550 C - 950 °C Loss)		
Gross CO_2 Loss of CMU	4 Week	13 Week	26 Week
Gross % of Total Weight	1.697	2.087	2.538
Net CO_2 Loss of CMU			
% of Total Weight	0.81	1.20	1.65
% of Cement Weight	10	15	21
% of Potential Carbonation	24	35	49
kg per m^3 of Concrete	17	26	35
lb of CO_2 per SqFt	0.34	0.51	0.69

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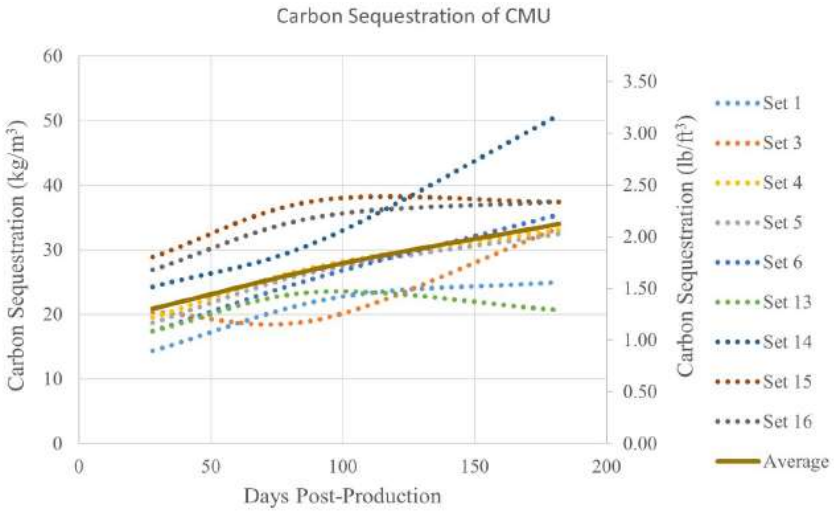
Carbon Sequestration Research
Early Results in ASTM Paper

Paper "published" through ASTM summarize results through 26-wks:

28 Day Uptake:
21 kg/m^3 or 25% of potential

26 Week Uptake:
34 kg/m^3 or 41% of potential



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Carbon Sequestration Research
Latest Results

- Original nine sets have now reached ***2 years*** of age
- The ***average results fit a logarithmic model*** with a very high degree of correlation
  - Model shows ***high level of sequestration early*** on with diminishing but significant ***additional sequestration over longer time periods***
- ***Model can predict*** approximate carbon uptake levels ***5 to 25 years out***

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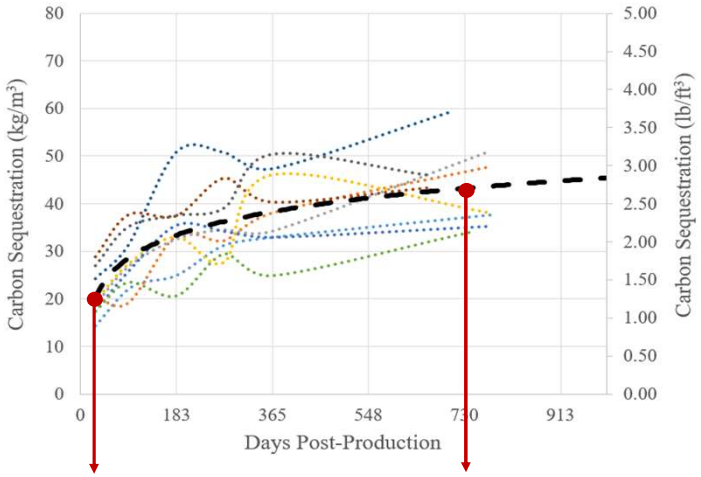
Carbon Sequestration Research
Latest Results

Average results (from model)

- 28 days - 21 kg/m^3 - 25% of potential
- 26 weeks - 33 kg/m^3 - 40% of potential
- 1 year - 38 kg/m^3 - 46% of potential
- 2 years - 43 kg/m^3 - 52% of potential

Projected results (from model)

- 5 years - 50 kg/m^3 - 61% of potential
- 20-25 yrs - 60 kg/m^3 - 73% of potential



28 days = 21 kg/m^3 2 years = 43 kg/m^3

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Carbon Sequestration Research
Future Research Plans

- Measure carbon uptake of CMU from ***Day 1 to Day 28***
- Assess ***effect of exposure conditions*** on uptake rate
- Measure carbon uptake of ***hardscaping products***
  - ***Pavers***
  - ***Segmental Retaining Wall units (SRW)***

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Carbon Sequestration Research
Summary & Discussion

- Research undertaken by NCMA (CMHA) has refined an analytical test method using ***Thermogravimetric Analysis (TGA)*** to measure the ***carbon sequestration of concrete after manufacture***.
- The research has documented that ***CMU*** have a ***high amount*** of carbon sequestration ***during early life*** averaging ***25% of the total Carbonation Potential after 28 days***
- Diminishing but significant ***additional sequestration continues*** over longer time periods and reaches approximately ***50% of total Carbonation Potential at 2 years***

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Carbon Sequestration Research
Summary & Discussion

- This behavior is ***different than*** what is experienced by ***'regular' wet-cast*** concrete for two reasons:
  - ***Dry-cast*** manufactured concrete is much ***more permeable to CO_2*** from the air because of its ***inter-connect void structure***
  - The ***geometry of the CMU*** (1 – 1.5 inch thick face shells and webs with hollow cores) ***exposes much of the concrete*** to CO_2 even when stacked in the yard ***during storage***
- Research will continue on CMU and will be started on ***Pavers and SRW*** units

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Carbon Sequestration Research

Questions?

Thank you!

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