Laboratory for the Chemistry of Construction Materials

UCLA Samueli School of Engineering

CarbonBuilt

NATIONAL ENERGY TECHNOLOGY LABORATORY

Achieving Unprecedented CO_2 Utilization in CO_2Concrete™: System Design, Product Development and Process Demonstration

Project Number: DE-FE0031915

Project Manager: Isaac “Andy” Aurelio

Prepared by: Dr. Dale Prentice, Dr. Manas Sarkar, Prof. Dante Simonetti and Prof. Gaurav Sant

Institute for Carbon Management (ICM)

UCLA Samueli School of Engineering

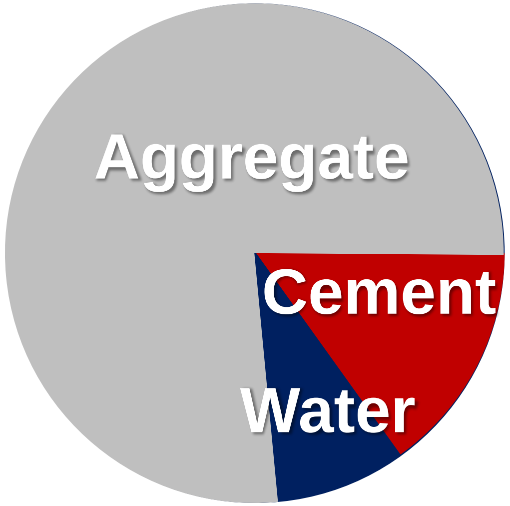
Prepared for: 2023 Carbon Management Research Project Review Meeting

August 30th, 2022

Where: Pittsburgh, PA

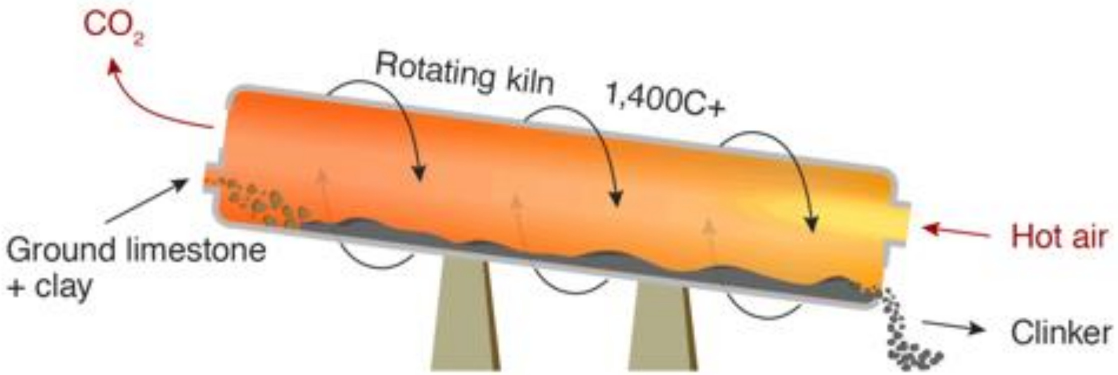
The problem at hand – CO_2 emissions from cement/concrete

- **Concrete ~ 8% of global CO_2 emissions**
  - Most widely used substance after water
  - 90% of emissions from production of cement
- **No broadly-applicable alternatives**
  - 2x the combined volume of steel, plastics, wood, aluminum
- **CO_2 curing appears promising, but…**
  - Enabling materials have been expensive or scale-limited
  - Traditionally has required concentrated and purified CO_2
- **Large-scale demonstrations needed**
  - Technology feasibility needs to be rigorously proven



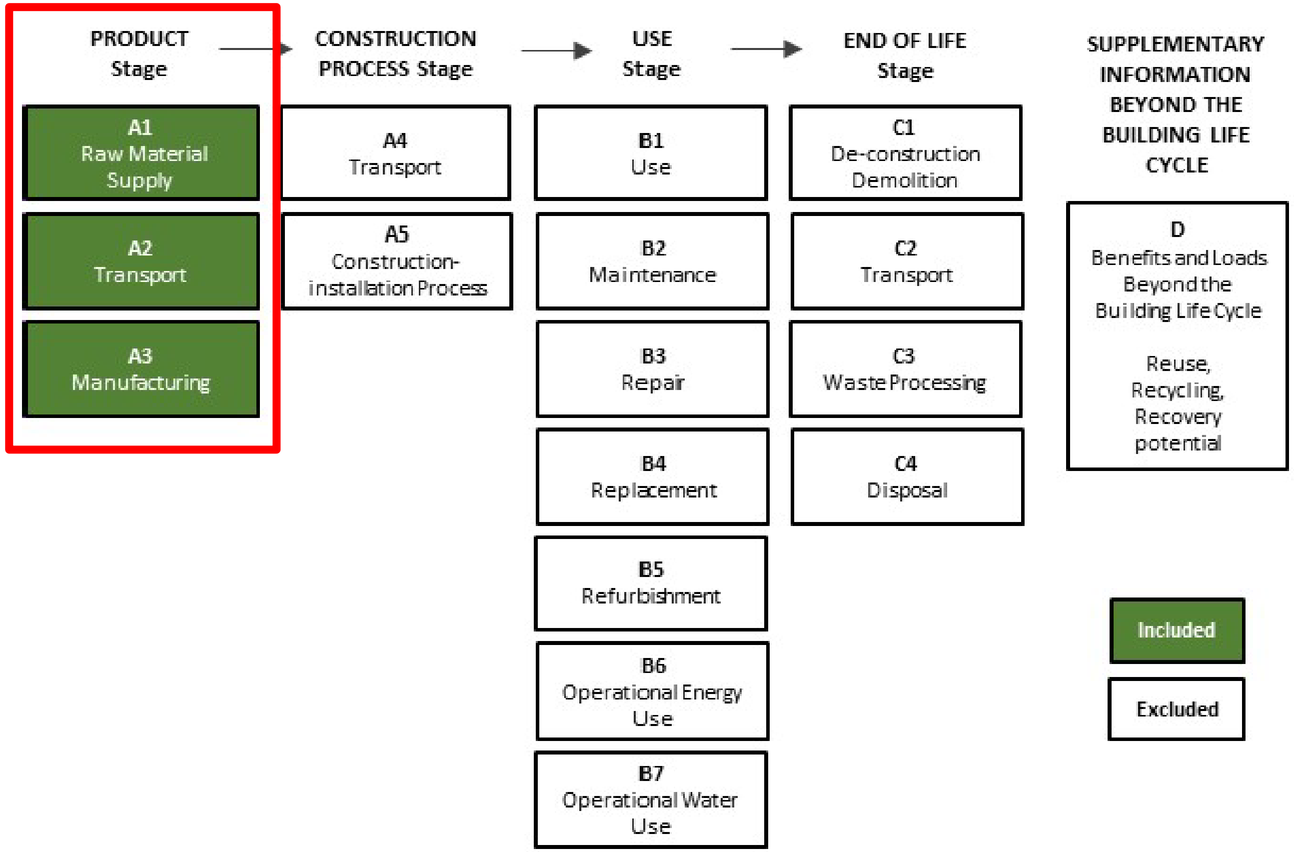
Concrete Composition (mass)

CO_2 Emissions are Inherent to Ordinary Portland Cement



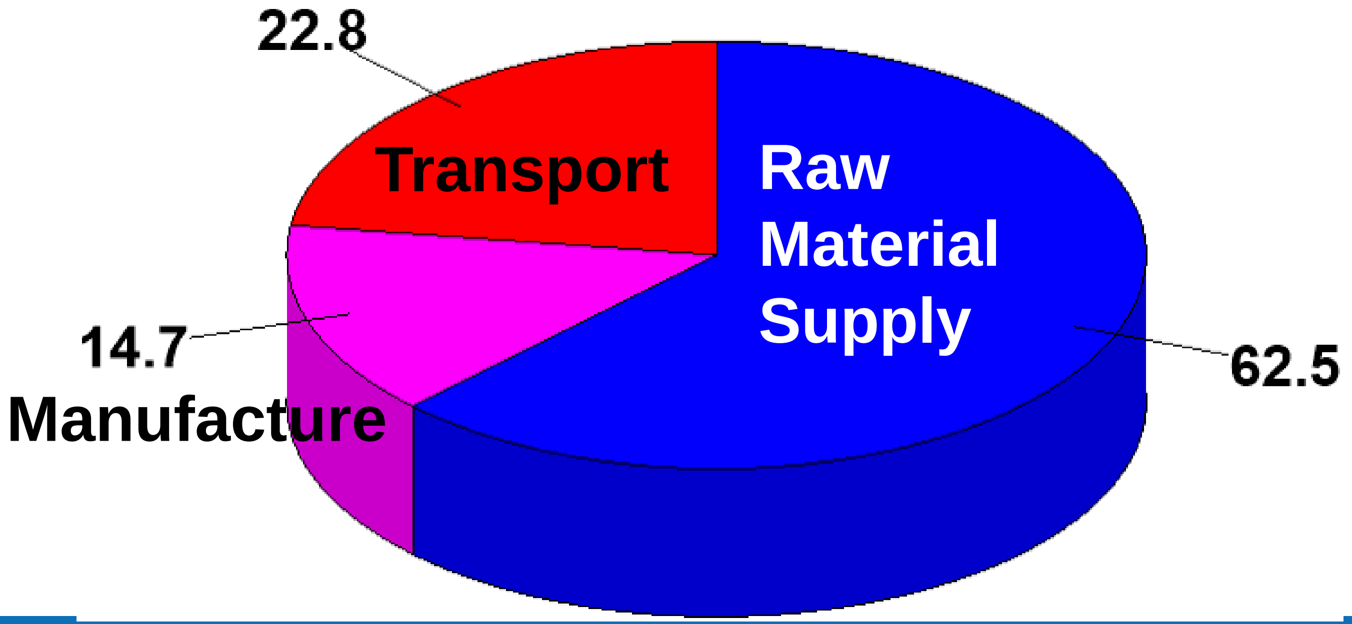
Life Cycle Analysis of Concrete

- Life cycle analysis (LCA) of concrete considers 4 key stages of concrete lifecycle
- For concrete producers – key stage is **product stage**
  - Raw material supply
  - Manufacturing
  - Transport
- Raw material supply is greatest contributor to global warming potential (GWP)



Life Cycle Analysis of Concrete

- Life cycle analysis (LCA) of concrete considers 4 key stages of concrete lifecycle
- For concrete producers – key stage is **product stage**
  - **Raw material supply**
  - **Manufacturing**
  - Transport
- Example of average concrete masonry unit (CMU)
- Raw material supply is greatest contributor to global warming potential (GWP) ~ 63% (~58% cement)



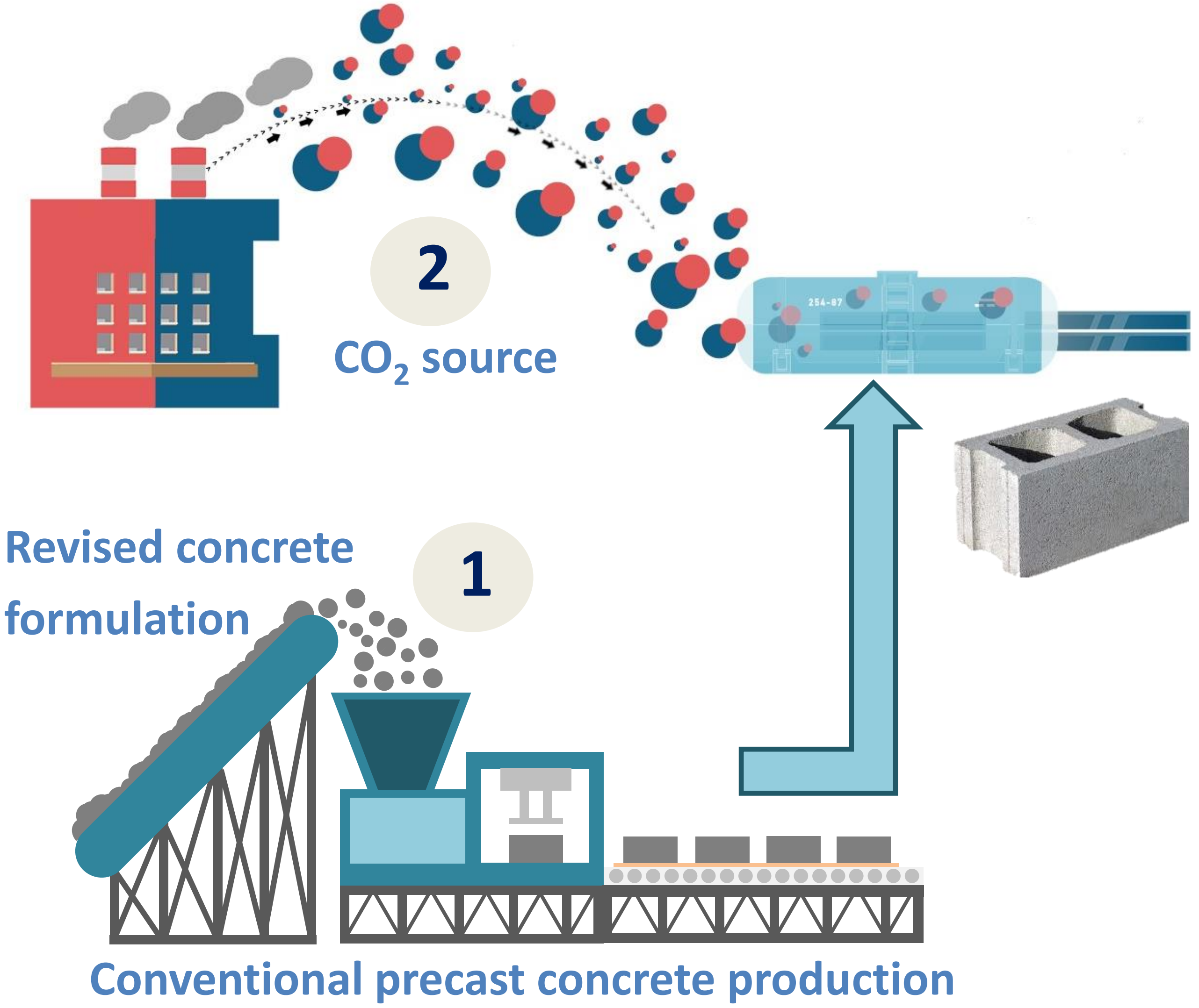
Concrete production using accelerated carbonation

1. Concrete (hydrated lime/cement/SCMs/waste byproducts)

- Replace cement in concrete with alternative materials
- Pricing < cement, and less carbon intensive
- Converts to limestone ($CaCO_3$) when exposed to CO_2

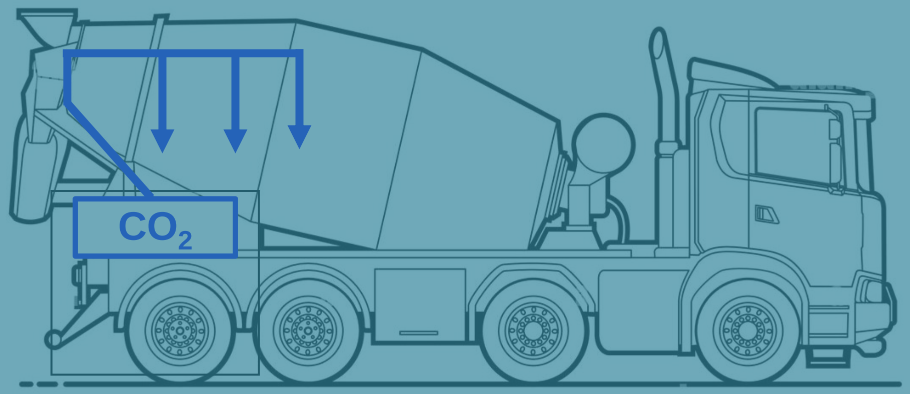
2. Dilute CO_2

- Ambient temperature and pressure
- No need for capture, purification or compression
- Direct from kiln, thermal power plant or other source



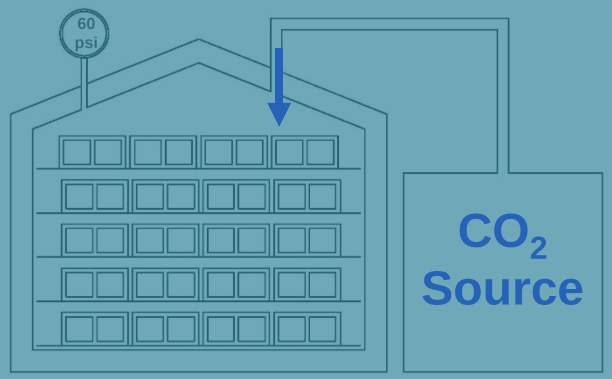
Accelerated concrete carbonation curing pathways

Carbonation during mixing

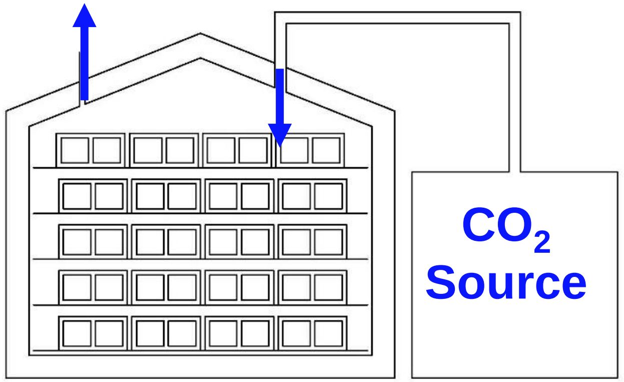


- Utilizes 100% CO_2
- Requires processing to purify CO_2
- Additional transport required to obtain CO_2
- Example company: CarbonCure

Carbonation post-forming



- **Pressure reactor** – CO_2 steadily released into reactor to maintain specified pressure
- Utilizes 100% CO_2
- Example company: Solidia

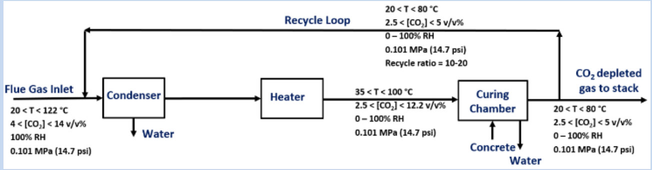


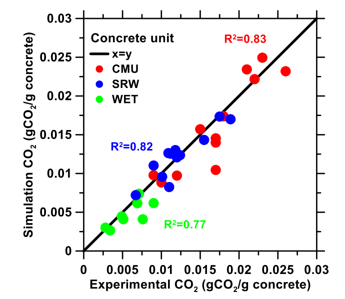
- **Flow through reactor** – uses CO_2 straight from emitter
- Requires gas processing
- Utilizes 2-100% CO_2
- Example company: CarbonBuilt

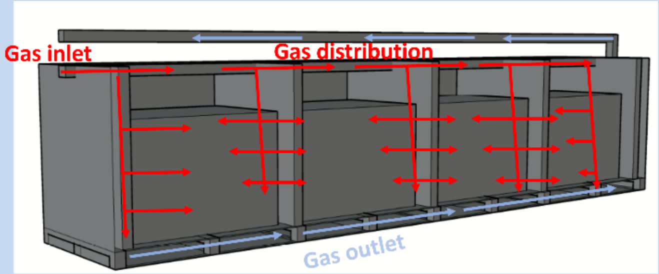
Targets for ongoing project: DE-FE0031915

- Identification of three most-preferred geometries compatible with the Reversa™ process
- Development of a process model that informs the scale-out of the process to produce diverse precast (structural) components
- Modification and validation of existing prototype
- Completion of TEA and LCA to quantify the market viability and lifecycle impact of the Reversa™ technology



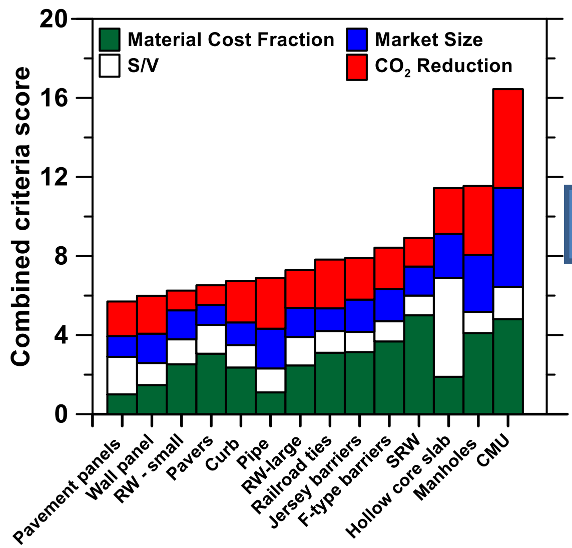


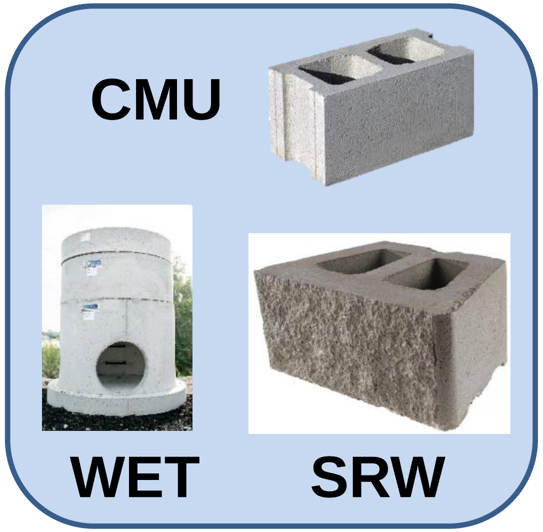




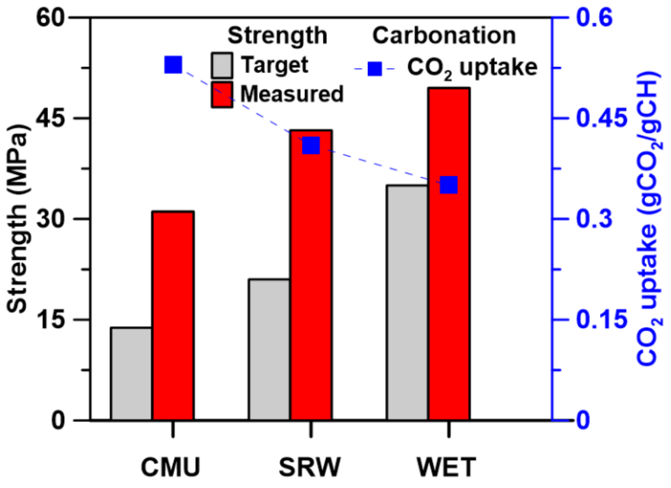
Concrete component selection and strength targets

- Concrete units were chosen based on technical and market prospects
- Based on combined scoring criteria: concrete masonry units (CMU), segmented retaining walls (SRW), and wet-cast manholes were selected
- Optimized processing and mixture formulation produced for each product exceeded ASTM strength targets
- Portlandite was used as main feedstock **and exceeded conversion and kinetic targets (0.2 gCO_2/gCH and $1x10^{-4}$ s^{-1})**



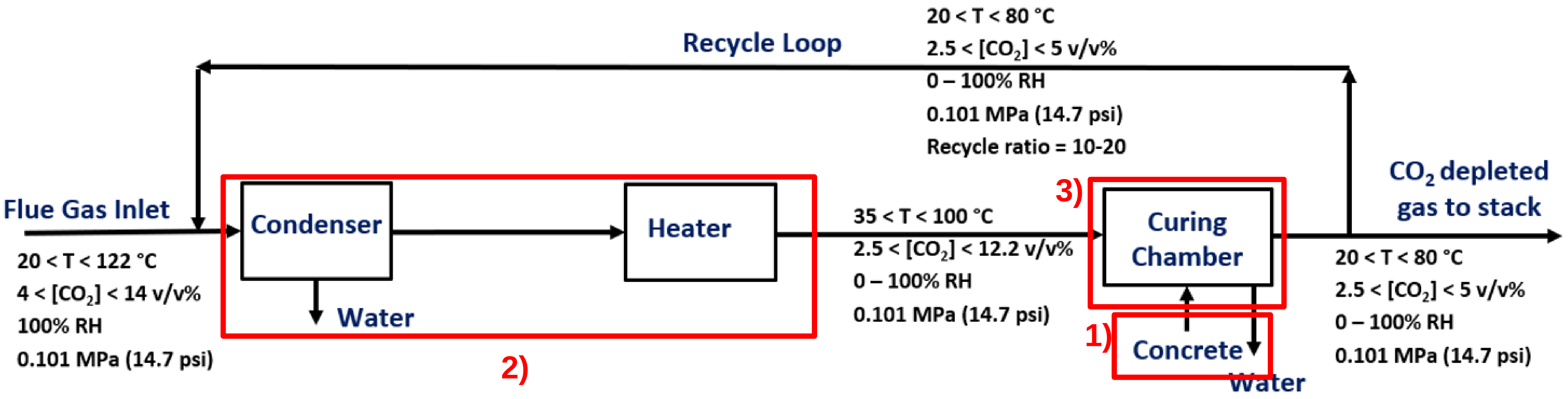


Strength of carbonated concrete and CO_2 uptake



Optimizing CO_2 curing regime – process model development

- Key stages for accelerated concrete carbonation: 1) concrete forming, 2) gas processing and 3) accelerated carbonation
- Aspen simulation developed to optimize CO_2 curing process
- Must balance gas processing energy penalties with CO_2 uptake from carbonation



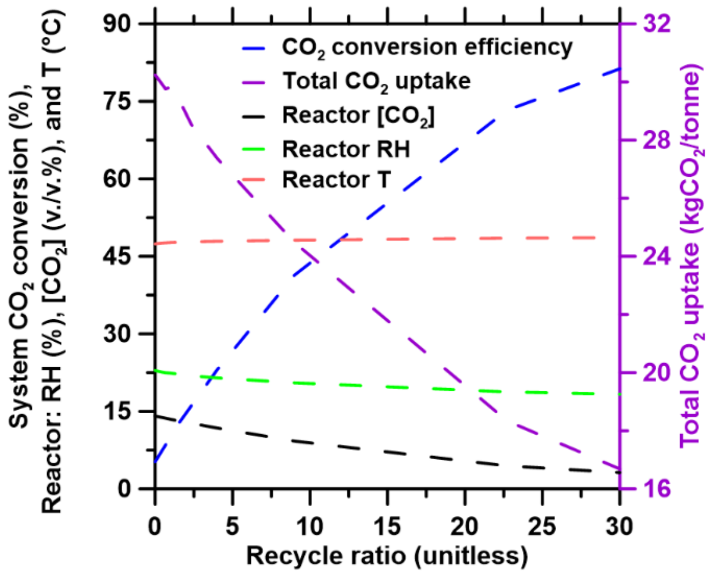
Process model outputs

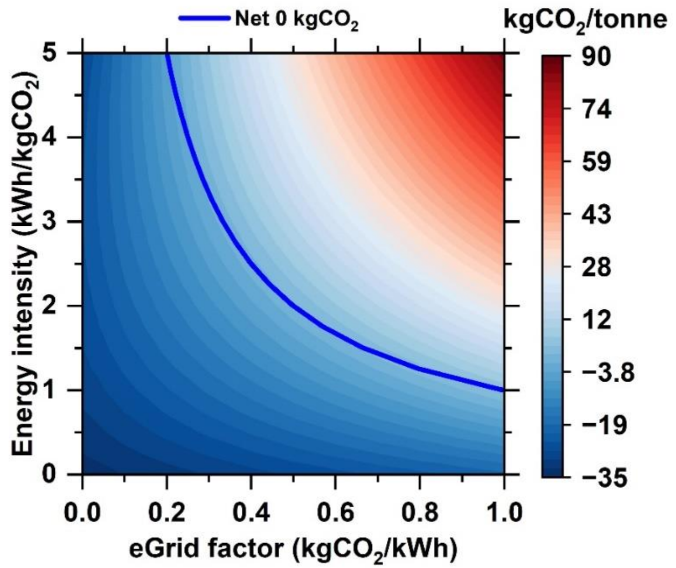
- Key model outputs:

1. Solid phase conversion – reactor conditions
2. Total gas conversion
3. System energy requirements

- Net CO_2 emissions of system can be determined:

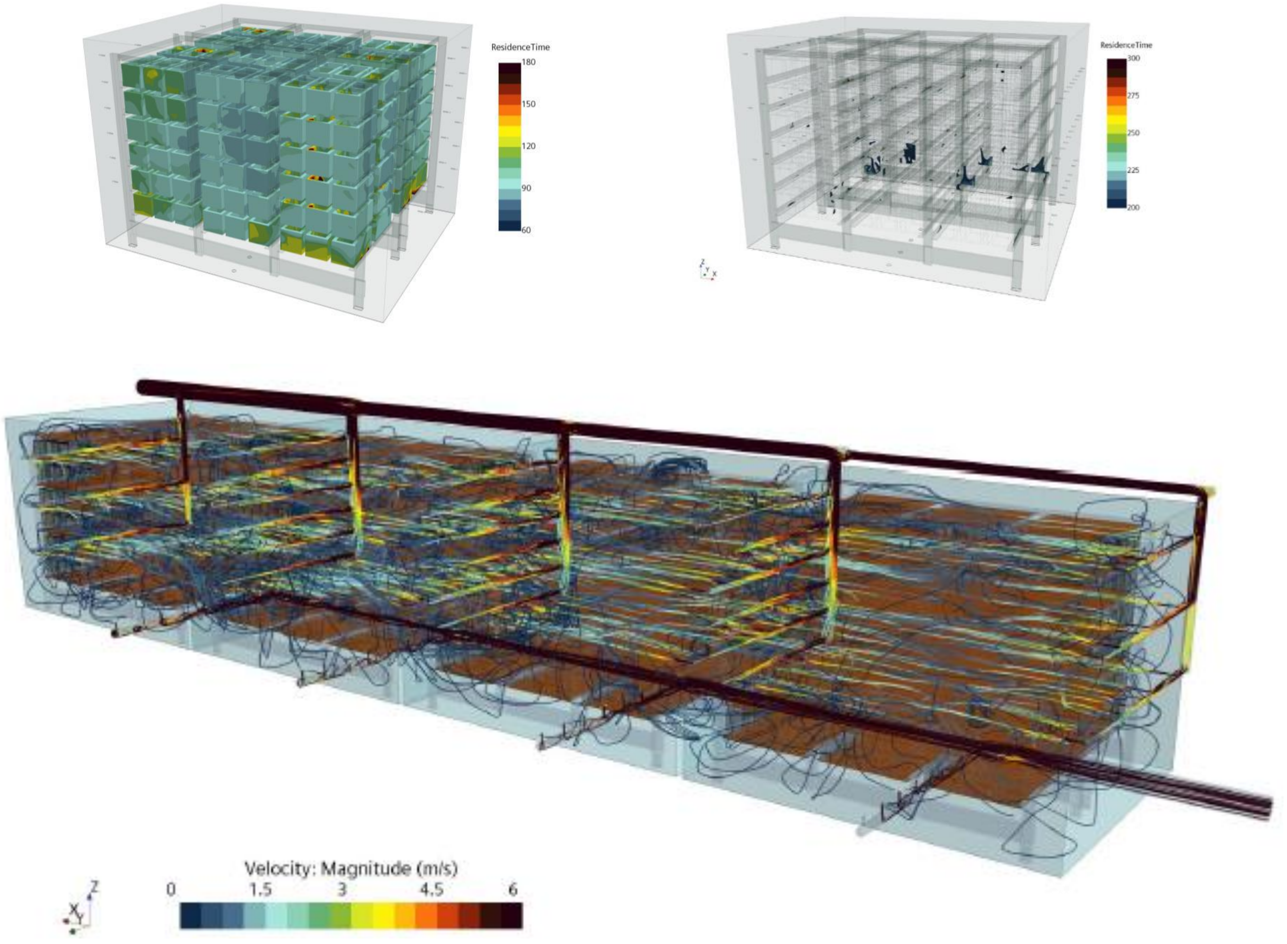
$$\textit{Net } CO_2 \textit{emissions} = \textit{Energy} \cdot \textit{eGrid factor} - CO_2 \textit{uptake}$$





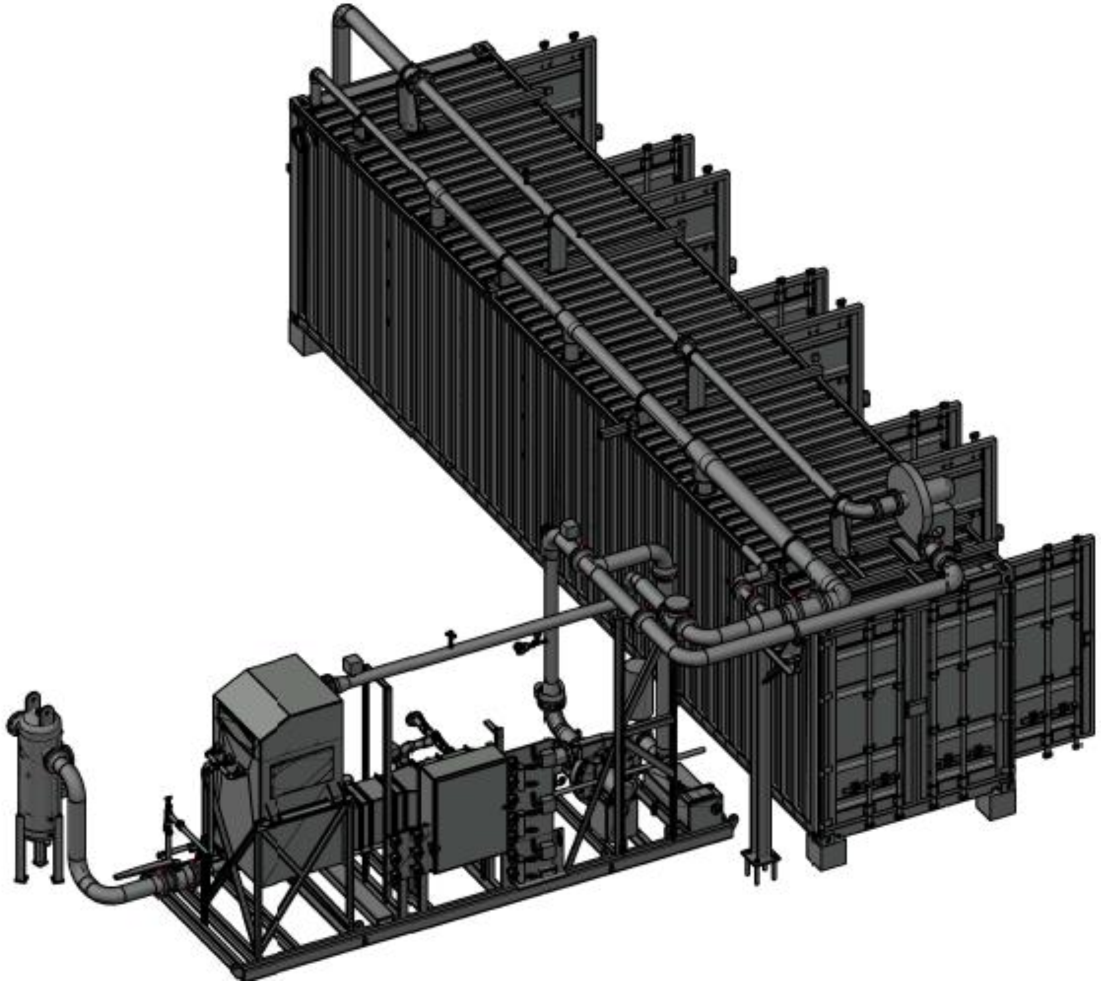
Upscaling to 10 tons/d concrete carbonation

- Designed the prototype from bench-scale data inputted into process model
- Process model was used to develop large-scale prototype to carbonate 10 tons/d concrete
- Computational fluid dynamics (CFD) used to optimize gas flow and internal reactor geometry for concrete elements
- CFD guided required concrete component flowrate coverage as input for process model



Construction of prototype

- Construction of system underway
- System comprises of gas processing skid and carbonation reactor
- System is targeting to produce ~10-13 ton/d carbonated concrete
  - 3 different products (CMU, SRW and manhole)



Presentation takeaways

- CO_2 mineralization enables an approach to produce construction products while utilizing CO_2 emissions, with strong market potential
- The UCLA team has successfully identified suitable concrete products for the Reversa process
- Appropriate mixture designs and operating conditions have been identified for optimum CO_2 uptake for each selected concrete component
- A process model has been developed to assist with scaling system design and assisting design work for system fabrication
- Computational fluid dynamics employed to direct reactor and system design
- Construction underway to proceed with large-scale demonstration

Future Work

- System build will aim to process 10-to-13 tons of concrete per day
- The process will be deployed at the National Carbon Capture Center (NCCC) in Wilsonville, Alabama in 2023
- Completion of TEA and LCA to quantify quality of system design post-demonstration

Thank you for listening

Questions??

Contact information

- **Dr Dale Prentice:**
  - **Email: dalepprentice@ucla.edu**

- **Prof. Gaurav Sant:**
  - **Email: gsant@ucla.edu**

Useful links:

Carbon built website:

https://www.carbonbuilt.com/

Institute for Carbon Management:

https://icm.ucla.edu/

Production of Inorganic Materials – Concrete and Cement

Technology Performance Data

	Units	Measured/Current Performance	Projected/Target Performance
Reaction Thermodynamics[1,2]			
Chemical Equation	mol^{-1}	$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$	
ΔH°_{rxn}	kJ/mol	-115.102	
ΔG°_{rxn}	kJ/mol	-74.953	
Reaction Conditions			
CO_2 Source[3]		Synthetic coal-fired flue gas	Coal-fired flue gas
Pressure	bar	1.01325	1.01325
CO_2 Partial Pressure	bar	0.02-0.14	0.02-0.14
Temperature	°C	25-75	25-75
Nominal Residence Time – batch reactor[4]	h	18-24	18-24
Alkaline Reactant Source[5]		$Ca(OH)_2$	$Ca(OH)_2$
Process Route[6]	(direct/ indirect)	Direct	Direct
Once-Through Performance[7]			
CO_2 Conversion[8]	(%)	NA	NA
CO_2 Uptake Potential[9]	(g-CO_2/g material)	0.59	0.59
CO_2 Uptake Actual[10]	(g-CO_2/g material)	0.35-0.53	0.2
Product Properties[11]			
Desired Product			
Compressive Strength[12]	(MPa)	20-49	13.8-42
Density	(kg/m^3)	2000	2000
Product Production	(kg/h)		
Commercial Product Properties[13]		**Current**	
Commercial Product		Concrete Masonry Units, Segmented retaining walls, and concrete manholes	
Compressive Strength[12]	(MPa)	13.8-42	
Density	(kg/m^3)	2000	
U.S. Market Size	(Tonnes/yr)	500 M	
Global Market Size	(Tonnes/yr)	>10 B	
Market Price	($/kg)	0.06-0.40	