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Current Trends on Concrete as Construction Materials to Capture CO2

Thursday, 9 June 2022 | Technical Topic Webinar

Presented By

Dr Ana Evangelista, Civil Engineering Lecturer & Course Coordinator

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Introduction - Presenter

Ana Evangelista

Ana is a passionate Civil Engineer and is currently a Lecturer and Work Integrated Learning Coordinator at EIT. Her research in Australia has been focused on sustainability in construction and engineering materials and her PhD research was mostly concentrated on non-destructive tests to evaluate concrete structures.

Agenda

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1	Welcome and Introduction
2	UN SDGs and Engineering
3	Concrete Composition
4	Cementitious Materials & Carbon Emissions
5	Concrete - Carbonation
6	Concrete & CO2 storage
7	Current improvments
8	Conclusion and Q&A

Why Sustainability in Engineering ?

- Sustainable engineering is the process of using resources in a way that does not compromise the environment or deplete the materials for future generations.
- Sustainable engineering requires an interdisciplinary approach in all aspects of engineering and it should not be designated as a sole responsibility of environmental engineering.

Why Sustainability in Civil Engineering ?

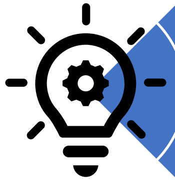
‘that a healthy economy is underpinned by a healthy environment and respect for all life on earth’
(Engineers Australia)

How can we reduce the environmental impacts in AEC sector ?

Using materials with low(er) embodied energy

Reducing transport of materials and associated fuel, emissions and road congestion

Preventing waste going to landfill



Designing and constructing for ease of reuse and recycling at end-of-life (design for deconstruction).

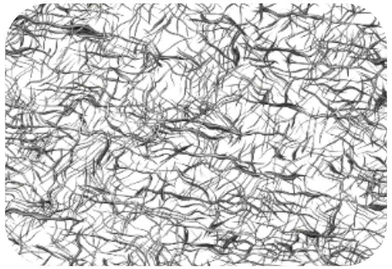
Conventional Concrete

Portland cement

Fine aggregate

Coarse aggregate

Water



Fibers

Admixtures/ Additives

Cementitious Materials & Carbon Emissions

Carbon emissions arise from fossil fuel combustion and from the **calcining reaction :**

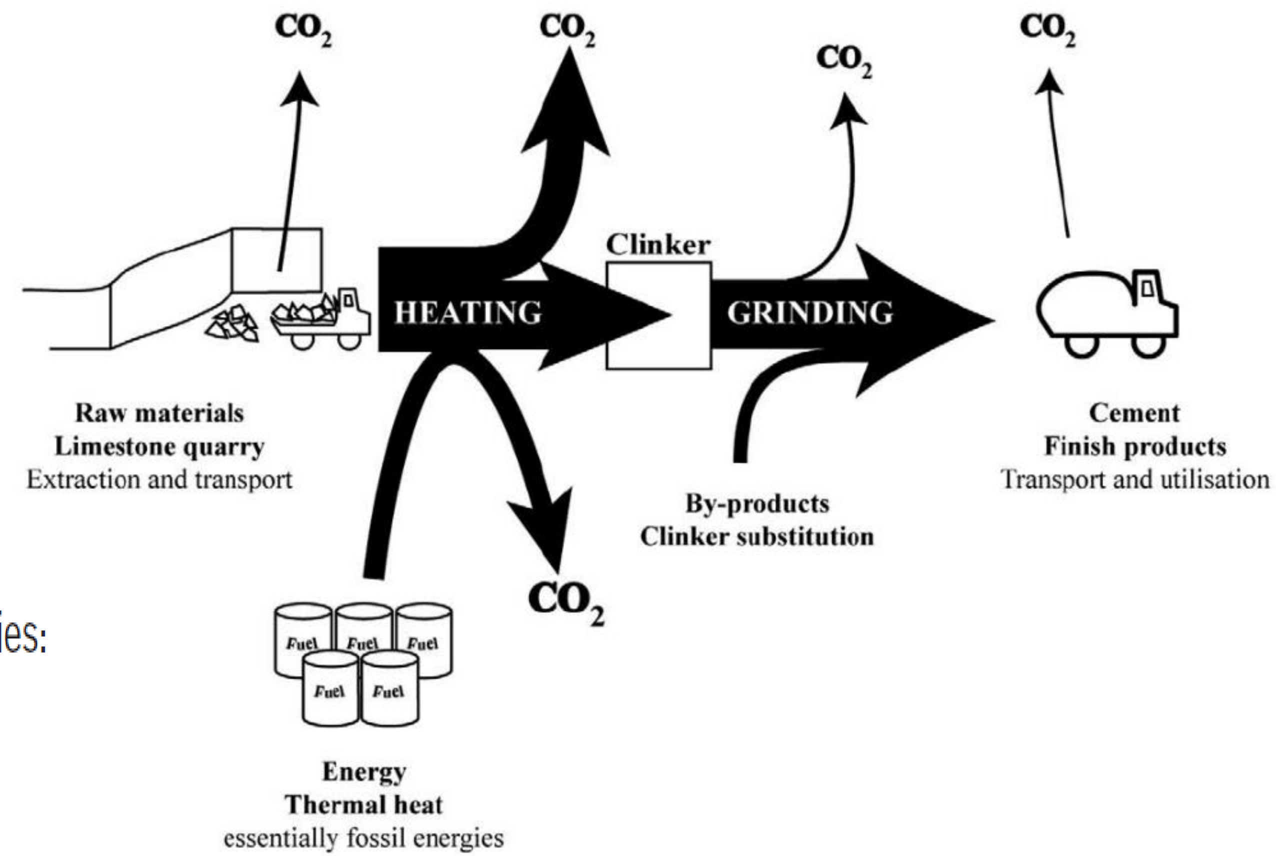
$$(CaCO_3 \rightarrow CaO + CO_2)$$

CO_2 emissions from a cement plant are divided into two source categories:

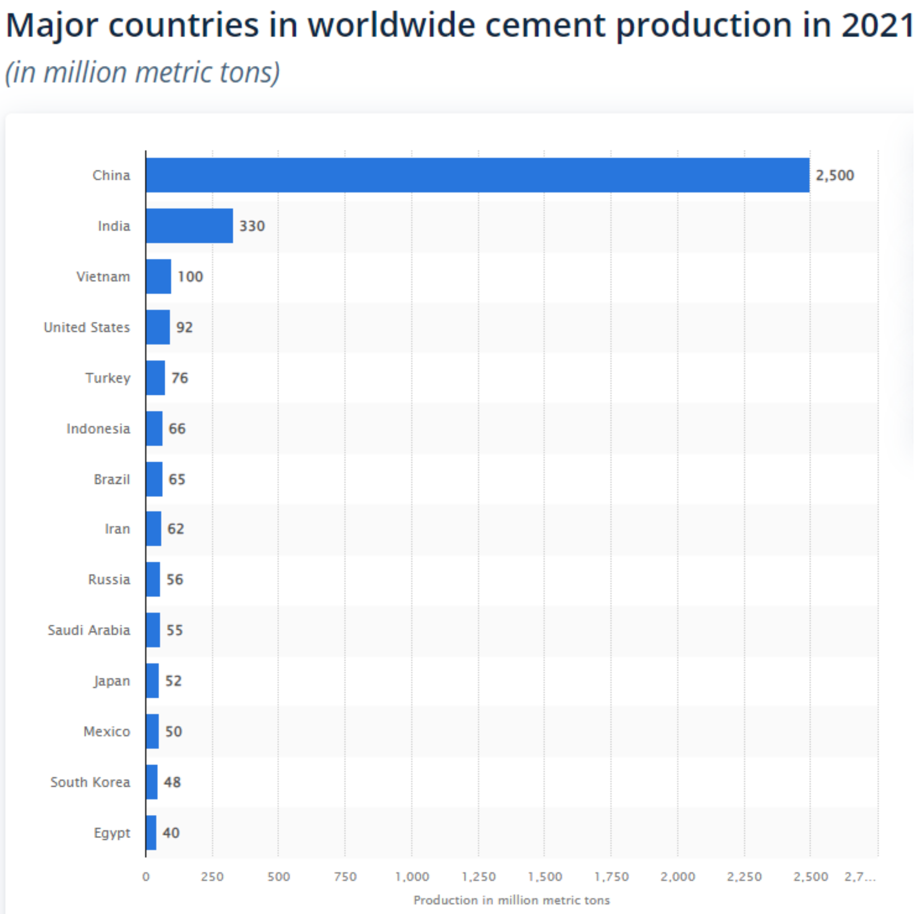
- Combustion (40 percent of emissions)
- Calcination (60 percent of emissions)

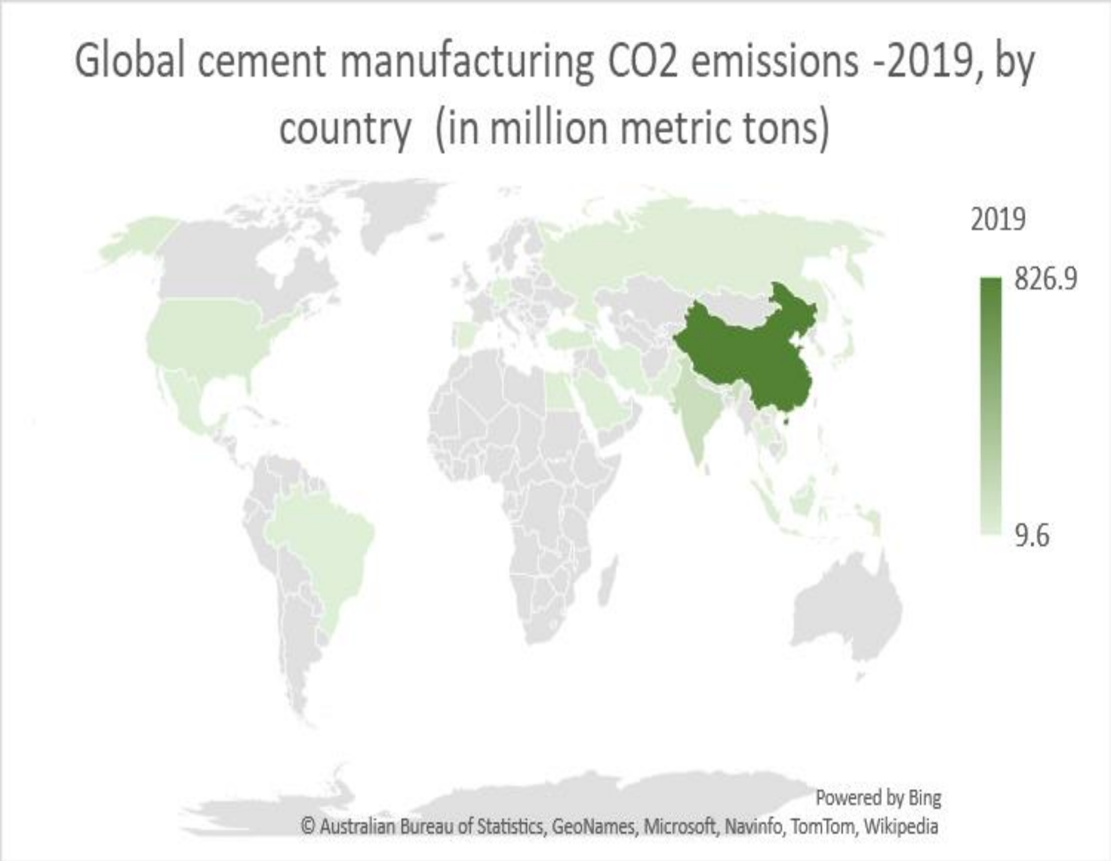
1 tonne of cement releases around 1 tonne of CO_{2eq}

G. Habert et al. / Cement and Concrete Research 40 (2010) 820–826



Cementitious Materials & Carbon Emissions





https://pubs.usgs.gov/periodicals/mcs2022/mcs2022.pdf

Source: Andrew, 2019

Cementitious Materials & Carbon Emissions

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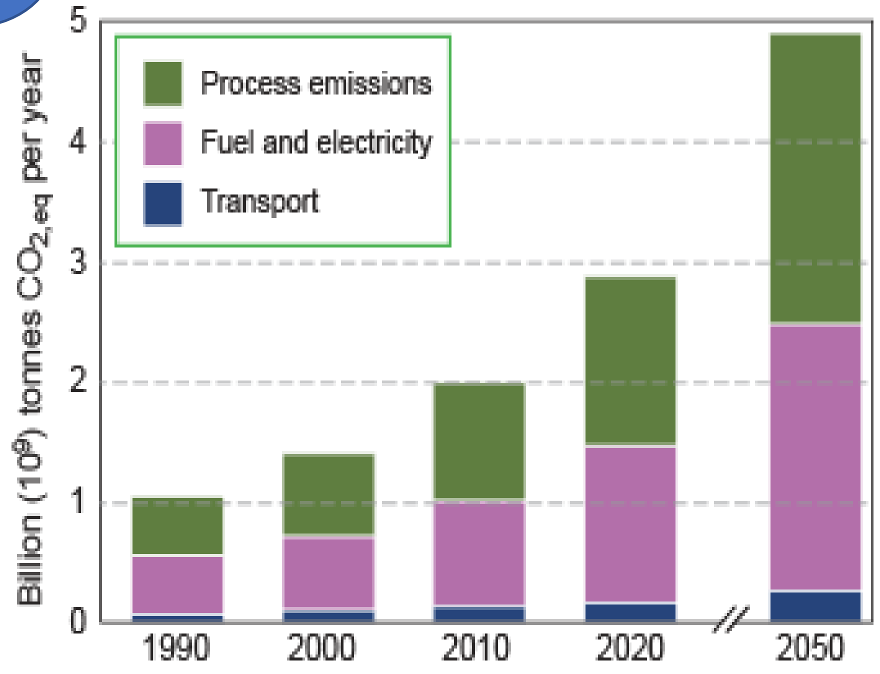
Carbon emissions arise from fossil fuel combustion and from the **calcining reaction :**

1 tonne of cement releases around 1 tonne of CO_{2eq}

$$(CaCO_3 \rightarrow CaO + CO_2)$$

Globally 5% of all greenhouse gas emissions are from making **cement**; expected emissions of 5 billion tonnes/year by 2050 (grantadesign.com)



Alternatives to reduce emissions from clinker

The use of alternative sources of decarbonated materials is one option for significantly reducing CO2 emissions

Waste materials and by-products from other industries can be used to replace some of the limestone

In producing cement simultaneously recover energy and recycle minerals from a variety of waste streams (Co-processing) and use biomass

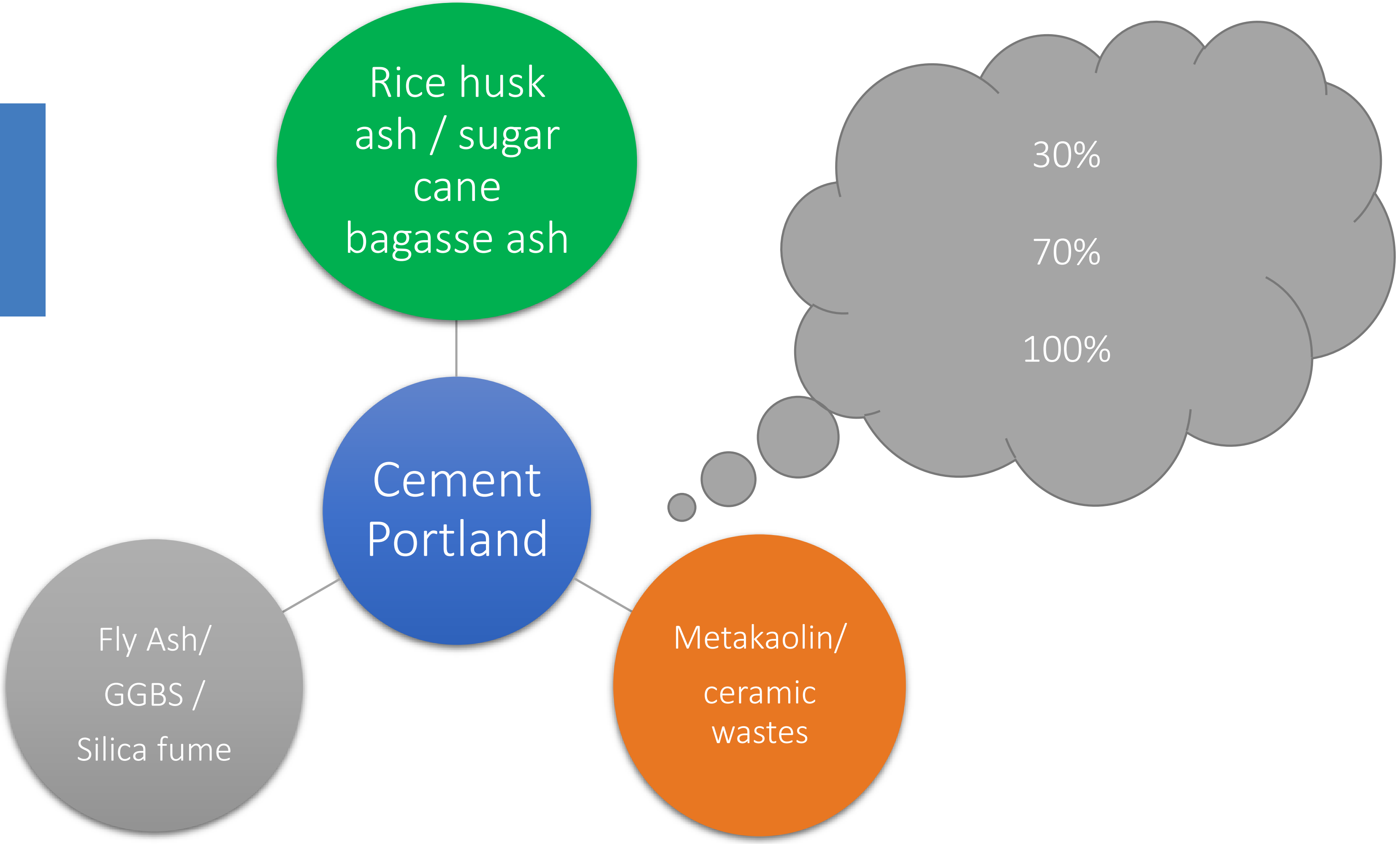
CEMBUREAU targets to reach 60% alternative fuels containing 30% biomass in 2030, and 90% alternative fuels with 50% biomass by 2050

Examples of these include Sulpho-Aluminate Clinker (SAC), Ferro-Aluminate Clinker (FAC), Belite- Ye'elimite-Ferrite Clinker, Calcium Aluminate Clinker and Amorphous Clinker (X-Clinker).

Source: Cementing the European Green Deal -https://cembureau.eu/library/reports/2050-carbon-neutrality-roadmap/

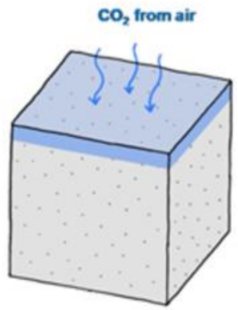
Cementitious materials

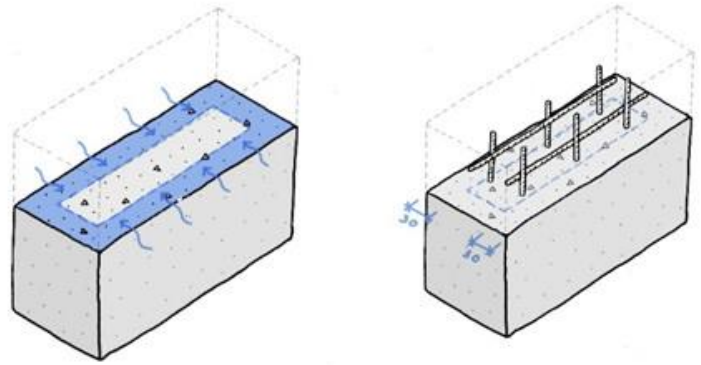
The pozzolanic activity of SCM depends on its amorphous silica content (SiO_2) , its surface area and its fineness



On the other hand … Concrete (Re)Carbonation

- Carbonation is the reaction of carbon dioxide in the environment with the calcium hydroxide in the cement paste;
- Hydrated cement used in concrete or mortars naturally absorbs CO_2 during its lifetime, a process known as (re)carbonation, thus removing carbon from the atmosphere :





Reversible calcination - Carbonation

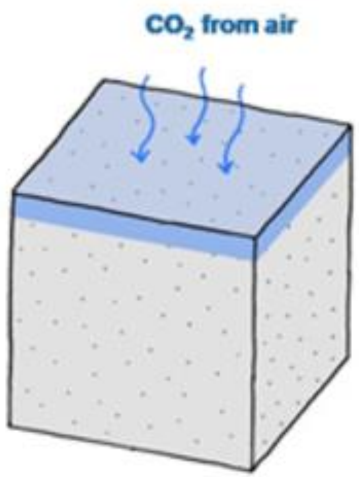
$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

A high pH is needed to protect the reinforcement against corrosion. This is solved by designing using high strength concrete with a cover layer, typically 30 mm or more

Source : https://www.ivl.se/

On the other hand … Concrete (Re)Carbonation

- Carbon capture and utilization for concrete production (CCU concrete) is estimated to sequester 0.1 to 1.4 gigatons of carbon dioxide (CO_2) by 2050 (Ravikumar et al. 2021);
- The long term CO_2 sequestration in the form of stable carbonate beyond the life-time of the infrastructure (>60 years)



- ✓ The carbonation process is a slow process
- ✓ The time aspect is thus an important issue
- ✓ The transport of CO_2 molecules into the concrete is thus also an important factor.
- ✓ Water is required for carbonation to take place.

Source : https://www.ivl.se/

On the other hand … Concrete (Re)Carbonation

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In the built environment, re-carbonation occurs naturally in all concrete infrastructure;

According to research by IVL, 23% of process CO_2 emissions of cement used, is being captured annually which equates to a 8% saving of total CO_2 emissions for the cement manufactured;

Re-carbonation increases after demolition of a concrete building. The recycled concrete aggregates have a higher surface area and can absorb more easily CO_2 within the concrete paste (cement, water and sand) from the ambient air.

Source : https://www.ivl.se/

Carbon capture and utilization for concrete production

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CCU

- Carbonation of recycled concrete aggregates;
- CO_2 sequestration in alternative MgO based binders;
- CO_2 mineralization in industrial waste-derived aggregates and filler;
- CO_2 dissolution in mixing water;
- CO_2 mixing - CO_2 is injected into fresh concrete during batching and mixing;
- In CO_2 curing, CO_2 is utilized as a curing agent to accelerate precast concrete fabrication;

CCU - recycled aggregate concrete

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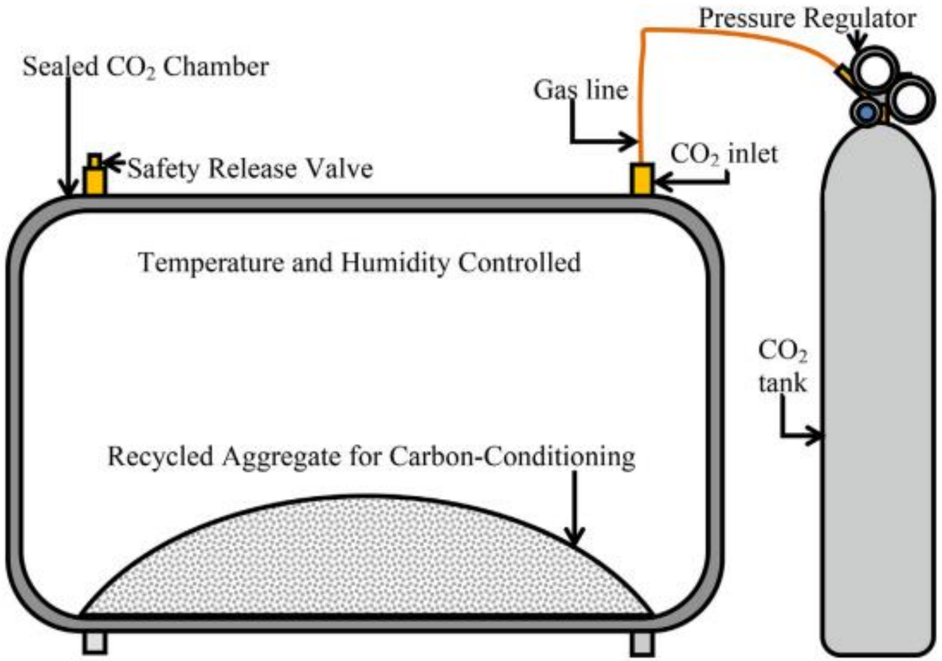
- Carbon-conditioning is the injection of CO2 into recycled aggregate, accomplished with the assistance of a sealable carbonation chamber;
- Carbon-conditioning strengthens the attached cement of recycled aggregate, improving recycled aggregate;



Source : V.W.Y. Tam et al. / Construction and Building Materials 250 (2020) 118903

CCU - alternative MgO based binders

The lower clinkering temperatures, reduced carbon emissions during calcination, associated with the manufacture of reactive MgO supported the consideration of this material as an alternative to PC;

Reactive MgO cement (RMC) presents several advantages such as its ability to absorb CO_2 while gaining strength;

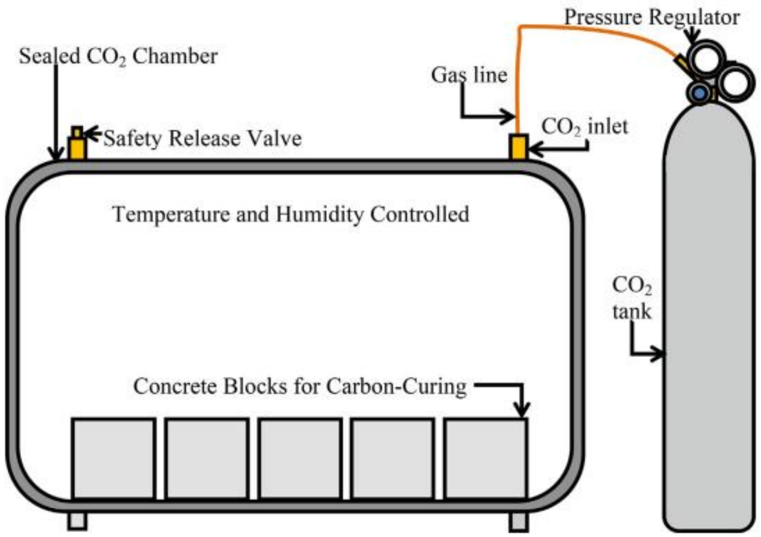
The life cycle assessment (LCA) considers the actual amount of CO_2 mineralized by the binders and their 28-day compressive strength, as well as different manufacturing process (dry and wet) and energy sources (fossil fuels and electricity) to produce rMgO;

According to Zhang et al. (2021), the wet route to produce rMgO looks particularly promising for a future decarbonized construction sector since no CO_2 is chemically released during its manufacture;

CCU - Carbonation for concrete curing

- Carbon-curing carbonates entire concrete blocks after concrete mixing. The technique carbonates new cement paste, permitting in some cases an accelerated curing period alongside an enhancement of concrete quality;
- CO_2 can be used as a curing agent to improve performance of cement-based materials;
- The CO_2 gas acts as a reactant, rather than a catalyst, yielding a binding matrix distinct from that obtained from conventional hydration.

The urgency of mitigating greenhouse gas emissions, however, re-ignited interest in carbonation curing, particularly after the 2000s. Dramatically rapid strength gain has been observed for CO_2-cured Portland Cement (D. Zhang et al, 2017).



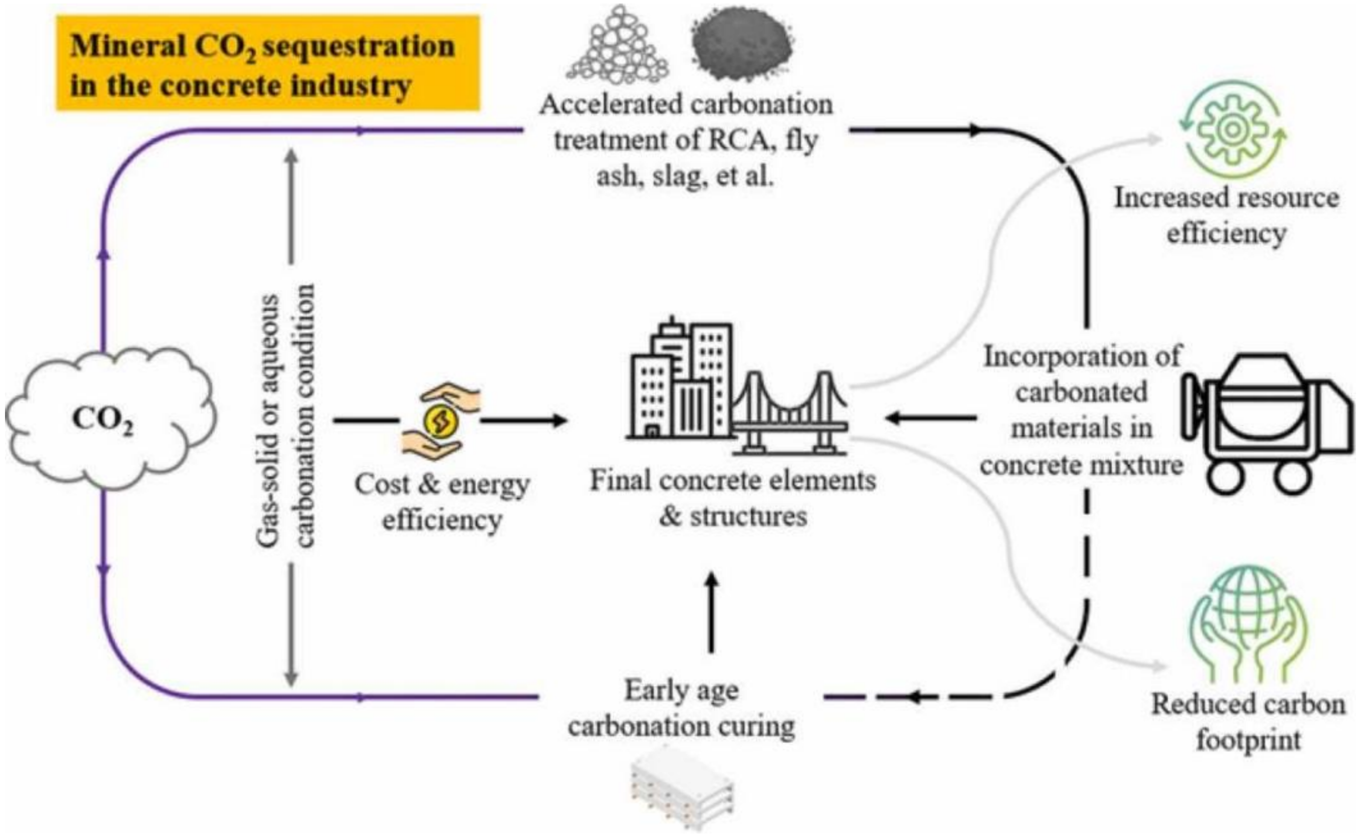
Source : V.W.Y. Tam et al. / Construction and Building Materials 250 (2020) 118903

CCU - mineral CO2 sequestration

- The industrial waste materials that are mostly investigated for mineral CO_2 sequestration in the concrete industry include fly ash, slag, recycled concrete aggregates (RCA);
- CO_2 sequestration of fly ash :
  - Carbonation approach – aqueous, gas-solid
  - Carbonation capacity – 0.8% (low-calcium fly ash) to 26.4 % (high-calcium flyash)
  - Carbonation efficiency – 13% to 86.4 %
- CO_2 sequestration of slag:
  - Under the same carbonation condition, the CO_2 sequestration capacity and efficiency of slags are closely related to its chemical compositions, particle sizes, and microstructures

Source : Liang Li, Min Wu (2022)

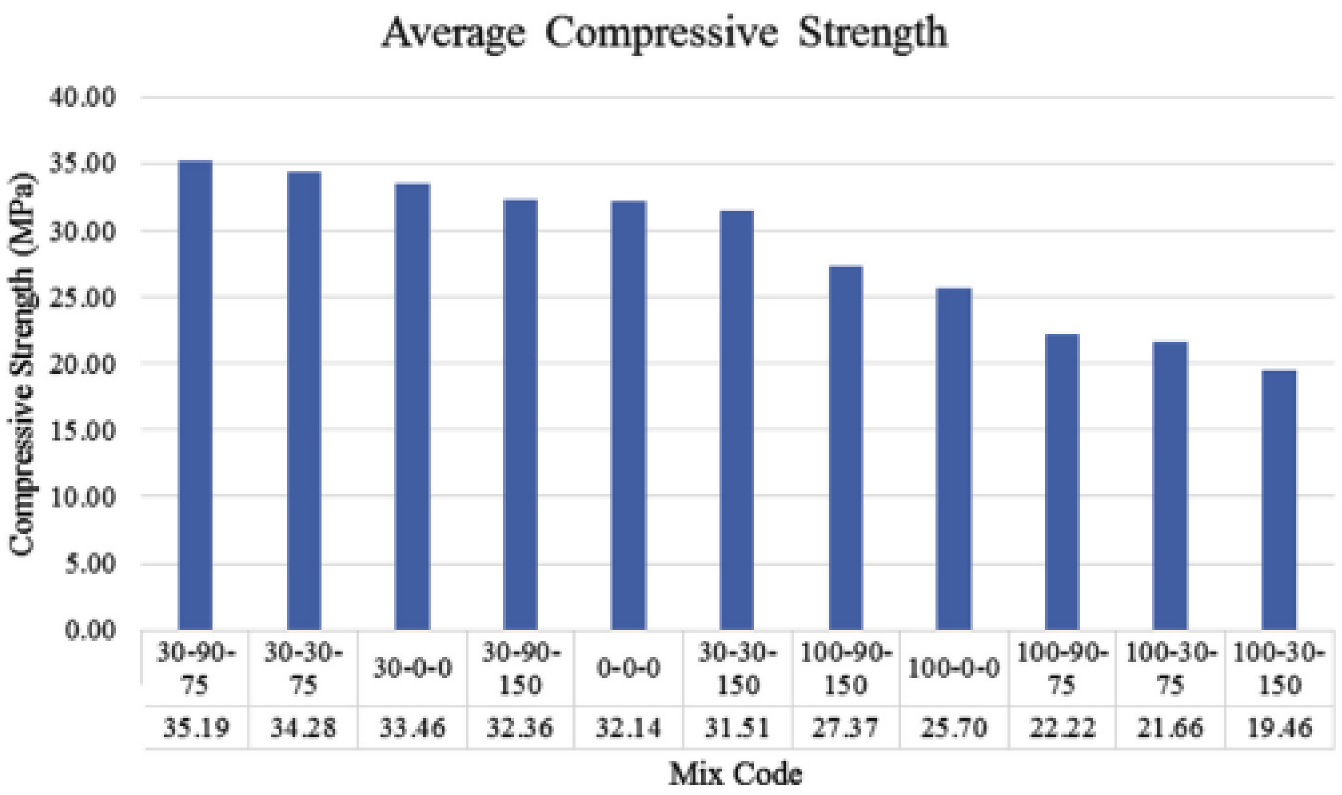
CCU - mineral CO_2 sequestration - applications



Source : Liang Li, Min Wu (2022)

CCU - mineral CO_2 sequestration - applications

› Recycled aggregate

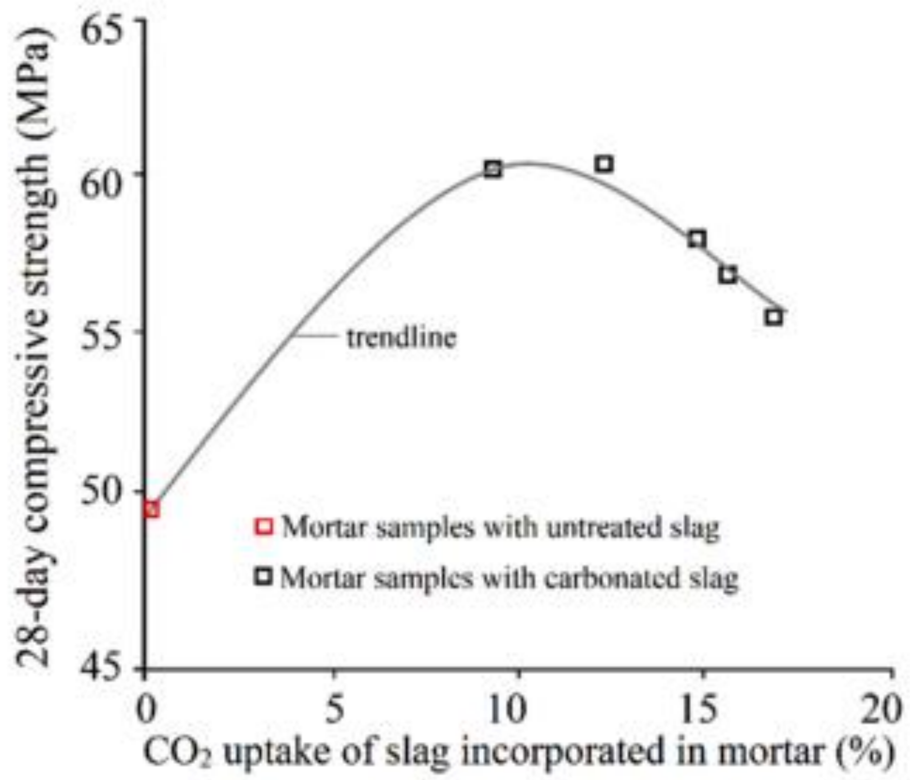


V.W.Y. Tam et al. / Journal of Cleaner Production 133 (2016)

CCU - mineral CO_2 sequestration - applications

- Supplementary Cementitious Materials
  - Promising utilization of the carbonated materials is the incorporation into the production of concrete as substitutes for Portland cement;

L. Li and M. Wu



Source : Liang Li, Min Wu (2022)

CCU - mineral CO_2 sequestration - applications

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To apply mineral CO2 sequestration at a commercial scale, the environmental impact of accelerated carbonation treatment must be considered, since the energy consumption required as an input to accelerate carbonation reactions is usually significant!

Life Cycle Assessment

CO2 emissions higher than CO2 sequestration

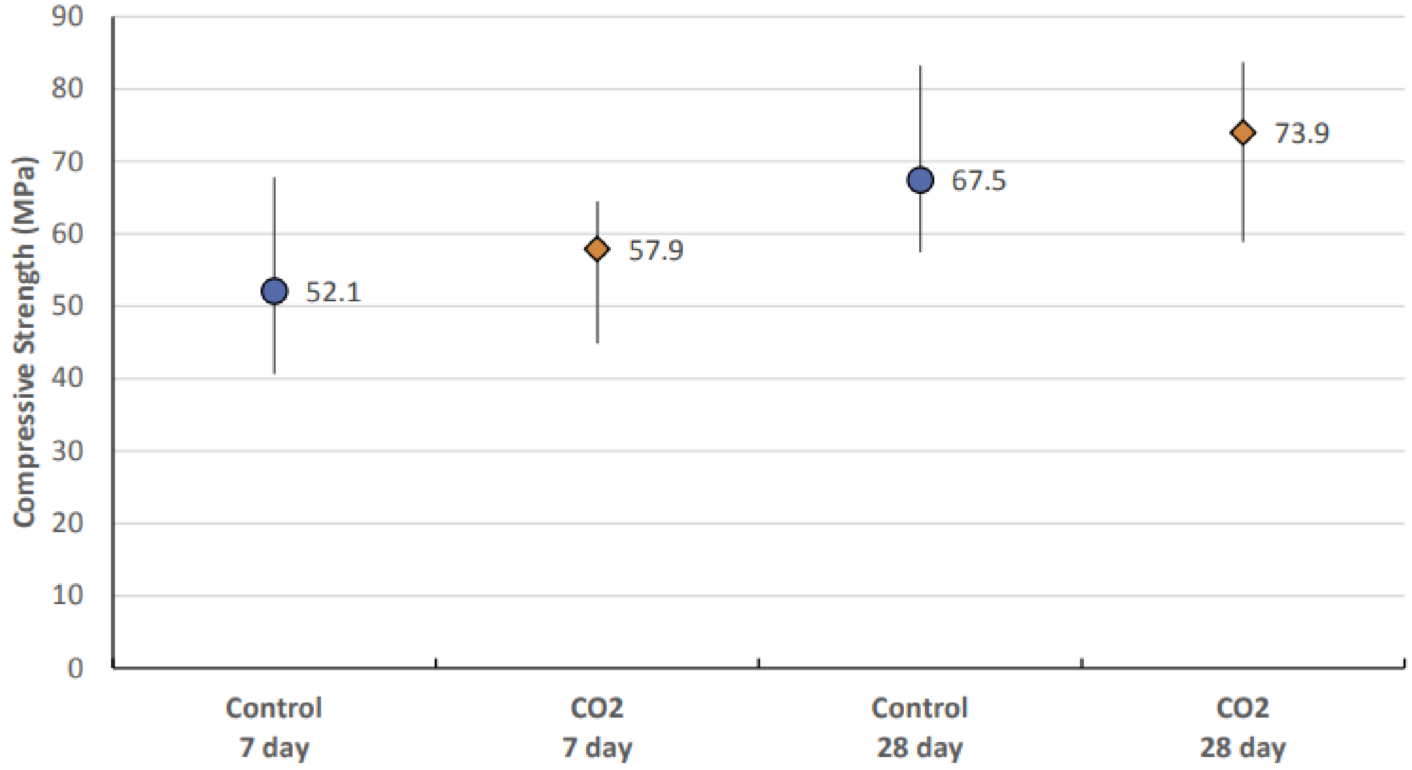
CO2 sequestration higher than CO2 emissions

CCU – CO_2 in concrete mixing and batching

- Carbon dioxide utilization in the production of ready mixed concrete was investigated through the injection of an optimal amount of CO_2 during batching and mixing ;
- CO_2 addition could allow for a 5% to 8% reduction in binder loading without compromising strength;
- The carbon dioxide is delivered into the fresh concrete, at a specified flow rate over a fixed injection interval, whereupon it reacted with the hydrating cement during initial mixing

CCU – CO_2 in concrete mixing and batching

S. Monkman, M. MacDonald / Journal of Cleaner Production 167 (2017) 365–375



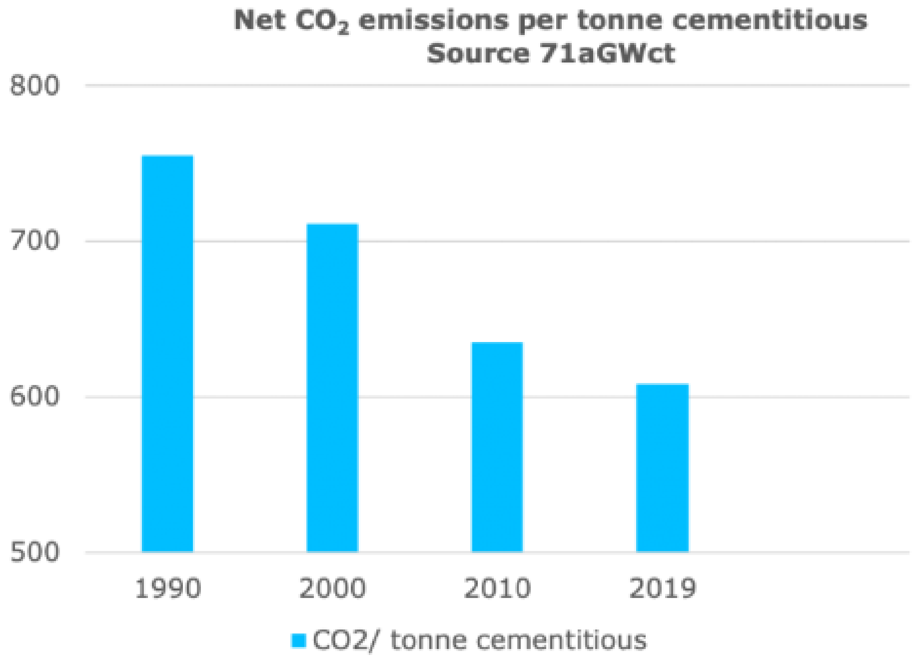
Compressive strength development (7 and 28 days) of Mix 80T produced with a CO_2 addition and an average cement reduction of 6.0%.

The dosage of CO_2 varied slightly from batch to batch but can be generalized as 0.15% by weight of cement

Current improvements …

- ✓ One example of the progress made to date is the use of biomass and alternative fuels, such as municipal and industrial wastes
- ✓ The benefits of fuels substitution are multiple

- Reducing CO2 emissions
- Reducing dependence on fossil fuels
- Material recycling
- Offering an alternative to landfill



- 19.5%

CO_2 reduction per tonne cementitious

x 9.7

Fossil Fuel substitution

- 18.5 %

energy efficiency improvement

Source:https://gccassociation.org/sustainability-innovation/gnr-gcca-in-numbers/

Current improvements …

- Using efficient structural design, it is possible to reduce embodied carbon by up to 30% for certain types of buildings;
- For older buildings there is a move towards re-using the concrete structure of a building rather than demolishing it entirely;
- Explore the "design for deconstruction" model where a building is conceived at origin with the objective to disassembly at end of life

Summary

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- It’s thermodynamically favorable to make carbonates and requires less energy input to achieve. This makes this market attractive for developers because the technology is more readily scalable today.
- The two main CO2U technologies used in building materials are mineralization for carbonate aggregates and the use of CO2 to cure concrete.
- Key innovators include Carbon8, Solidia Technologies and CarbonCure. Aggregates are coarse particles used in construction and can be gravel or crushed stones or other similar materials.
- Until the overall emissions are cut worldwide, the environment will continue to be polluted with over 4 billion tonnes of carbon dioxide annually due to this industry.
- About 50-60% of these emissions emanate from the raw materials and thus has a potential to be reabsorbed by carbonation of the concrete, partly during the use phase of the concrete products, and partly in the end-of-life and secondary use stage

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Q&A

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