ipcc
INTERGOVERNMENTAL PANEL ON climate change
Task Force on National Greenhouse Gas Inventories (TFI)

IPCC Expert Meeting on Carbon Dioxide Removal Technologies

01 TO 03 JULY 2024

Vienna, Austria

IECA
INSTITUTO ESPAÑOL DEL CEMENTO Y SUS APLICACIONES

State of the art on the quantification of natural carbonation of cement-based materials as a CO_2 capture mechanism

Miguel Ángel Sanjuán
Scientific and Technical Coordinator of IECA (Spanish Institute of Cement and its Applications)

1. Background
2. CO_2 emissions-absorption (cement sector)
3. "Concrete CO_2 sink" Project
4. Sixth Assessment Report (AR6)
5. Conclusion → AR7 & Inventories

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Background

Brief preliminary outline of existing IPCC TFI guidance on these topics provided in Table 1

Source/sink: Cement carbonation

2.2.1.4 Free lime (CaO not part of the formulae of the clinker minerals mentioned above) released during the curing of concrete (i.e., from the hydration of the clinker minerals) can potentially re-absorb atmospheric CO_2 - a process called carbonation. However, the rate of carbonation is very slow (years to centuries) and, as a practical matter, should not be considered for good practice. This is an area for future work before inclusion into national inventories.

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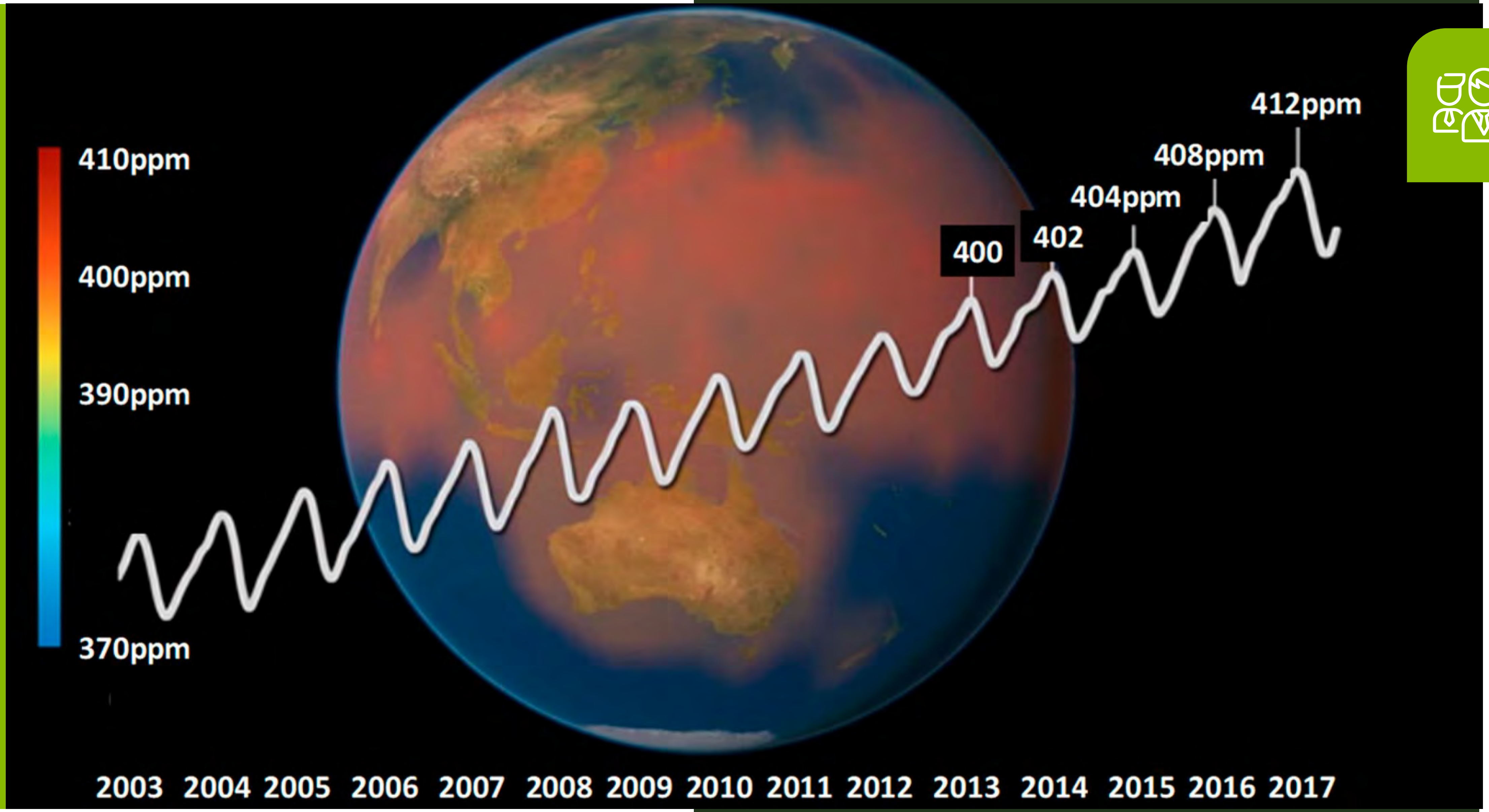


Global Warming Potential (GWP)

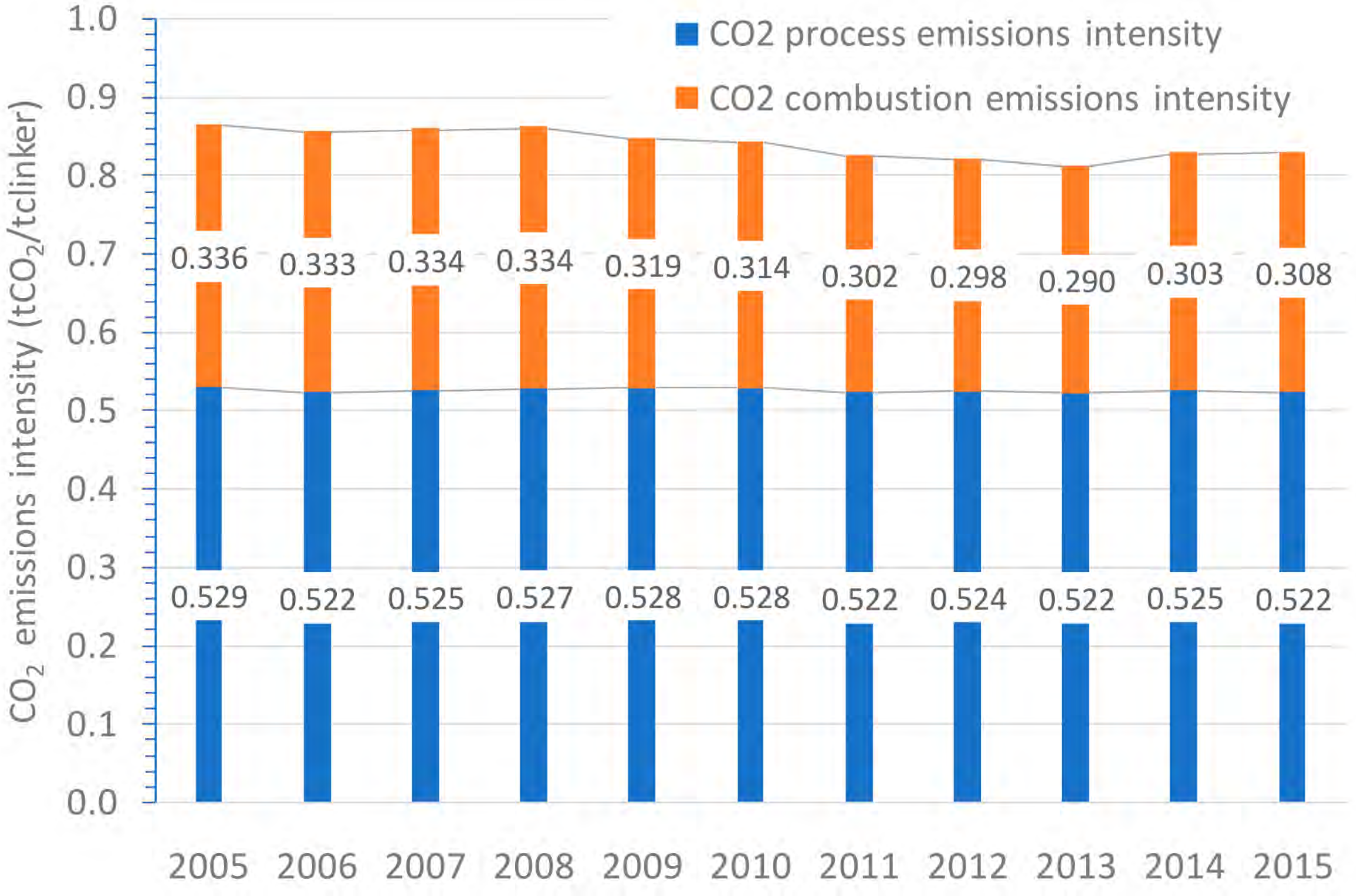
Carbon dioxide

Cement sector: 7.4% of global emissions.

IPCC Expert Meeting on Carbon Dioxide Removal Technologies

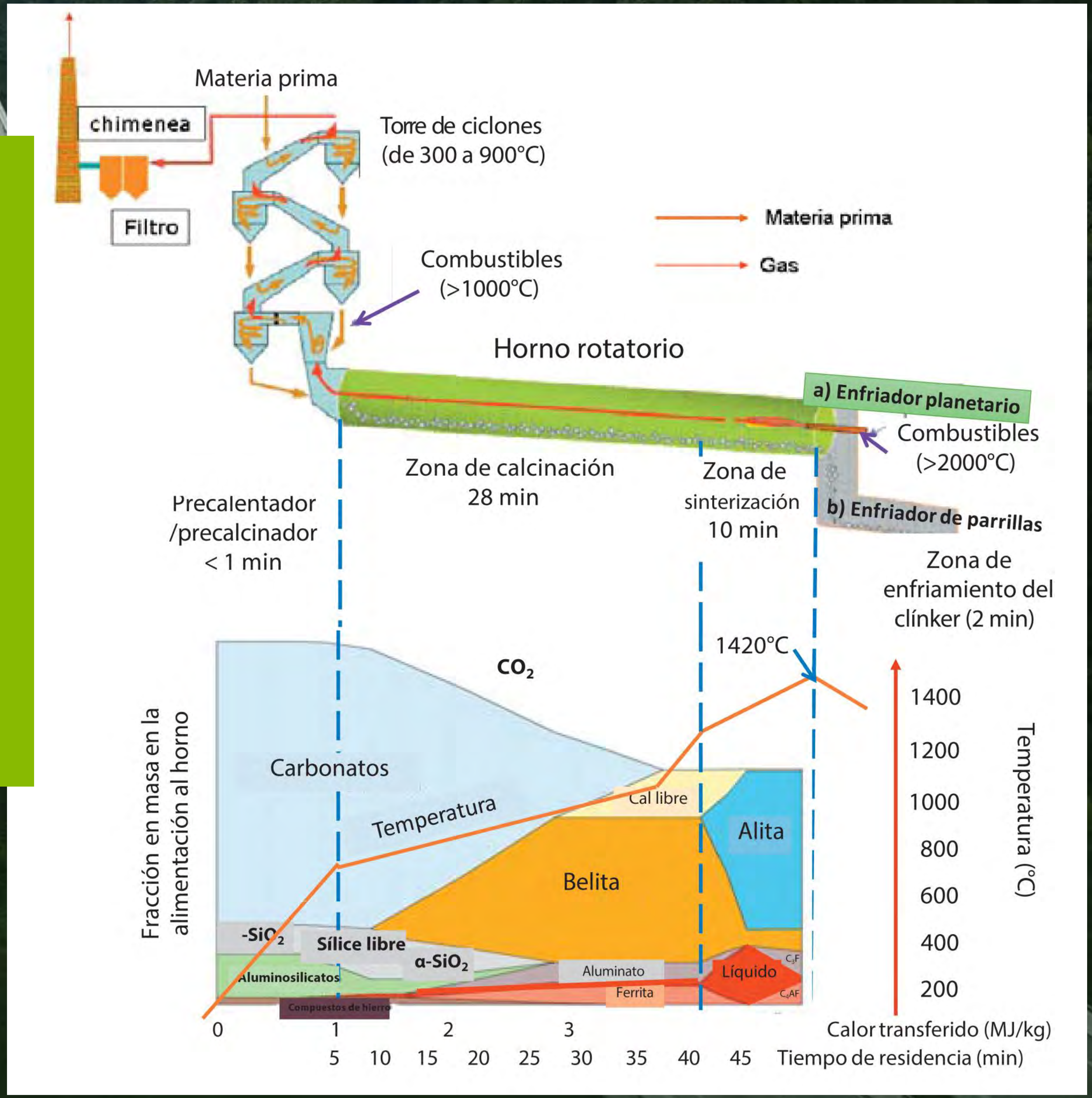
Sanjuán, M.Á.; Andrade, C.; Mora, P.; Zaragoza, A. Carbon Dioxide Uptake by Cement-Based Materials: A Spanish Case Study. *Appl. Sci.* **2020**, *10*, 339. https://doi.org/10.3390/app10010339

Cement sector emissions

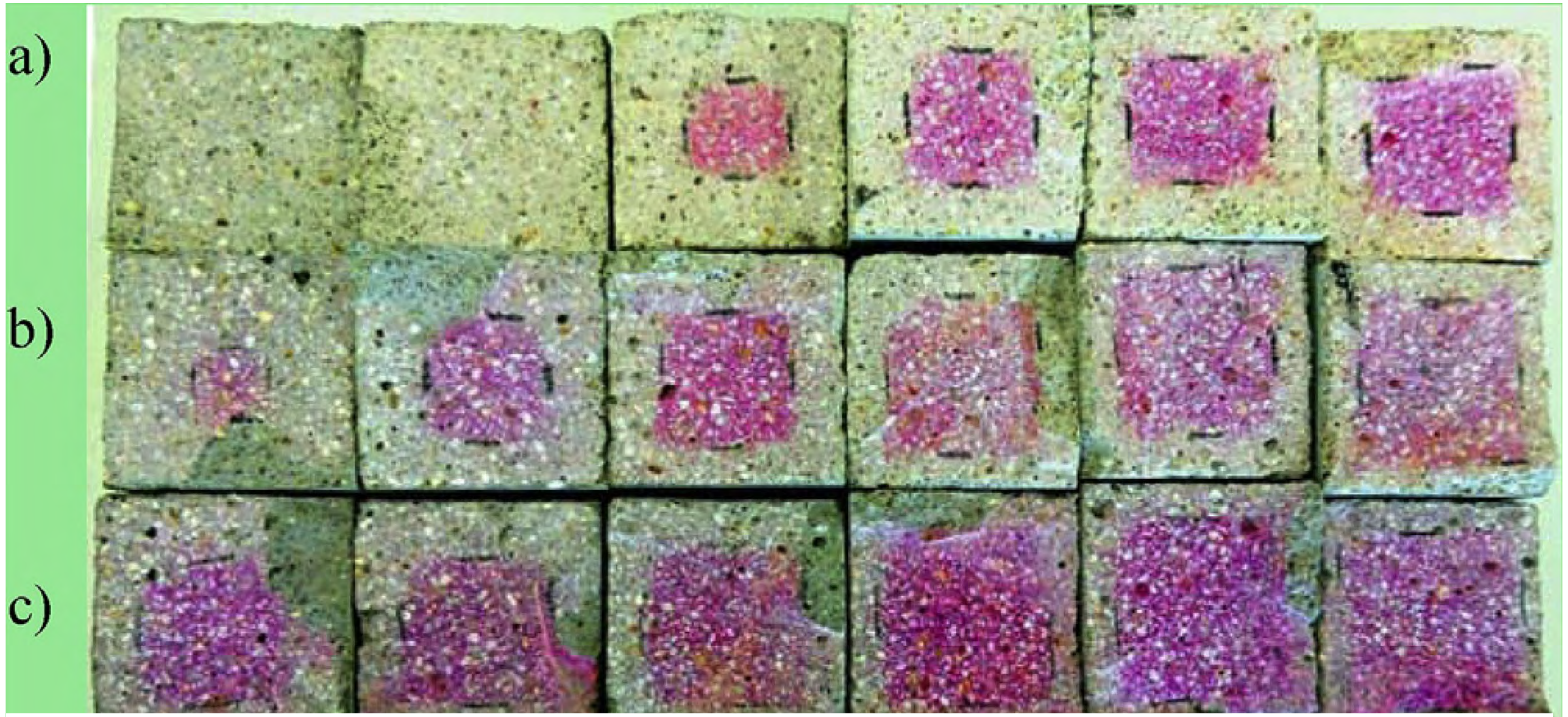


$$CaCO_3 \rightarrow CaO + CO_2 \quad ; \quad 0{,}52 \quad t_{CO_2} / t_{clinker}$$

$$C_xH_y + \left(\frac{y}{4} + x\right)O_2 \rightarrow \frac{y}{2}H_2O + xCO_2 \quad ; \quad 0{,}30 \quad t_{CO_2} / t_{clinker}$$



Carbonation



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

$$20\% \Rightarrow 0{,}52\ t_{CO_2}/t_{clinker} \Rightarrow 0{,}42\ t_{CO_2}/t_{clinker}$$

$$23\% \Rightarrow 0{,}52\ t_{CO_2}/t_{clinker} \Rightarrow 0{,}40\ t_{CO_2}/t_{clinker}$$

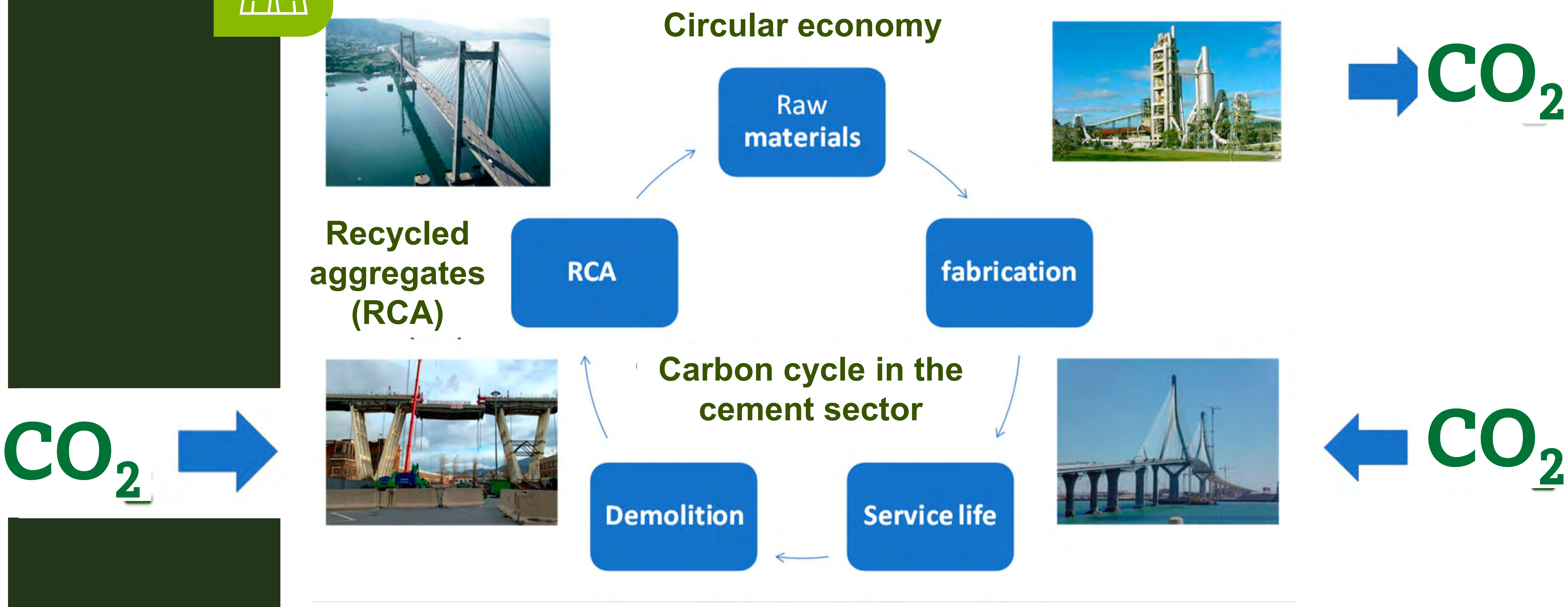
0 1 3 7 14 28 days

Mortars

a) d) CEM I 52.5 R-SR 3
b) CEM III/B 32.5 N-LH/SR
b) CEM II/A-S 42.5 N
c) CEM III/A 42.5 N

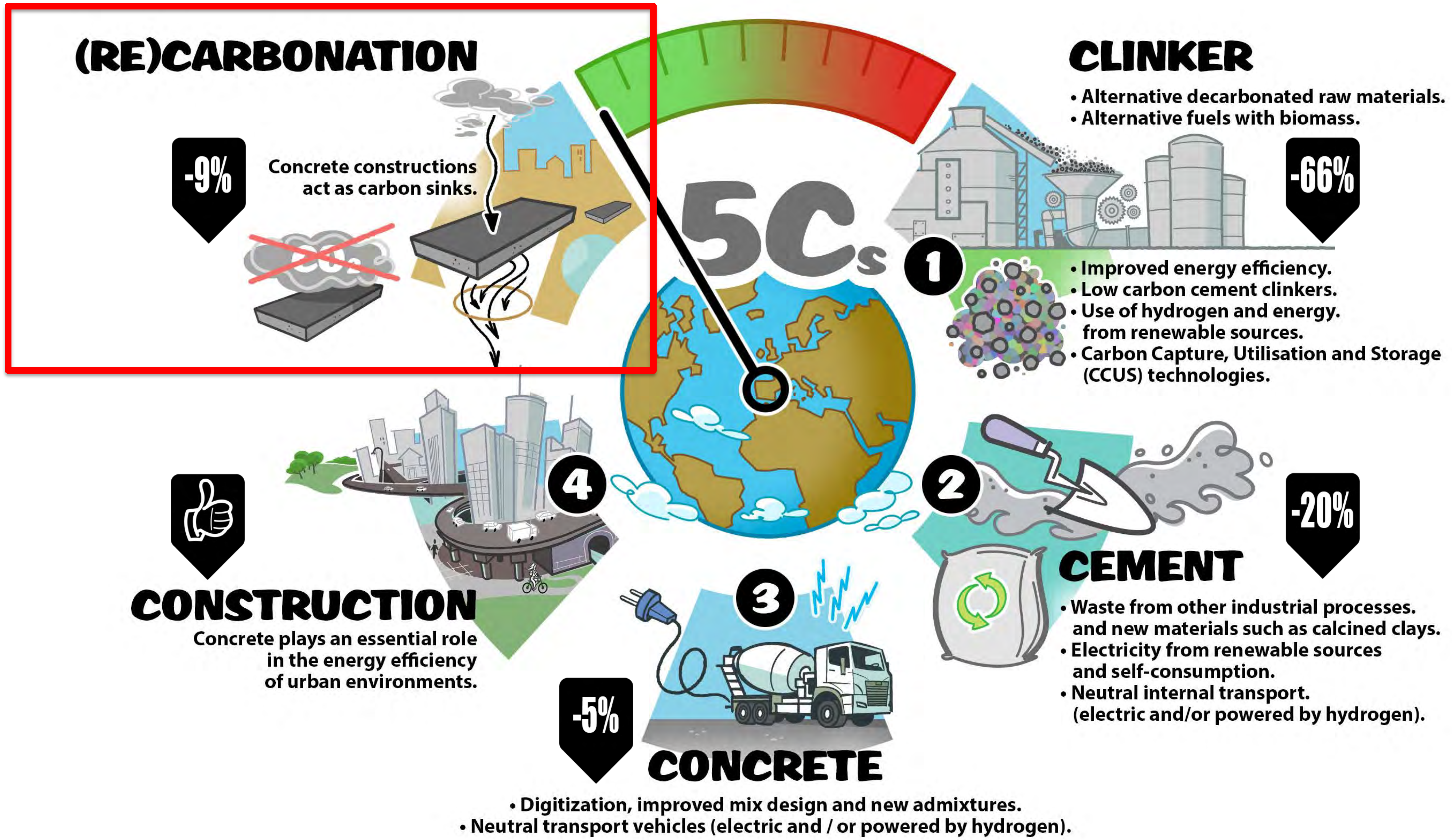
Carbon cycle in the cement sector

CO_2
Emission-absorption



Sanjuán, M.Á.; Andrade, C.; Mora, P.; Zaragoza, A. Carbon Dioxide Uptake by Cement-Based Materials: A Spanish Case Study. *Appl. Sci.* **2020**, *10*, 339. https://doi.org/10.3390/app10010339

Roadmap for the cement sector



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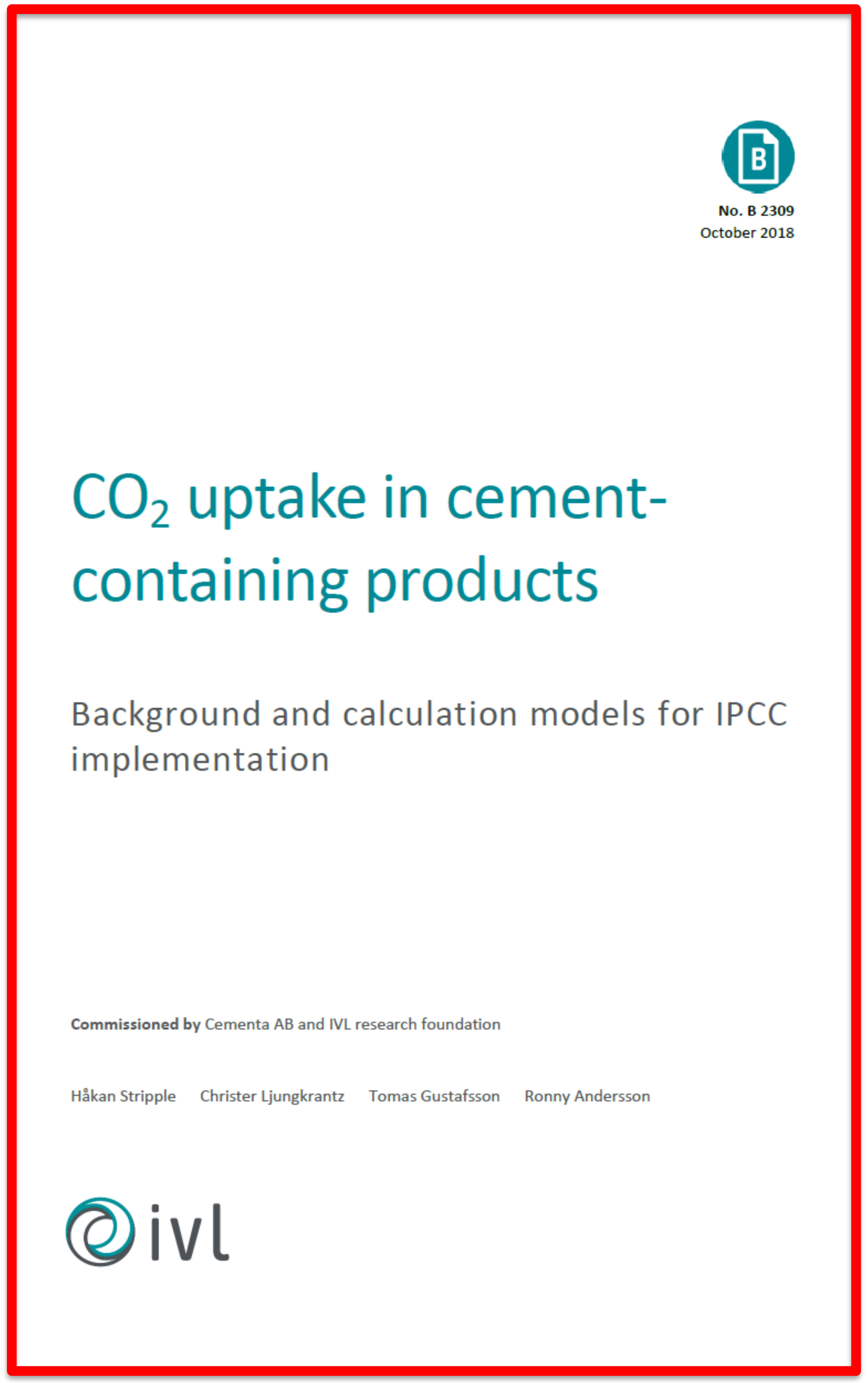
“Concrete CO_2 sink” Project

Carbonation

In 2018, CEMBUREAU, Portland Cement Association (PCA), Cement Sustainability Initiative (CSI), IECA and Cementa (HeidelbergCement Sverige), formed the (Re-)carbonation Project to develop a **method to estimate the carbonation** of mortars and concretes, and its **incorporation in the 2019 IPCC Guidelines for National Greenhouse Gas Inventories**

"Concrete CO_2 sink" Project


No. B 2309
October 2018

CO₂ uptake in cement-containing products

Background and calculation models for IPCC implementation

Commissioned by Cementa AB and IVL research foundation

Håkan Stripple Christer Ljungkrantz Tomas Gustafsson Ronny Andersson

ivl

Result

The most important result was the document '**CO_2 uptake in cement-containing products**' (*IVL Swedish Environmental Research Institute Report*) coordinated by Christer Ljungkrantz and Ronny Andersson (CEMENTA AB), in which two methods were established, the first one proposes that **23% of CO_2 process emissions** (calcination) can be discounted directly, while the second one is based on the procedure defined in Annex BB of **EN 16757**. Currently, **Annex G.**

October 2018

IPCC Expert Meeting on Carbon Dioxide Removal Technologies

“Concrete CO_2 sink” Project

Result

For the moment, the desired objective of being included in the ***2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*** was **not achieved** (Chapter 2: Mineral Industry Emissions), published in 2019.

2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories
https://www.ipcc.ch/report/2019-refinement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/

2019

IPCC Guidelines for National Greenhouse Gas Inventories

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2006 + 2019 IPCC Guidelines for National Greenhouse Gas Inventories

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2.3 Lime production
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Volume 5 Waste

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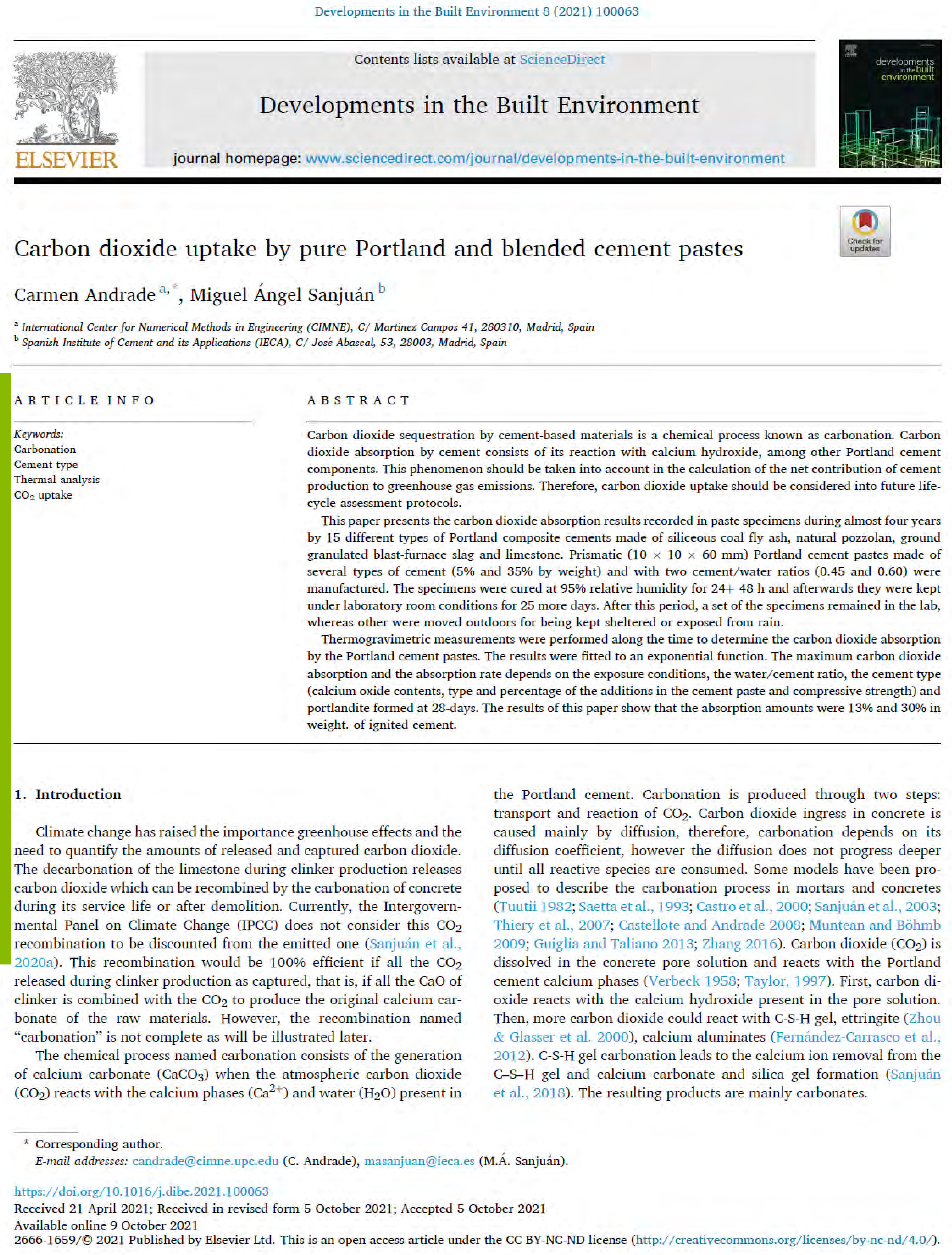
CO_2 uptake modelling (cement sector)



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Carbon dioxide uptake by pure Portland and blended cement pastes

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Carbonation
Cement type
Thermal analysis
CO_2 uptake

ABSTRACT

Carbon dioxide sequestration by cement-based materials is a chemical process known as carbonation. Carbon dioxide absorption by cement consists of its reaction with calcium hydroxide, among other Portland cement components. This phenomenon should be taken into account in the calculation of the net contribution of cement production to greenhouse gas emissions. Therefore, carbon dioxide uptake should be considered into future life-cycle assessment protocols.

This paper presents the carbon dioxide absorption results recorded in paste specimens during almost four years by 15 different types of Portland composite cements made of siliceous coal fly ash, natural pozzolan, ground granulated blast-furnace slag and limestone. Prismatic (10 × 10 × 60 mm) Portland cement pastes made of several types of cement (5% and 35% by weight) and with two cement/water ratios (0.45 and 0.60) were manufactured. The specimens were cured at 95% relative humidity for 24+ 48 h and afterwards they were kept under laboratory room conditions for 25 more days. After this period, a set of the specimens remained in the lab, whereas other were moved outdoors for being kept sheltered or exposed from rain.

Thermogravimetric measurements were performed along the time to determine the carbon dioxide absorption by the Portland cement pastes. The results were fitted to an exponential function. The maximum carbon dioxide absorption and the absorption rate depends on the exposure conditions, the water/cement ratio, the cement type (calcium oxide contents, type and percentage of the additions in the cement paste and compressive strength) and portlandite formed at 28-days. The results of this paper show that the absorption amounts were 13% and 30% in weight. of ignited cement.

1. Introduction

Climate change has raised the importance greenhouse effects and the need to quantify the amounts of released and captured carbon dioxide. The decarbonation of the limestone during clinker production releases carbon dioxide which can be recombined by the carbonation of concrete during its service life or after demolition. Currently, the Intergovernmental Panel on Climate Change (IPCC) does not consider this CO_2 recombination to be discounted from the emitted one (Sanjuán et al., 2020a). This recombination would be 100% efficient if all the CO_2 released during clinker production as captured, that is, if all the CaO of clinker is combined with the CO_2 to produce the original calcium carbonate of the raw materials. However, the recombination named "carbonation" is not complete as will be illustrated later.

The chemical process named carbonation consists of the generation of calcium carbonate ($CaCO_3$) when the atmospheric carbon dioxide (CO_2) reacts with the calcium phases (Ca^{2+}) and water (H_2O) present in the Portland cement. Carbonation is produced through two steps: transport and reaction of CO_2. Carbon dioxide ingress in concrete is caused mainly by diffusion, therefore, carbonation depends on its diffusion coefficient, however the diffusion does not progress deeper until all reactive species are consumed. Some models have been proposed to describe the carbonation process in mortars and concretes (Tuutii 1982; Saetta et al., 1993; Castro et al., 2000; Sanjuán et al., 2003; Thiery et al., 2007; Castellote and Andrade 2008; Muntean and Böhmb 2009; Guiglia and Taliano 2013; Zhang 2016). Carbon dioxide (CO_2) is dissolved in the concrete pore solution and reacts with the Portland cement calcium phases (Verbeck 1958; Taylor, 1997). First, carbon dioxide reacts with the calcium hydroxide present in the pore solution. Then, more carbon dioxide could react with C-S-H gel, ettringite (Zhou & Glasser et al. 2000), calcium aluminates (Fernández-Carrasco et al., 2012). C-S-H gel carbonation leads to the calcium ion removal from the C–S–H gel and calcium carbonate and silica gel formation (Sanjuán et al., 2018). The resulting products are mainly carbonates.

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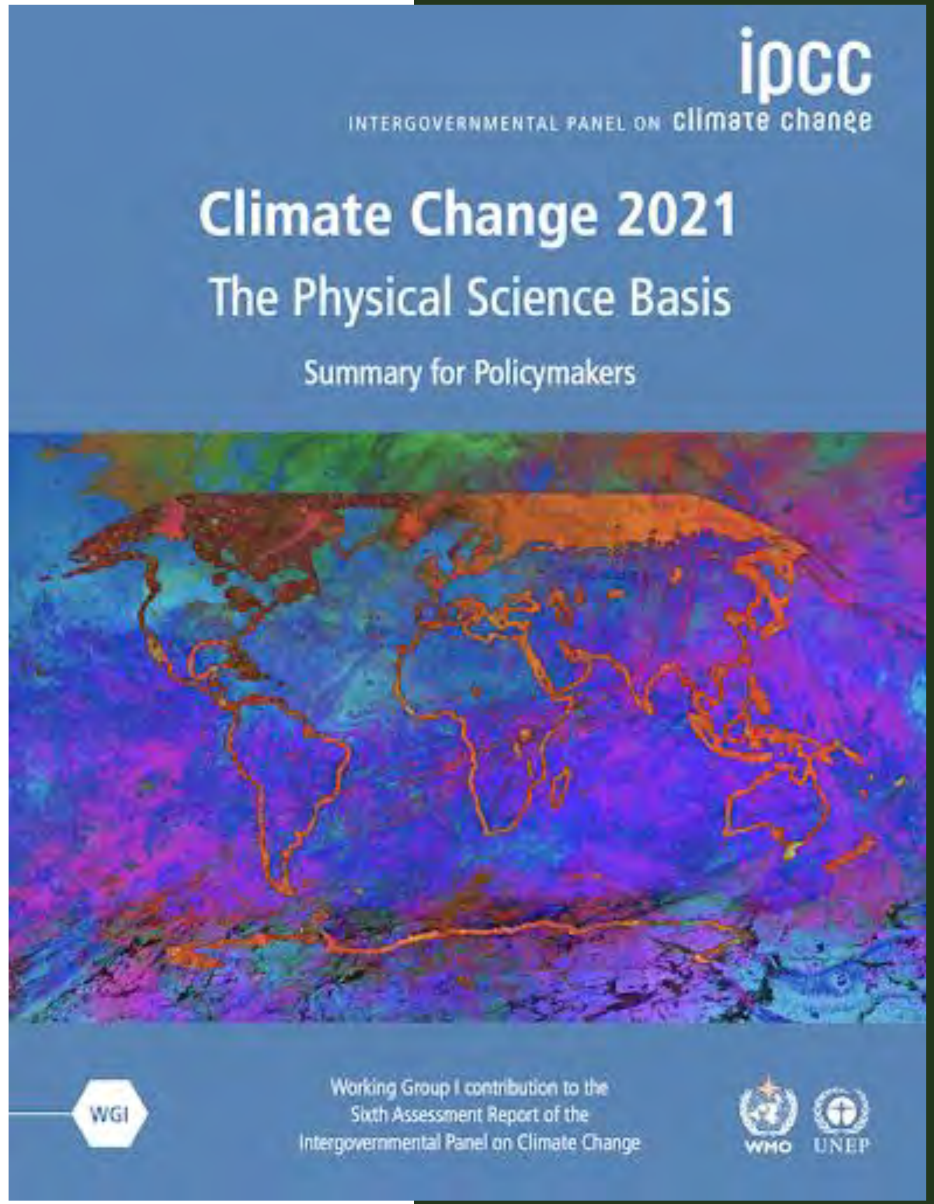
Sixth Assessment Report (AR6)



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climate change
WMO UNEP
Sixth Assessment Report

Sixth Assessment Report (AR6) - WG I "The Physical Science Basis"

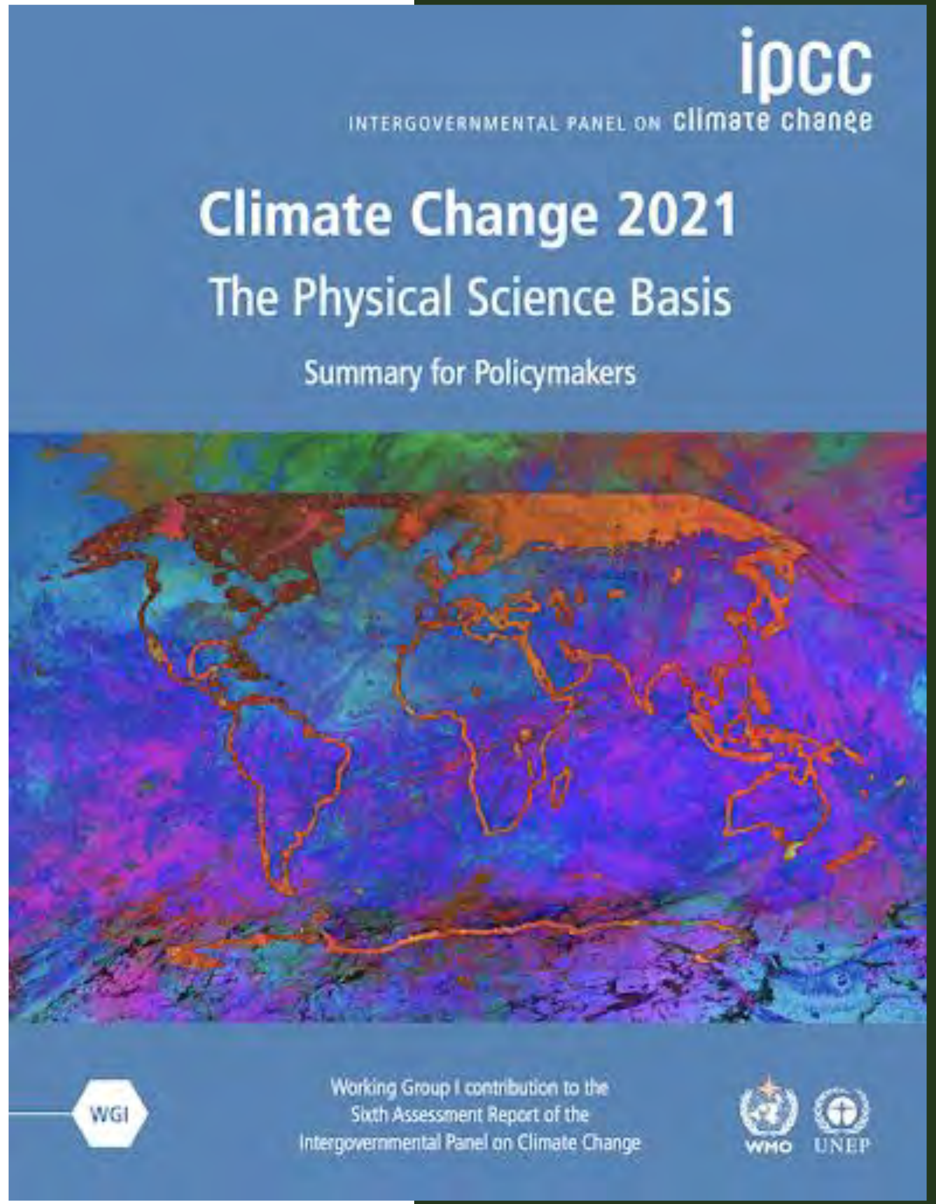
p.19 (full report 1171)

In 2019, fossil CO_2 emissions were estimated to be 9.9 ± 0.5 PgC yr-1 excluding carbonation (Friedlingstein et al., 2020) the highest on record. These estimates ***excluding the cement carbonation sink of around 0.2 PgC yr-1****.*

p. 5-20 (full report 1172)

Direct CO_2 emissions from carbonates in cement production are around 4% of total fossil CO_2 emissions and grew at 5.8% yr-1 in the 2000s but a slower 2.4% yr-1 in the 2010s. ***The uptake of CO_2 in cement infrastructure (carbonation) offsets about one half of the carbonate emissions from current cement production*** *(Friedlingstein et al., 2020).*

Sixth Assessment Report (AR6)



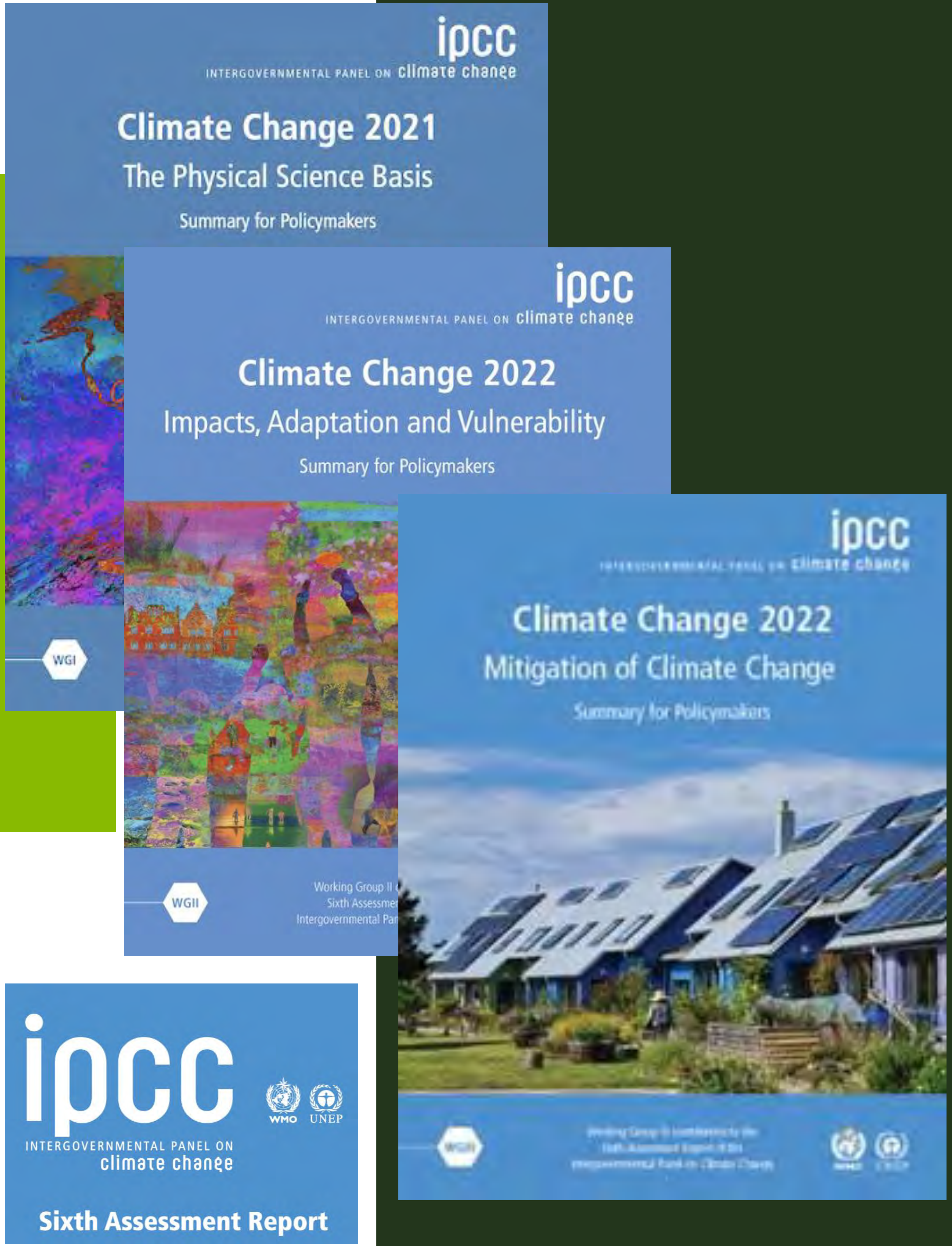
Sixth Assessment Report (AR6) - WG I "The Physical Science Basis"

p. 5-32 (full 1184)

Since AR5 (Ciais et al., 2013), a number of improvements have led to a more constrained carbon budget. Some new additions include: (i) the use of independent estimates for the residual carbon sink on natural terrestrial ecosystems (Le Quéré et al., 2018a), ***(ii) improvements in the estimates of emissions from cement production (Andrew, 2019) and the sink associated with cement carbonation (Cao et al., 2020).***

IPCC INTERGOVERNMENTAL PANEL ON climate change WMO UNEP

Sixth Assessment Report



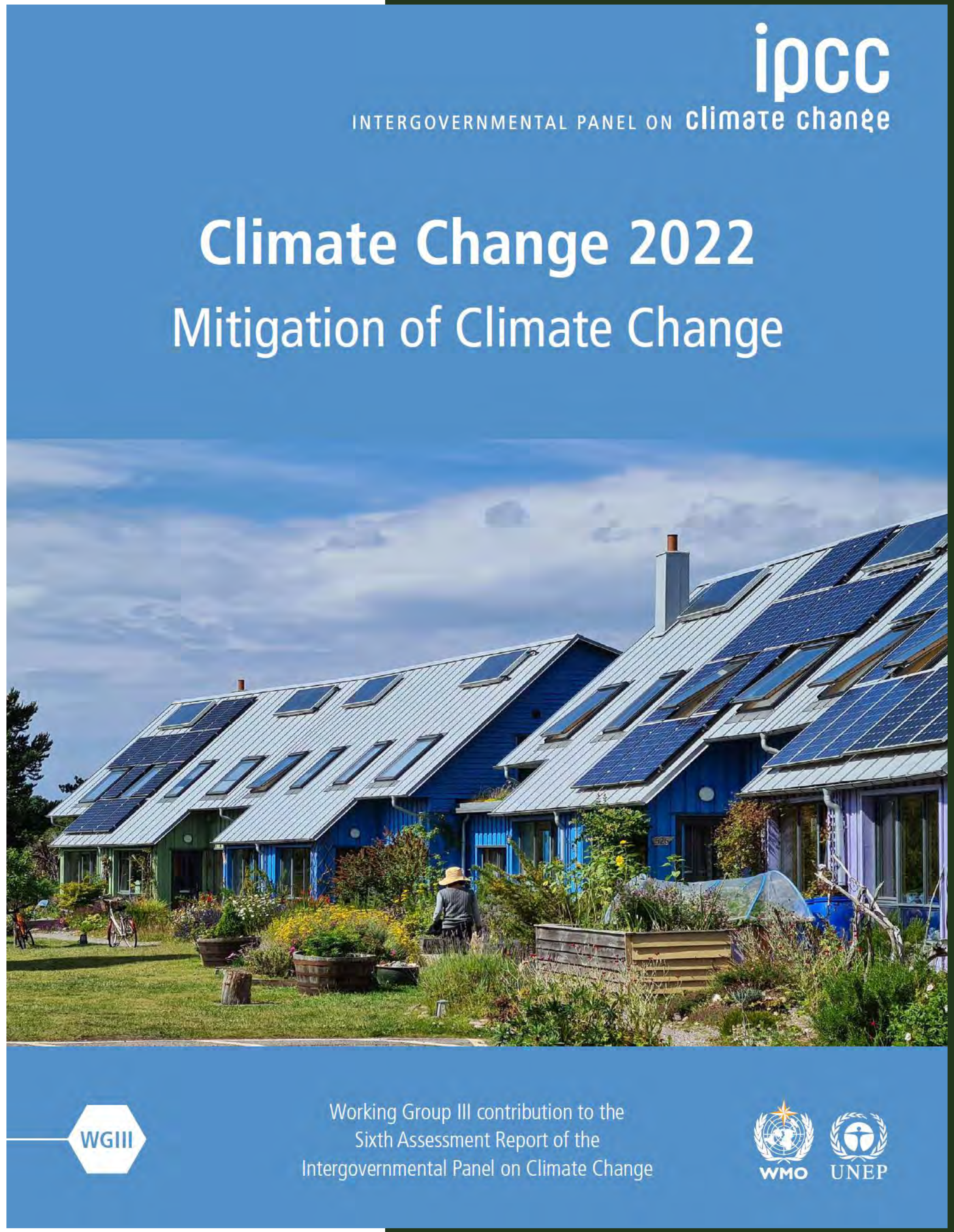
Sixth Assessment Report (AR6)

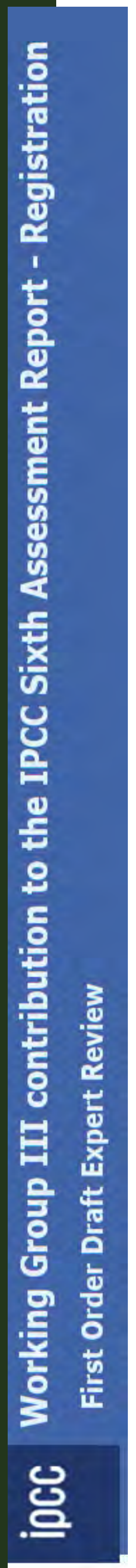
Sixth Assessment Report (AR6) - WG III

p. 430

The member companies of the **GCCA** (CSI) have become better prepared for future legislation on managing GHG emissions and developed management competence to respond to climate change in the cement sector (Busch et al. 2008; GCCA 2020). Accordingly, the cement industry has developed some **roadmaps to reach net zero GHG** around 2050 (Sanjuan et al. 2020).

Sixth Assessment Report (AR6)





Sixth Assessment Report (AR6) - WG III

p. 977

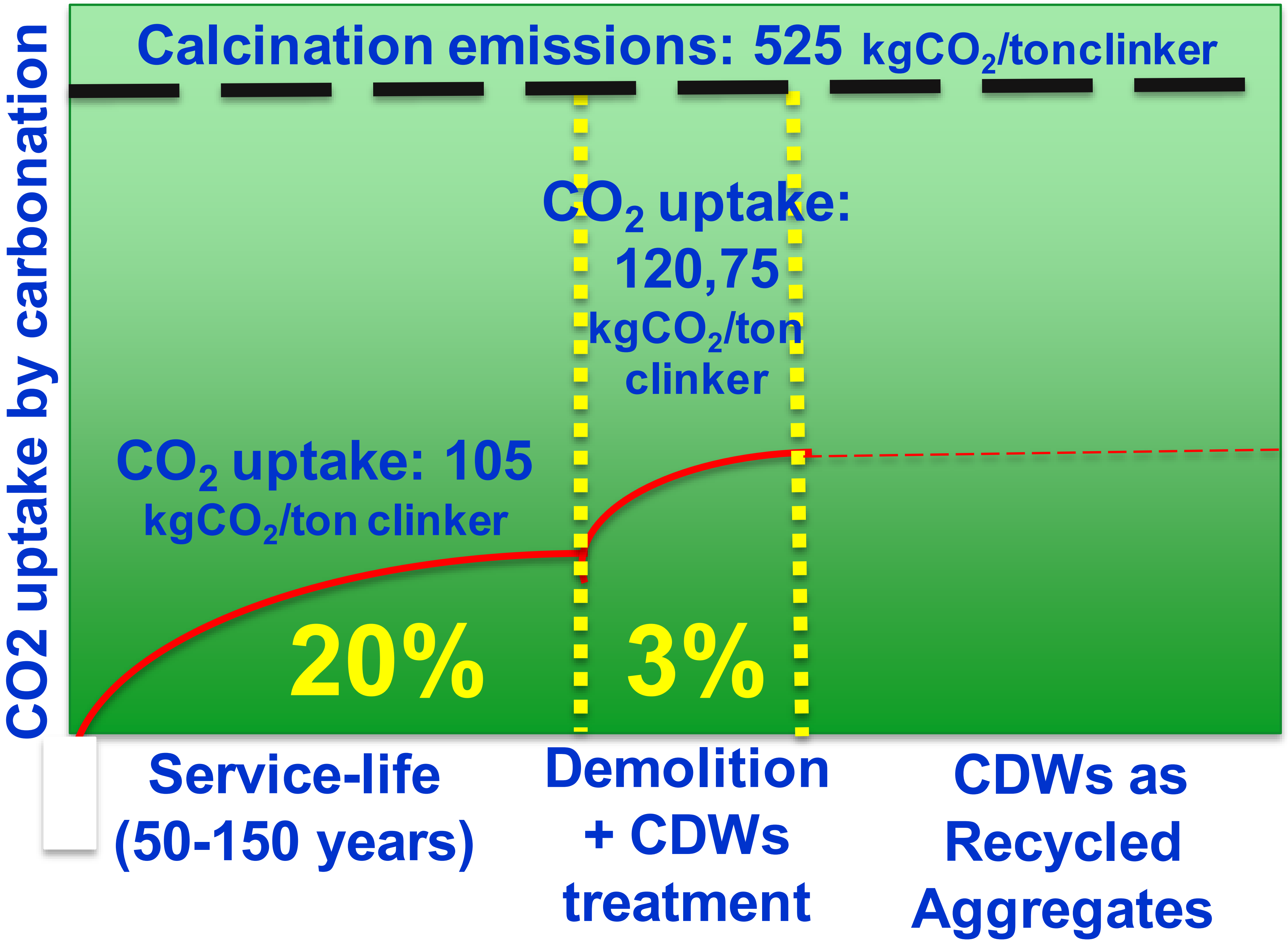
The concept of **buildings as carbon sinks** arise from the idea that wood stores considerable quantities of carbon with a relatively small ratio of carbon emissions to material volume and concrete has substantial embodied carbon emissions with minimal carbon storage capacity (Sanjuan et al. 2019; Churkina et al. 2020).

p. 1190

Some of the **CO_2 is reabsorbed into concrete** products and can be seen as avoided during the decades-long life of the products; estimates of this flux vary between **15 and 30% of the direct emissions** (Stripple et al. 2018; Andersson et al. 2019; Schneider 2019; Cao et al. 2020; GCCA 2021a). Some companies are **mixing CO_2 into hardening concrete**, both to dispose of the CO_2 and more importantly reduce the need for binder (Lim et al. 2019).

Methodologies

Tier 1



Modules: A B C D

Carbon Dioxide Uptake by Brazilian Cement-Based Materials

applied sciences **Tier 1** MDPI

Article

Carbon Dioxide Uptake by Brazilian Cement-Based Materials

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[4] Oficemen, C/José Abascal, 53, 28003 Madrid, Spain; azaragoza@oficemen.com
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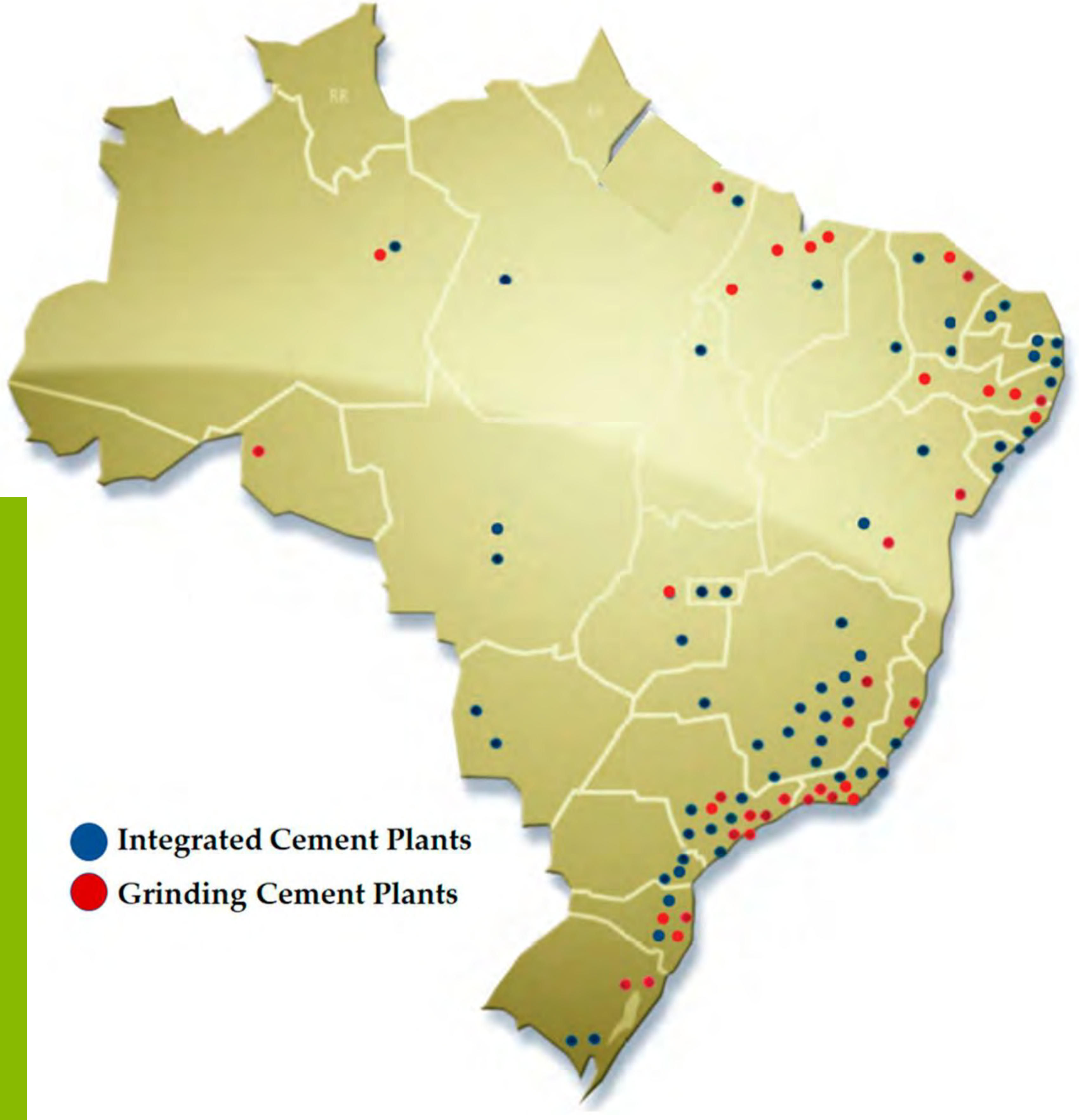
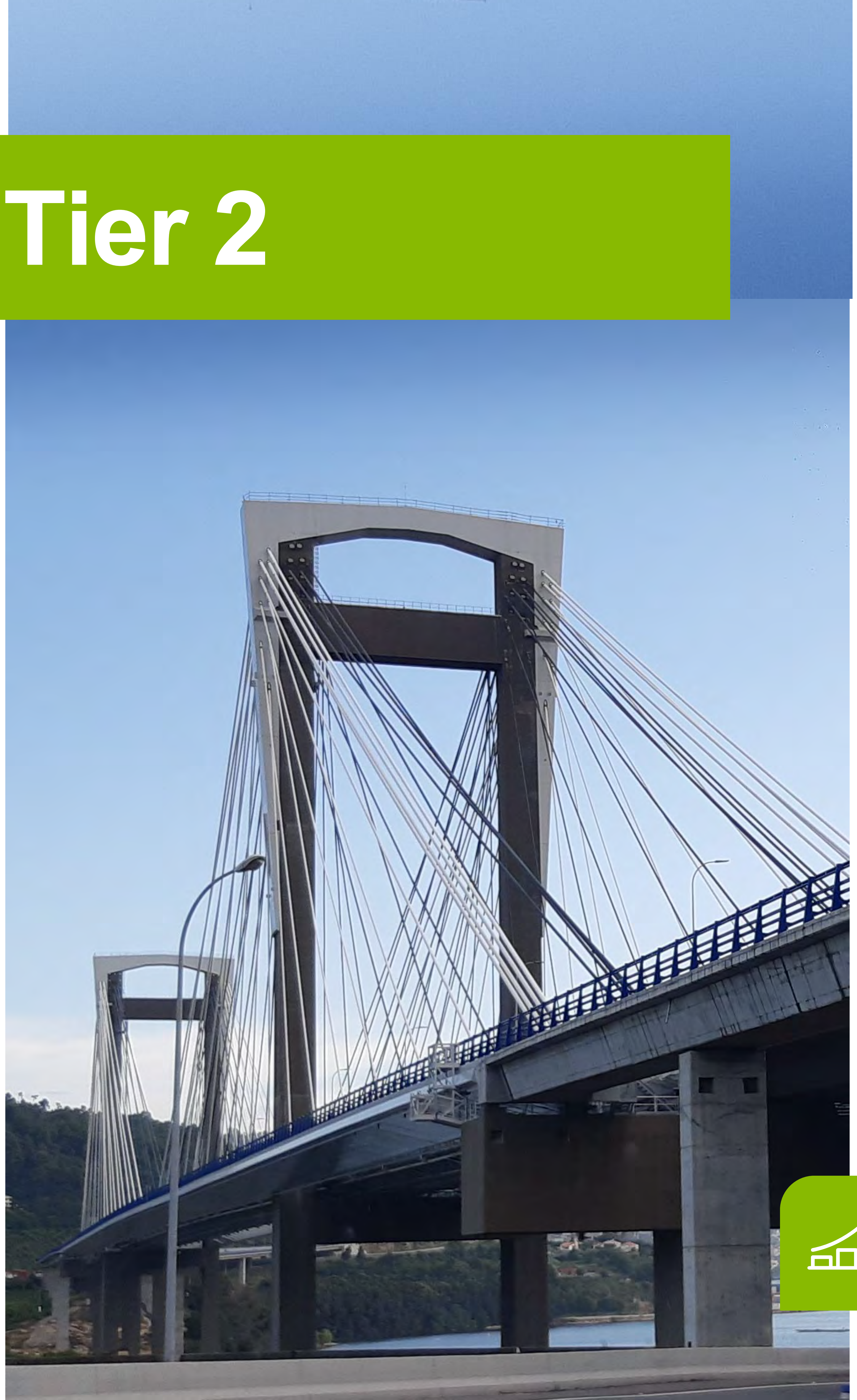


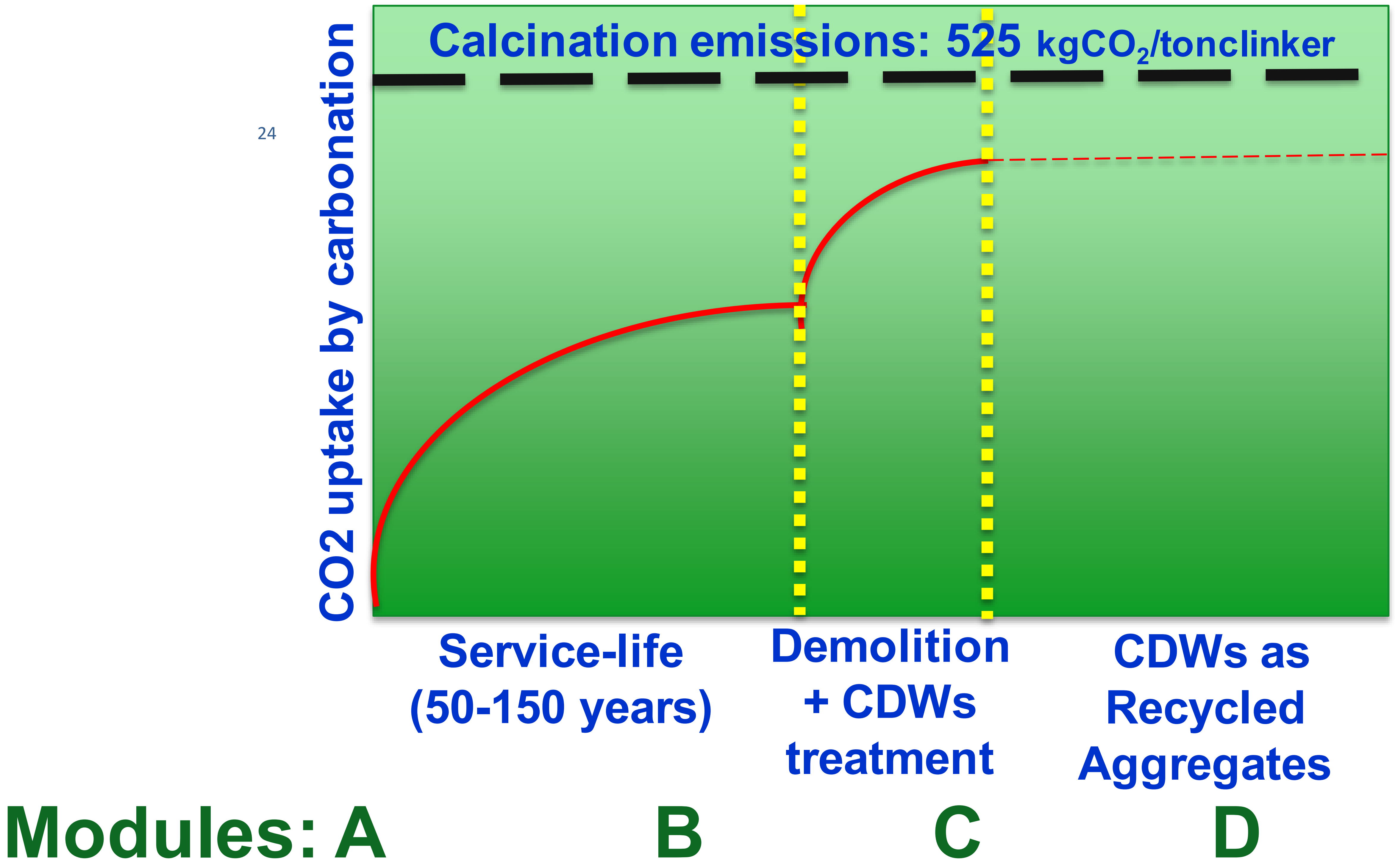
CO_2 uptake = (0.20 + 0.02 + 0.01) × calcination CO_2 emissions (1)

CO_2 uptake = 0.23 × calcination CO_2 emissions (NIR, national) (2)

da Silva Rego, J.H.; Sanjuán, M.Á.; Mora, P.; Zaragoza, A.; Visedo, G. Carbon Dioxide Uptake by Brazilian Cement-Based Materials. *Appl. Sci.* **2023**, *13*, 10386. https://doi.org/10.3390/app131810386

Tier 2

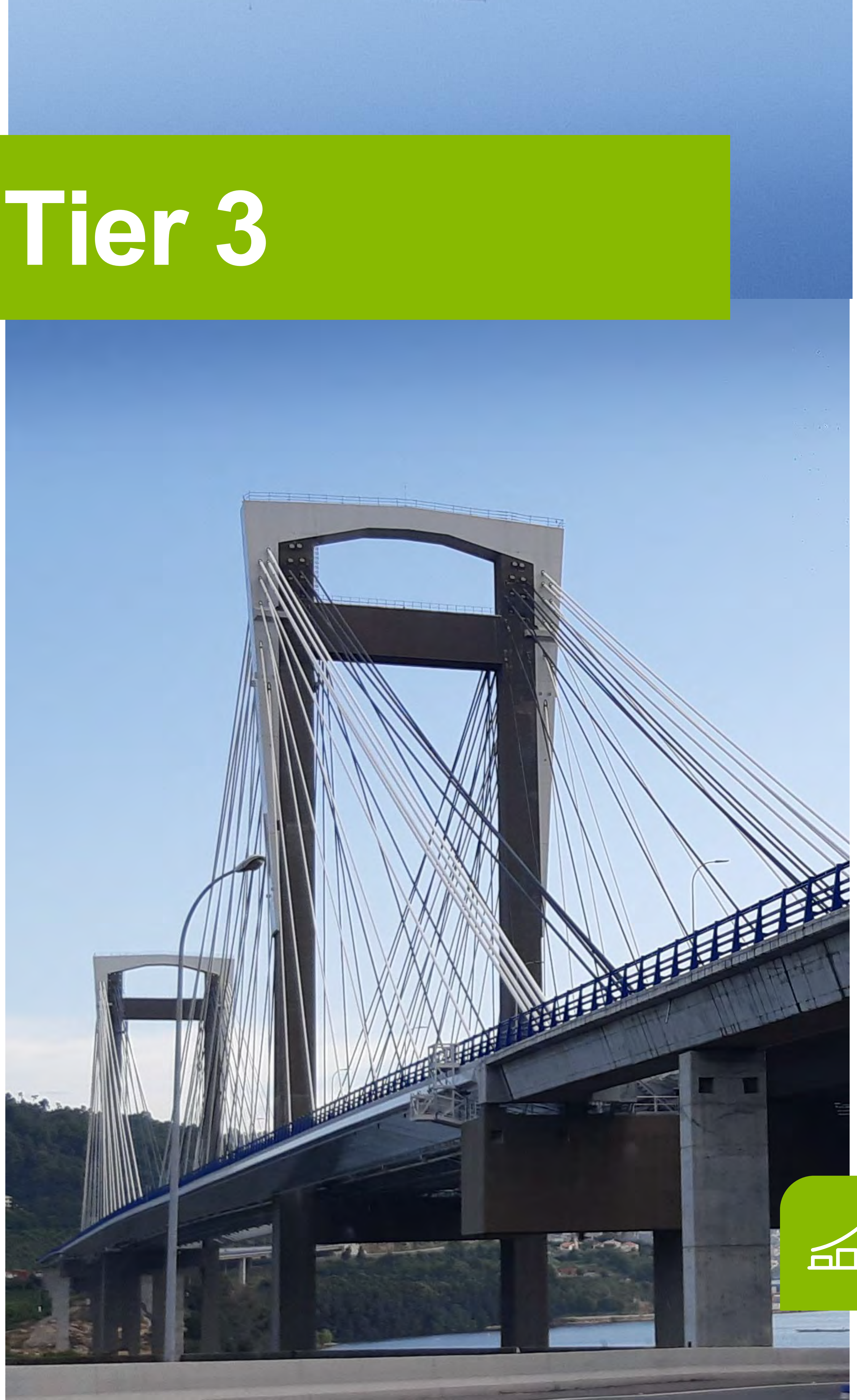




Tier 2: Advanced Methodology

EN 16757:2017. Sustainability of construction works - Environmental product declarations - Product Category Rules for concrete and concrete elements.

Tier 3



nature geoscience
LETTERS
PUBLISHED ONLINE: 21 NOVEMBER 2016 | DOI: 10.1038/NGEO2840

Substantial global carbon uptake by cement carbonation

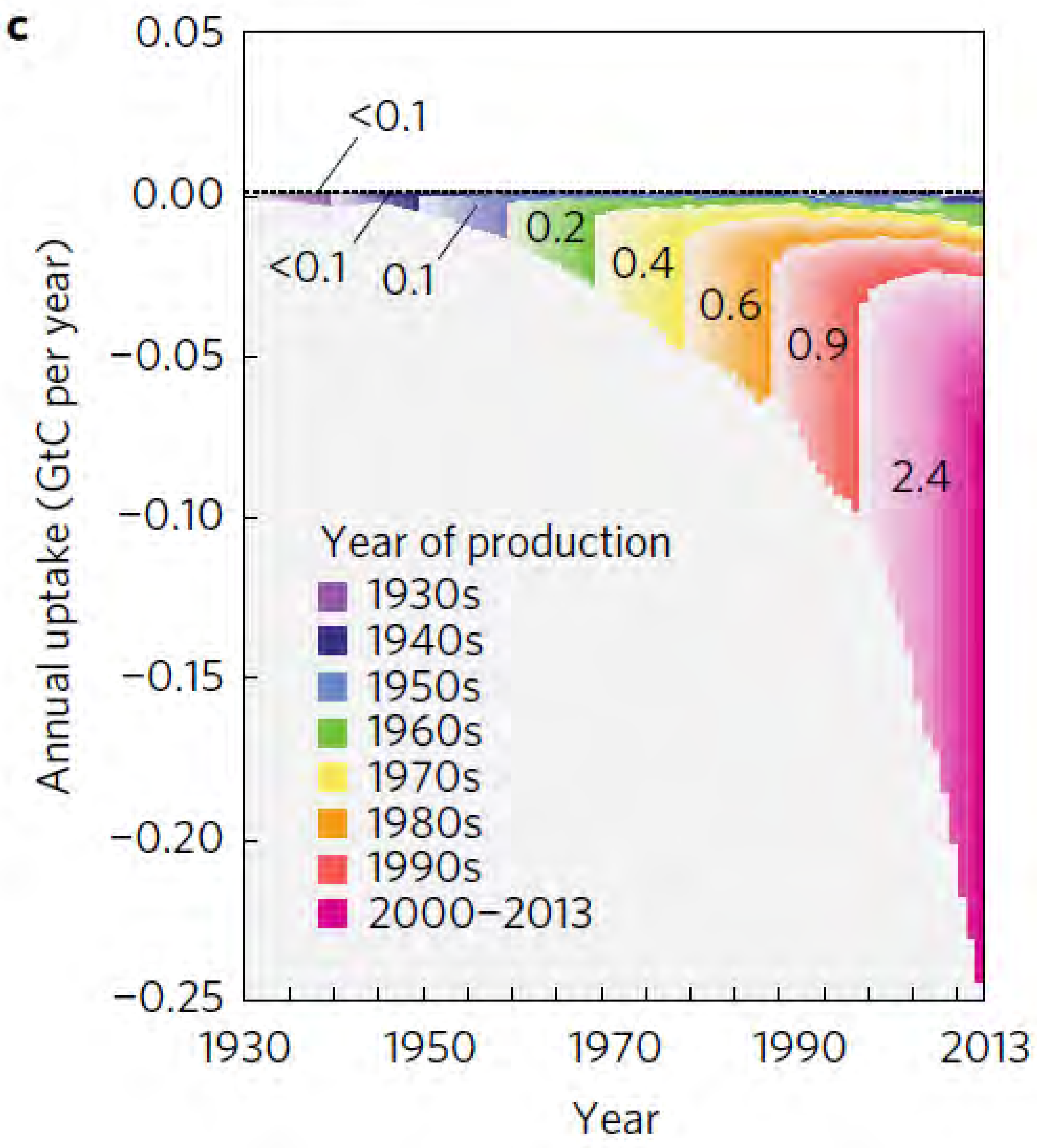
Fengming Xi[1,2,3], Steven J. Davis[1,4], Philippe Ciais[5], Douglas Crawford-Br
Claus Pade[8], Tiemao Shi[3], Mark Syddall[6], Jie Lv[9], Lanzhu Ji[1], Longfei Bin
Keun-Hyeok Yang[11], Björn Lagerblad[12], Isabel Galan[13], Carmen Andrade[1
and Zhu Liu[16,17]*

Calcination of carbonate rocks during the manufacture of cement produced 5% of global CO_2 emissions from all industrial process and fossil-fuel combustion in 2013[1,2]. Considerable attention has been paid to quantifying these industrial process emissions from cement production[2,3], but the natural reversal of the process—carbonation—has received little attention in carbon cycle studies. Here, we use new and existing data on cement materials during cement service life, demolition, and secondary use of concrete waste to estimate regional and global CO_2 uptake between 1930 and 2013 using an analytical model describing carbonation chemistry. We find that carbonation of cement materials over their life cycle represents a large and growing net sink of CO_2, increasing from 0.10 GtC yr^{-1} in 1998 to 0.25 GtC yr^{-1} in 2013. In total, we estimate that a cumulative amount of 4.5 GtC has been sequestered in carbonating cement materials from 1930 to 2013, offsetting 43% of the CO_2 emissions from production of cement over the same period, not including emissions associated with fossil use during cement production. We conclude that carbonation of cement products represents a substantial carbon sink that is not currently considered in emissions inventories[1,2,4].

A tremendous quantity of cement has been produced worldwide for the construction of buildings and infrastructure, namely: 76.2 billion tons of cement between 1930 and 2013, and 4.0 billion tons in 2013 alone[1]. When making cement, the high-temperature calcination of carbonate minerals (for example, limestone rocks) produces clinker (mainly calcium oxide), and CO_2 is released into the atmosphere from this process. These 'process' CO_2 emissions from cement production (as opposed to related emissions from fossil-fuel energy that may have been used during cement production) comprise approximately 90% of global CO_2 emissions from all industrial processes and 5% of global CO_2 emissions from industrial processes
Cumulative cement proces
38.2 Gt CO_2 from 1930 to
However, the calcium
over time, and cement
atmospheric CO_2 throu
carbonation[3–8]. Carbonati
pores of cement-based ma
in the presence of pore w
starts at the surface of th
moves inwards. Althougl
civil engineers due to the
structures[9,10], the resultin
been quantified. In contra
during manufacture of c
that takes place througho
materials[11]. The CO_2 u
materials is thus propor
consumption. Previous stu
to estimate concrete ca
timescales[9,11,12]. However,
materials in specific regio
in other types of cement
cement mortar, construc
dust worldwide.

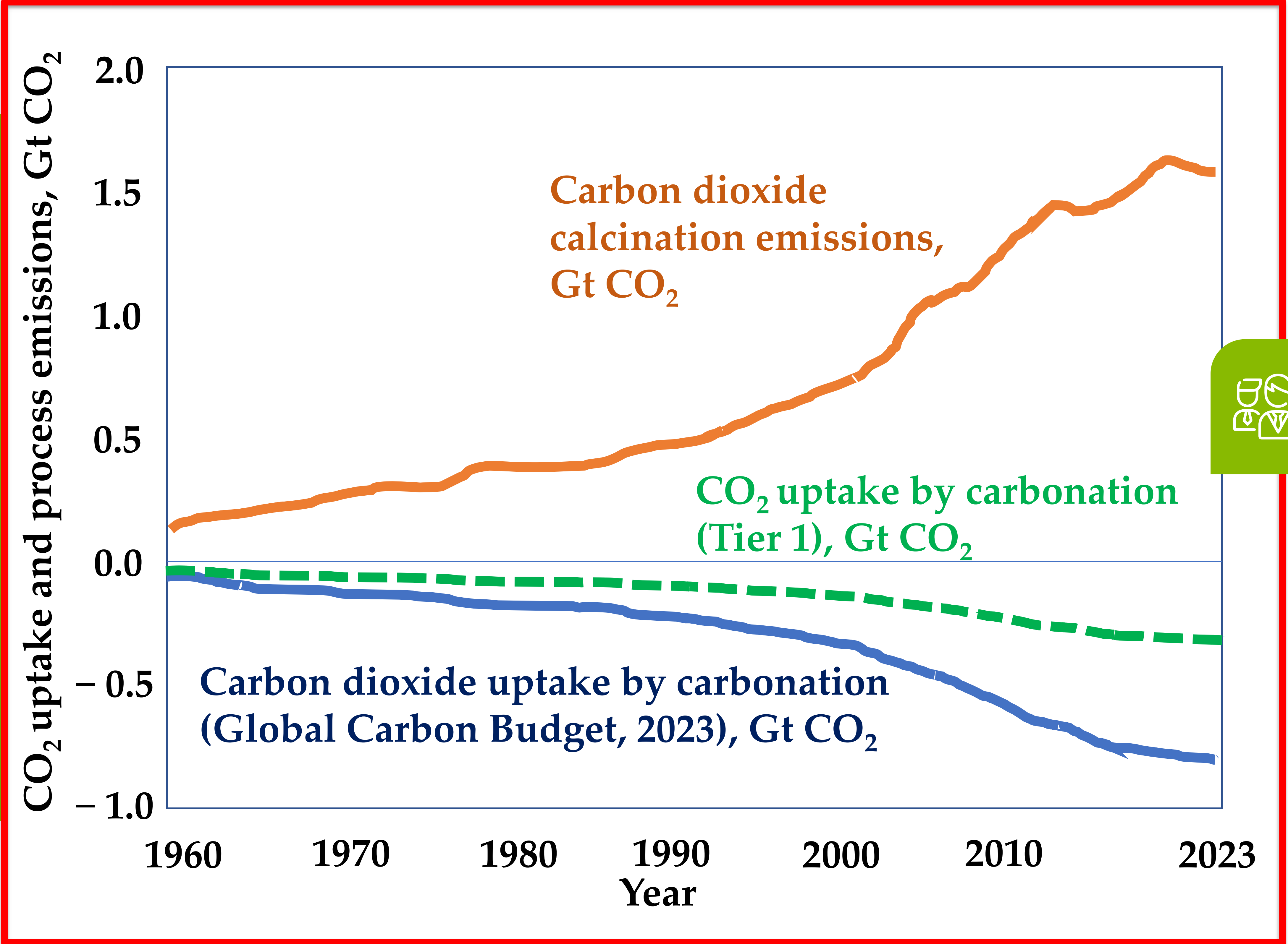
Based on new data set
and a comprehensive syn
Methods), we modelled th
different cement materials
waste, and cement kiln dus
(China, the US, Europe,
the sensitivity of our up
(see Methods).

[1]Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110016, China. [2]Key Laboratory of Poll



Tier 3: Ad-hoc Methodology

Xi, F., Davis, S., Ciais, P. … …. **Andrade, C.**, *et al.* Substantial global carbon uptake by cement carbonation. *Nature Geosci* **9,** 880–883 (2016). https://doi.org/10.1038/ngeo2840



Above 700 Mtons/year in 2023 for the cement carbonation sink

Global Carbon Budget de 2023

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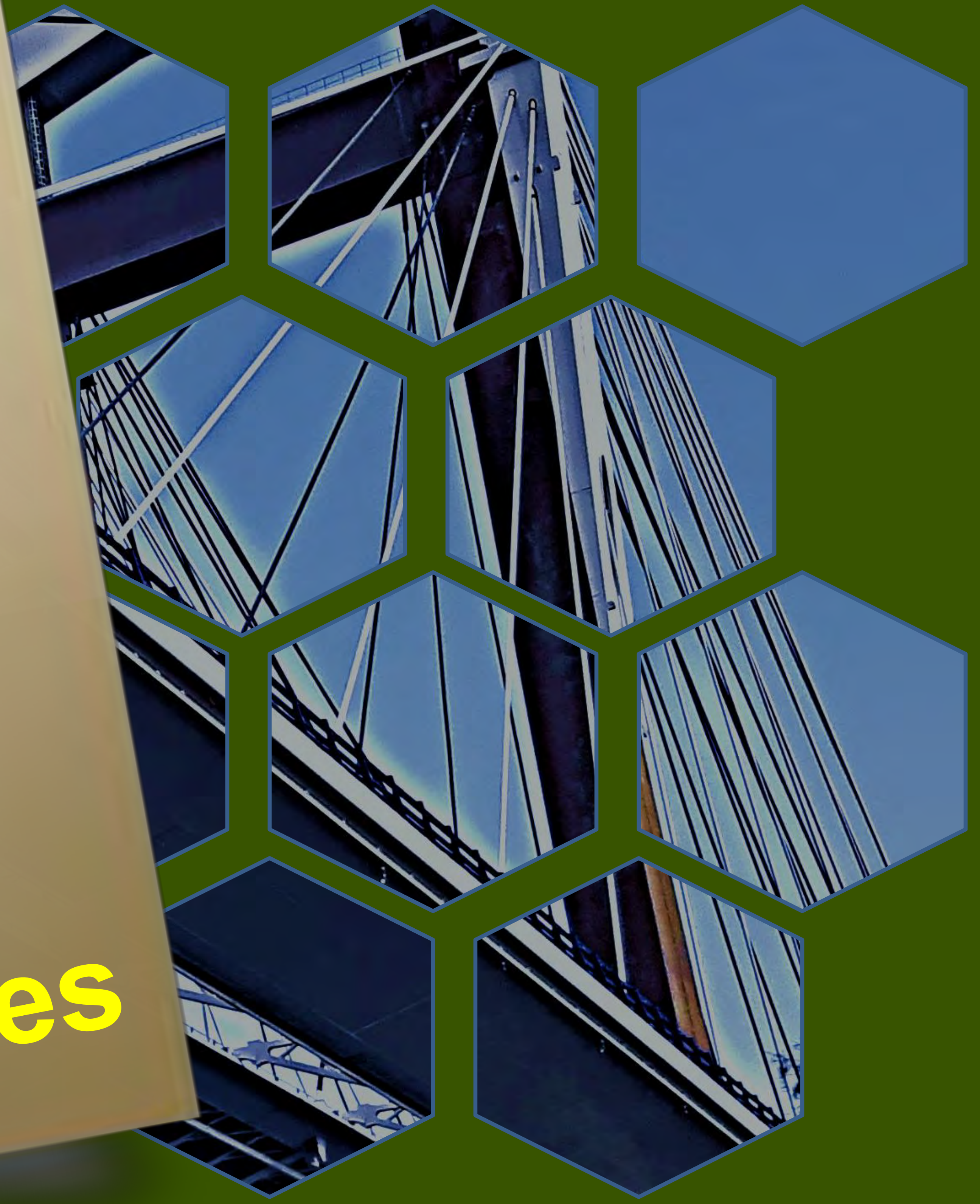
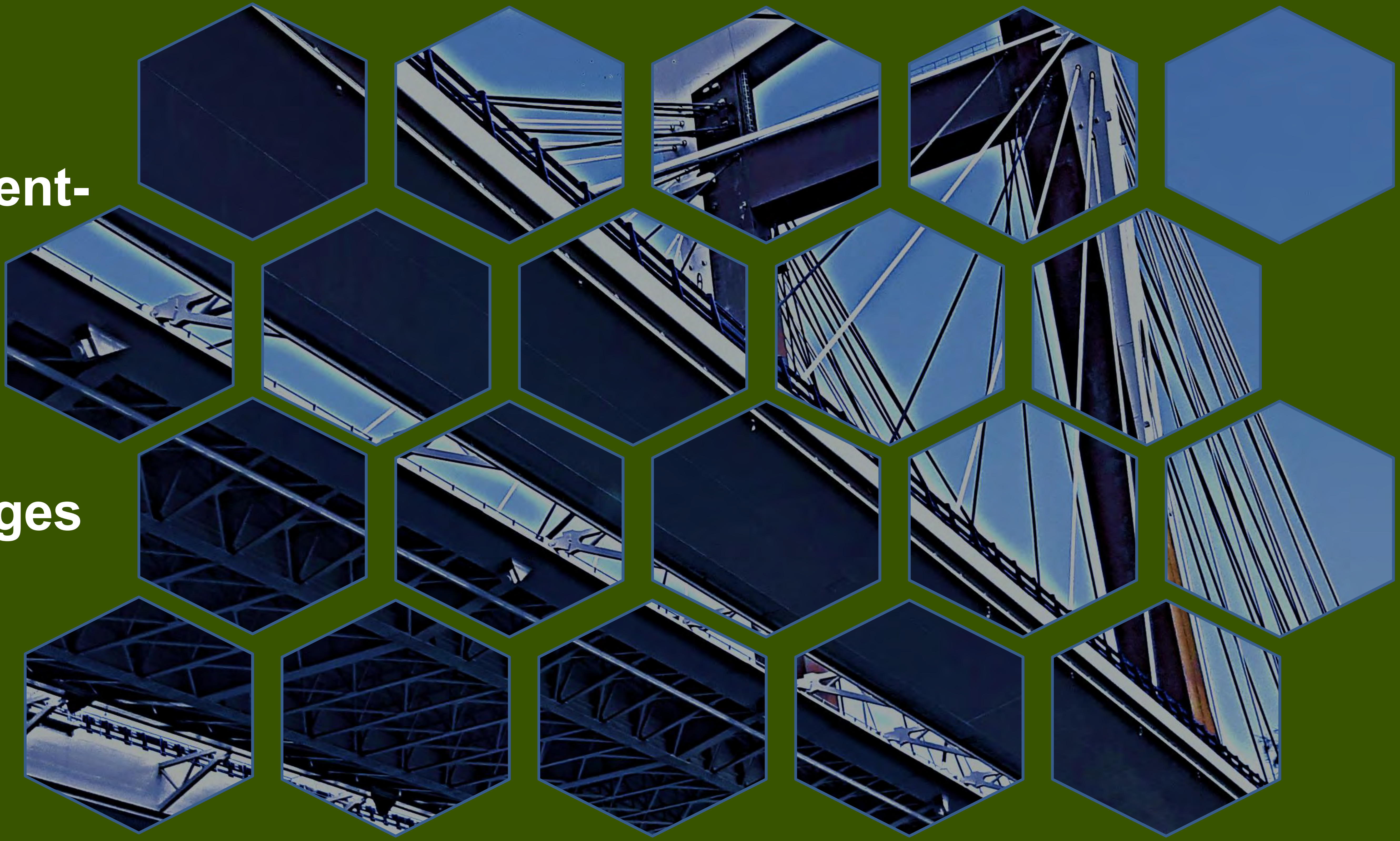


State of the art on the quantification of natural carbonation of cement-based materials as a CO_2 capture mechanism

Conclusion



Natural carbonation of cement-based materials is a well-known process.

The rate of carbonation ranges from 1 to 9 mm/year$^{0.5}$.

Cement carbonation sink could be about 700 million tons per year.

Natural carbonation of cement-based materials should be implemented in the IPCC Guidelines for National Greenhouse Gas Inventories

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