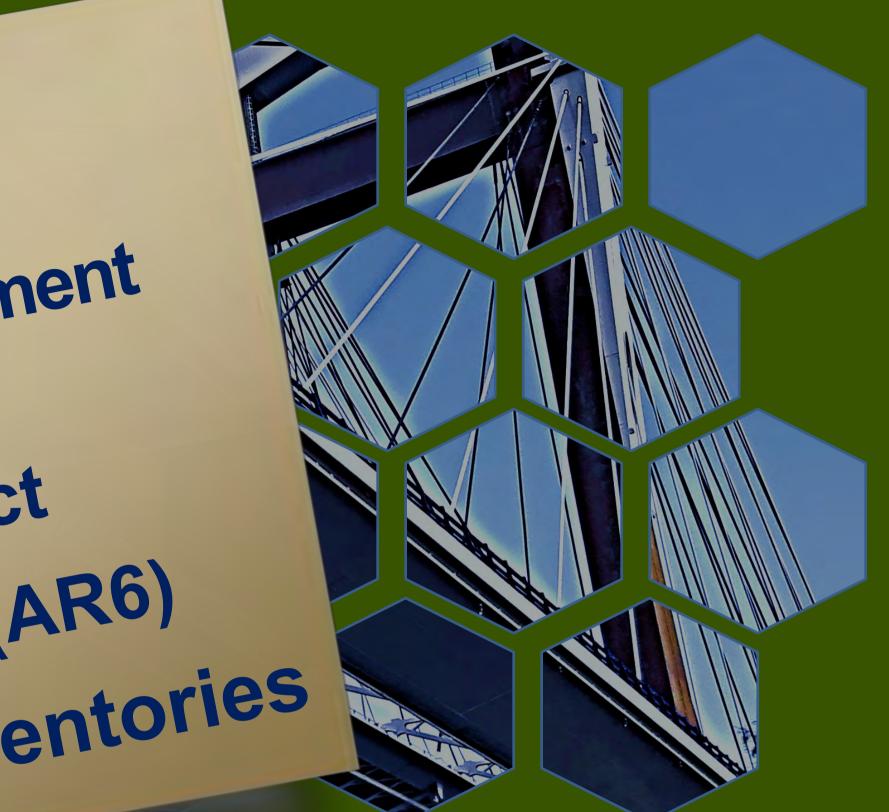


State of the art on the quantification of natural carbonation of cement-based materials as a CO<sub>2</sub> capture mechanism

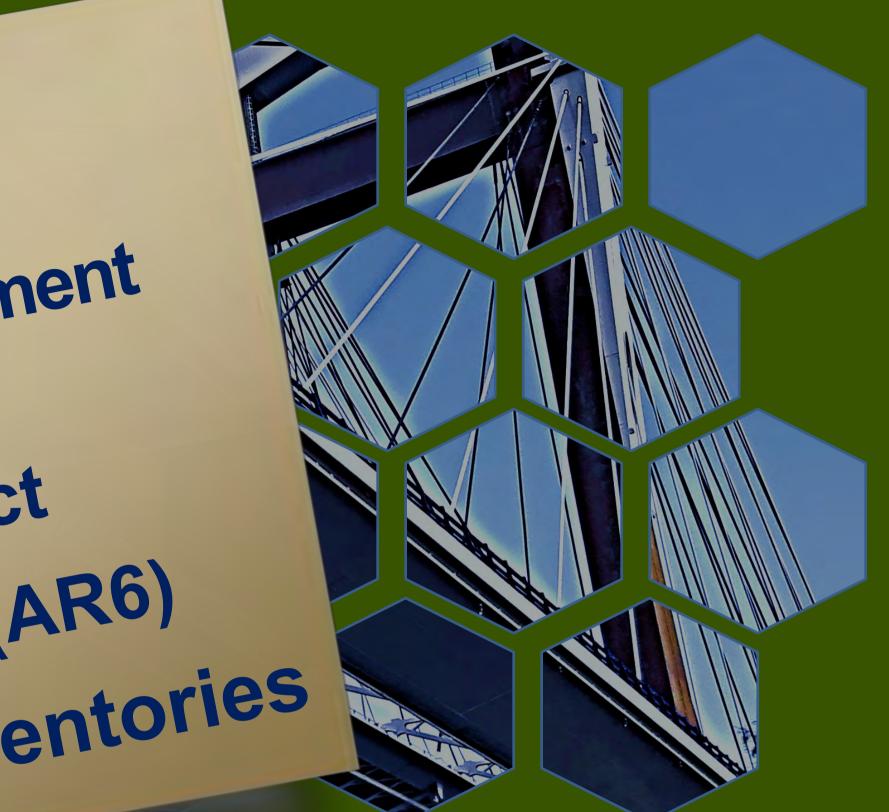
### **IPCC Expert** Meeting on Carbon Dioxide Remo Technol

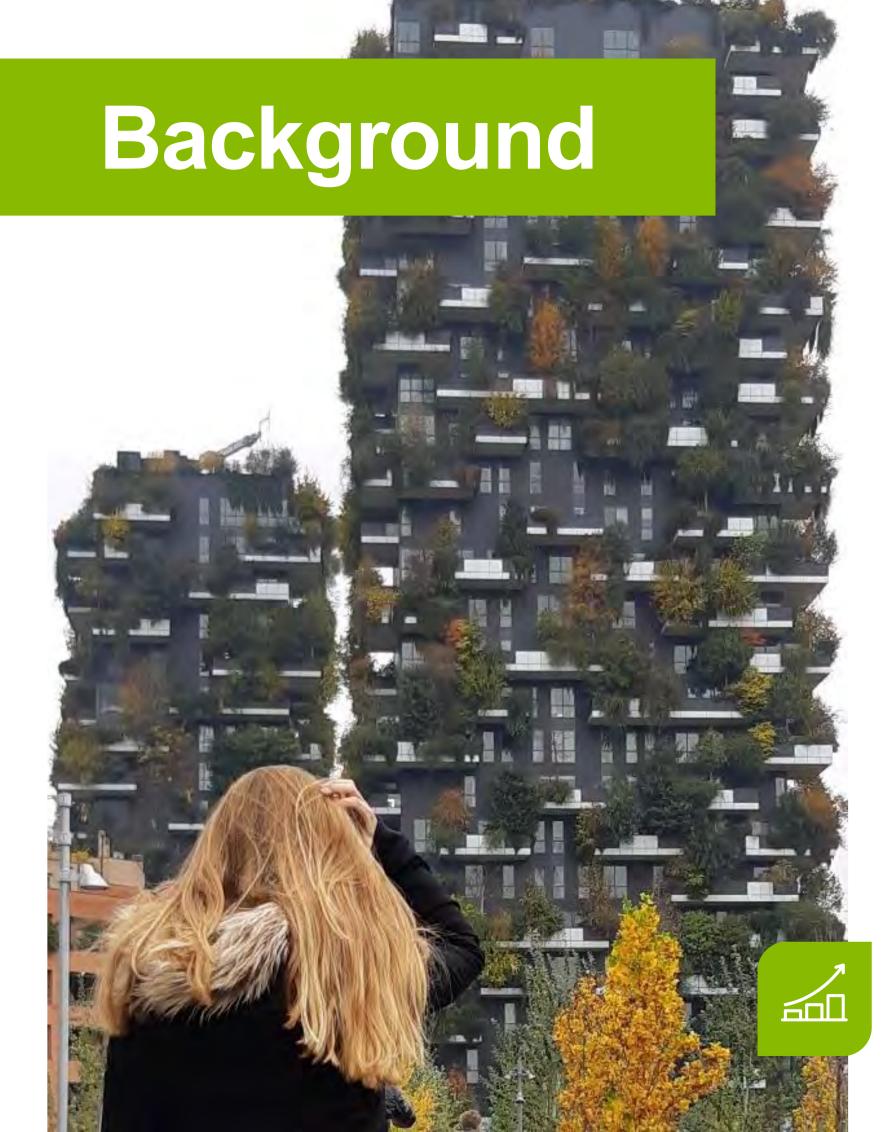
### Miguel Ángel Sanjuán Scientific and Technical Coordinator of IECA (Spanish Institute of Cement and its Applications)

2.  $CO_2$  emissions-absorption (cement 1. Background 3. "Concrete  $CO_2$  sink" Project 4. Sixth Assessment Report (AR6) 5. Conclusion -> AR7 & Inventories State of the art on the quantification of natural carbonation of cement-based materials as a CO<sub>2</sub> capture mechanism



2.  $CO_2$  emissions-absorption (cement 1. Background 3. "Concrete  $CO_2$  sink" Project 4. Sixth Assessment Report (AR6) 5. Conclusion -> AR7 & Inventories State of the art on the quantification of natural carbonation of cement-based materials as a CO<sub>2</sub> capture mechanism





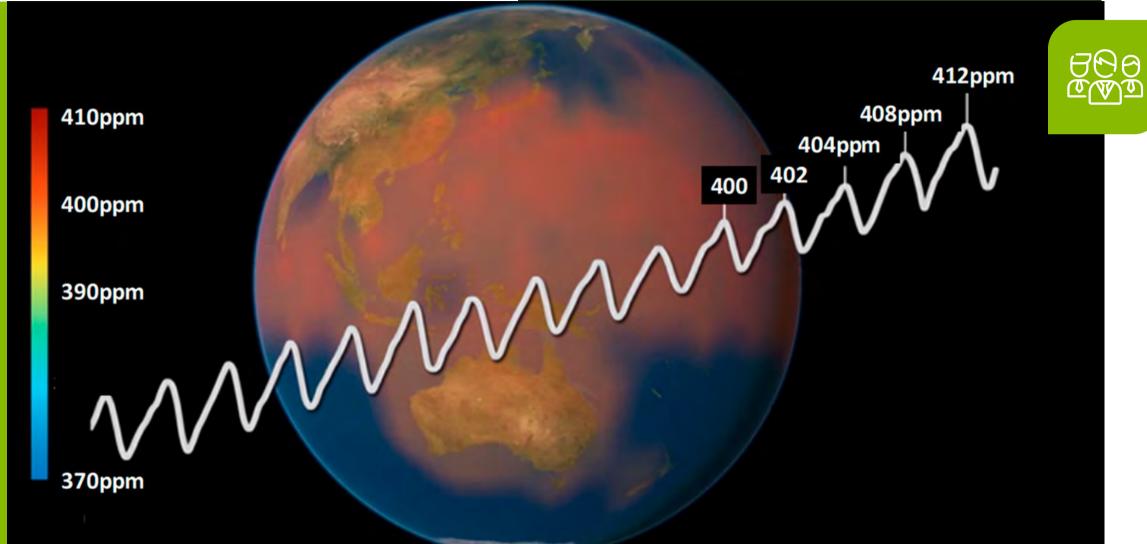
Brief preliminary outline of existing IPCC TFI guidance on these topics provided in Table 1 Source/sink: Cement carbonation

**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 CO2 - 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.

# 2. CO<sub>2</sub> emissions-absorption (cement 1. Background 3. "Concrete $CO_2$ sink" Project 4. Sixth Assessment Report (AR6) 5. Conclusion -> AR7 & Inventories



State of the art on the quantification of natural carbonation of cement-based materials as a CO<sub>2</sub> capture mechanism



2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017

**IPCC Expert Meeting** on Carbon Dioxide Removal Technologies



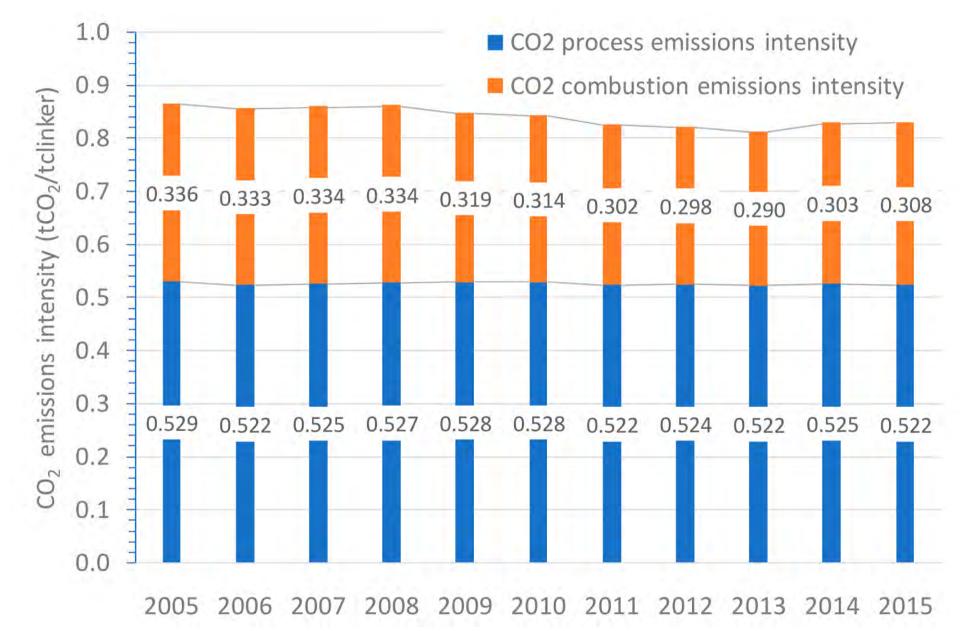
# **Global Warming Potential (GWP)**

## **Carbon dioxide**

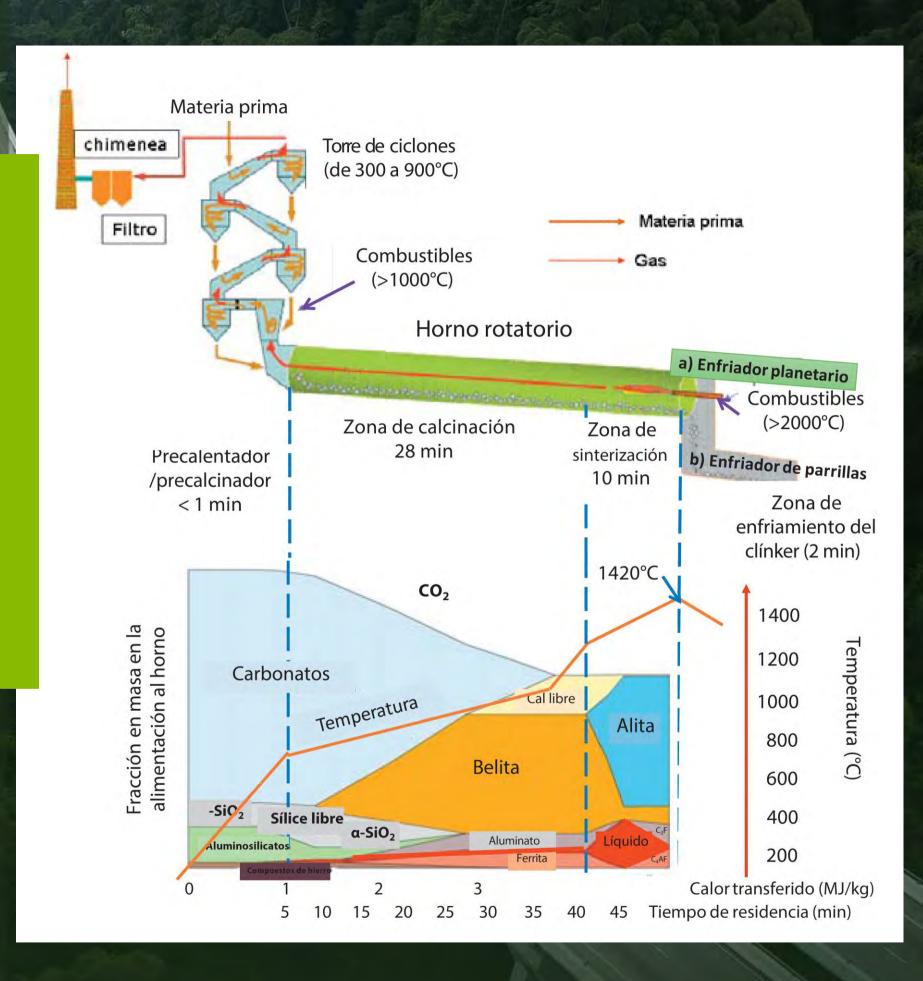
Cement sector: 7.4% of global emissions.

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. <u>https://doi.org/10.3390/app10010339</u>

# Cement sector emissions

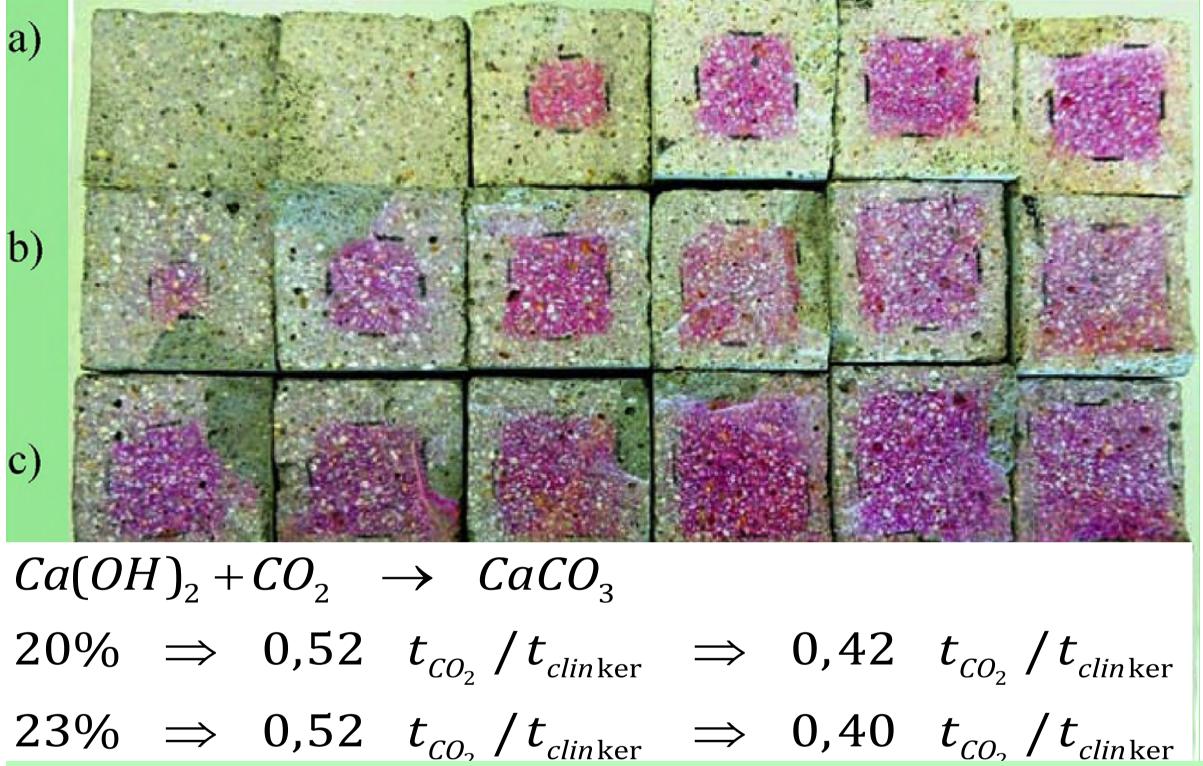


 $CaCO_{3} \leftrightarrow CaO + CO_{2} \quad ; \quad 0,52 \quad t_{CO_{2}} / t_{clinker}$   $C_{x}H_{y} + \left(\frac{y}{4} + x\right)O_{2} \rightarrow \frac{y}{2}H_{2}O + xCO_{2} \quad ; \quad 0,30 \quad t_{CO_{2}} / t_{clinker}$ 



# Carbonation





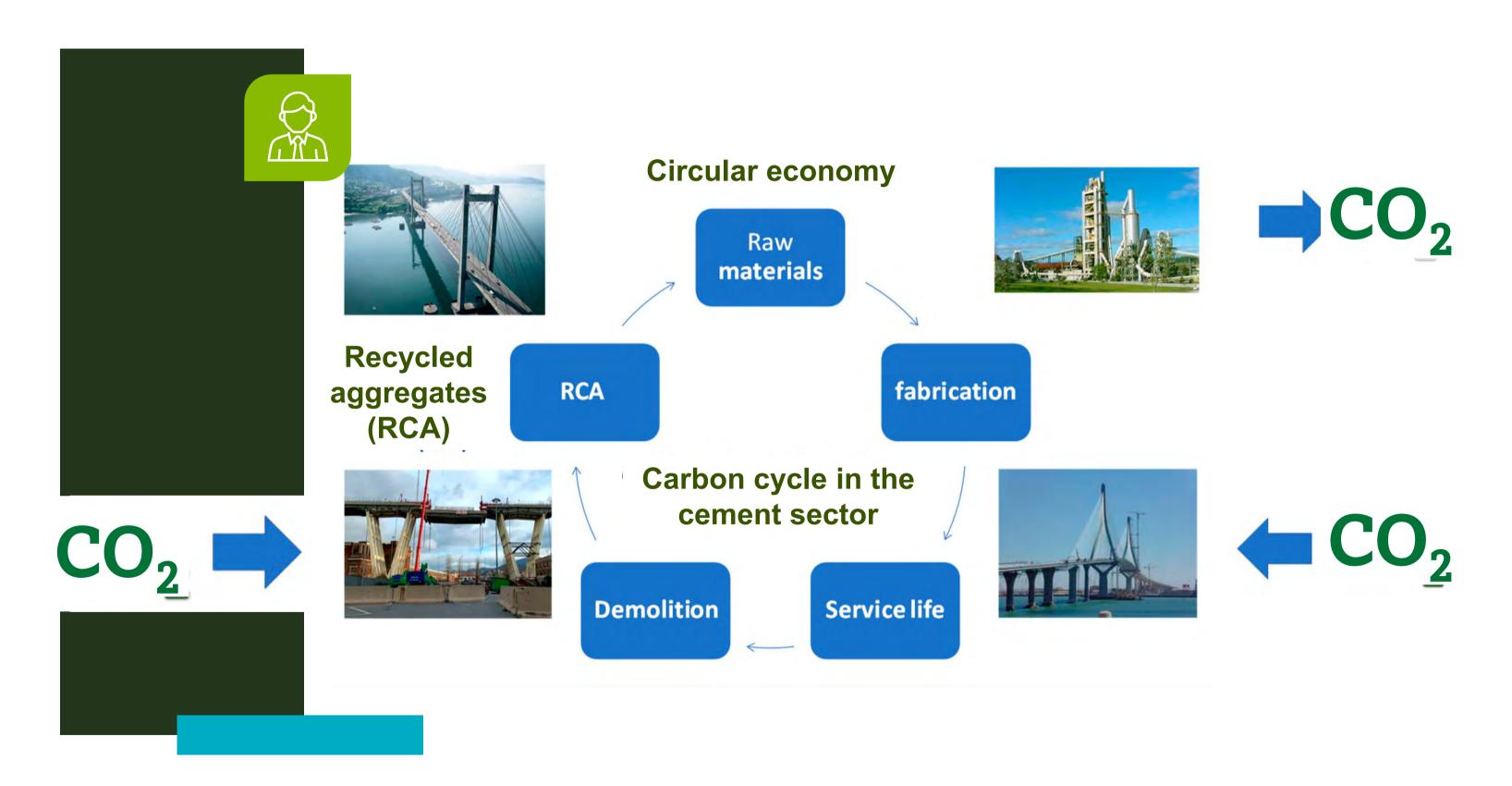
0 **Mortars** 

14 28 days 3

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

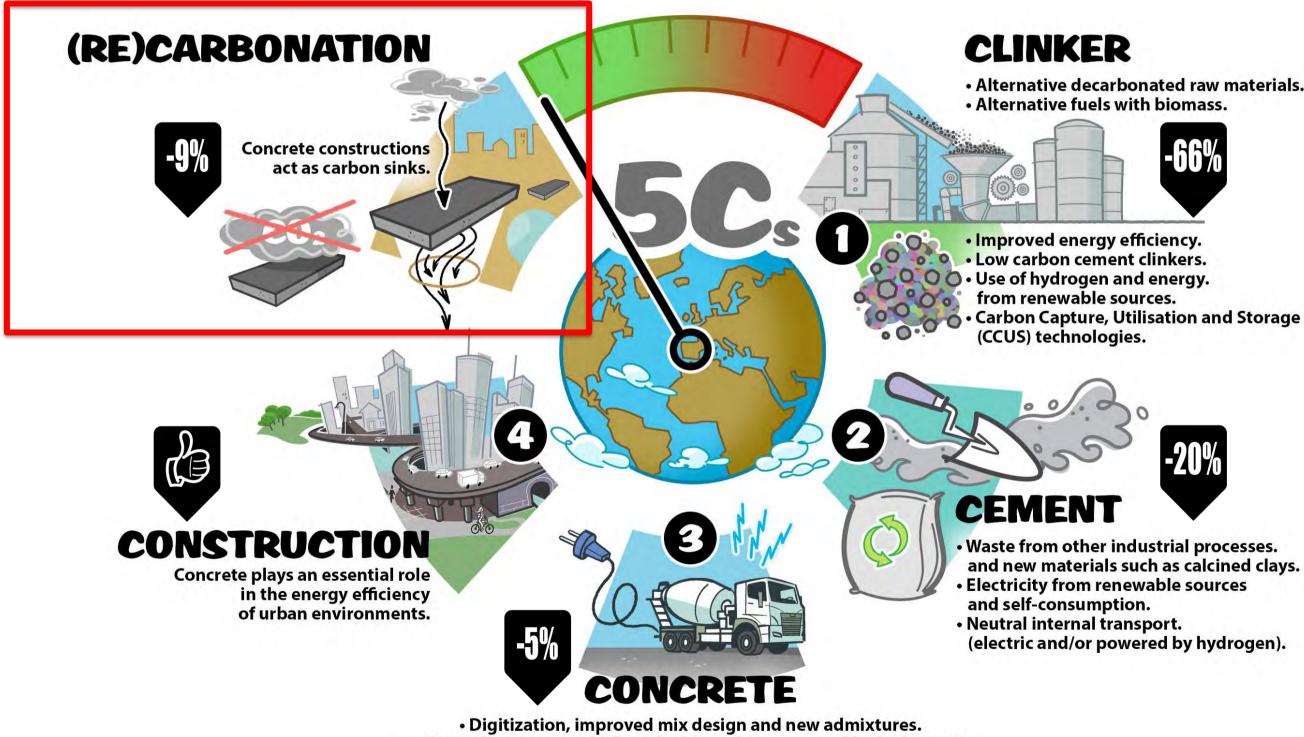
# Carbon cycle in the cement sector



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. <u>https://doi.org/10.3390/app10010339</u>

### CO<sub>2</sub> Emissionabsorption

# **Roadmap for the** cement sector



Neutral transport vehicles (electric and / or powered by hydrogen).

Alternative decarbonated raw materials.

**IPCC Expert Meeting on** Carbon Dioxide Removal **Technologies** 



# 2. $CO_2$ emissions-absorption (cement 1. Background 3. "Concrete CO2 sink" Project 4. Sixth Assessment Report (AR6) 5. Conclusion → AR7 & Inventories



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













# "Concrete CO2 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<sub>2</sub> sink" Project



### CO<sub>2</sub> uptake in cementcontaining products

Background and calculation models for IPCC implementation

Commissioned by Cementa AB and IVL research foundation

Håkan Stripple Christer Liungkrantz Tomas Gustafsson Ronny Anderssor

### @ivl

# Result

The most important result was the document **'CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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-ipccguidelines-for-national-greenhouse-gas-inventories/



2019





climate change

### TASK FORCE ON NATIONAL **GREENHOUSE GAS INVENTORIES (TFI)**

### 2019 REFINEMENT

2019 REFINEMENT TO THE 2006 IPCC GUIDELINES ON NATIONAL GREENHOUSE GAS INVENTORIES





#### **IPCC Inventory Software**

IPCC Side-event- IPCC-TFI tools for National GHGs Inventories **UN Climate Change Conference** Katowice, Poland 5 December 2018 Sekai Ngarize, IPCC TFI TSU INTERGOVERIMENTAL PANEL ON CHMOTE



Index 2006 + 2019 IPCC Guidelines for National **Greenhouse Gas Inventories** 

# **IPCC Guidelines for National Greenhouse Gas Inventories**

- Volume 1 General Guidance and Reporting Fuel CO<sub>2</sub> Volume 2 Energy **Volume 3 Industrial Processes and Product Use** Chapter 2 Mineral Industry Emissions and removals 2.1 Introduction Calcination 2.2 Cement production  $CO_2$ 2.3 Lime production 2.4 Glass production 2.5 Other process uses of carbonates Volume 4 Agriculture, Forestry and Other Land Use
- Volume 5 Waste



materials as a CO<sub>2</sub> capture mechanism

# <u>CO<sub>2</sub> uptake modelling</u> (cement sector)

material	5		MDPI				
Article Carbon Dioxide Cement-Based I	e Uptake Estimation f Materials	for Spanish					
Natalia Sanjuán <sup>1</sup> , Pedro Mo	ora <sup>2</sup> , Miguel Ángel Sanjuán <sup>3,*</sup> <sup>(5)</sup> and	Aniceto Zaragoza <sup>4</sup>					
	<ol> <li>Civil Engineering School, Technical Univer 2000 Madrid, Spain: natalia sanjuaritahar</li> <li>Department of Geological and Mines Engin of Madrid (UVM), C/Nes Ross, 21, 2000</li> <li>Spanish Institute of Cennot and Ibs Apple Officement C/Ioer Abacal, 53, 2000 Madr</li> <li>Correspondence: masanjuari@iccaes; Tel:</li> </ol>	applied sciences	e Uptake by Brazilia	n Cement-Based Materi	MDPI als		
	Abstract: The Intergovernmental Panel on for assessing the science related to climat process as a way of carbon offsetting with recognized as a carbon removal process certification of carbon removal is to prom	Joao Henrique da Silva Reg	20 <sup>1</sup> <sup>(1)</sup> , Miguel Ángel Sanjuán <sup>2,4</sup> <sup>(1)</sup> , P				
	removal processes. Therefore, the main ob dioxide uptake by cement-based materials the United Nations Framework Conventia natural carbonation should be added up should be included in the IPCC Guideli		henriquerego@unb.br 2 Spanish Institute of Coment and its App 3 Department of Geological and Mines E 4 Technical University of Madrid (UPM), 4 Ofiormen, C./José Abascal, 53, 28003 M	applied sciences	MDPJ	Cł	1
	accounting information should be made This paper provides the results of carbon 1990 to 2020 by using an easy method of method) considering the carbon dioxide re		<ul> <li><sup>5</sup> 'Environment and Sustainability, Nation 76-Jaguare', São Paulo 05347-902, Brazik</li> <li><sup>5</sup> Correspondence: masanjuan@icca.ex</li> <li>Featured Application: The Intergoven</li> </ul>	Carbon Dioxide Uptak Made with Portuguese	e by Mortars and Concretes Cements		A
check for updates Citation: Sanjuán, N.; Mora, P.; Sanjuán, M.A.; Zaragoza, A. Carbon Diosáde Uptako Estimation for	emissions). The outcome of this study reve by the mortar and concrete manufactured Keywords: carbon dioxide uptake; buildi		Report (AR6) recognizes the physico- utilizes a way of calculating carbon c methodology known as Tier 1 applied	Miguel Ángel Sanjuan <sup>1,</sup> <sup>1</sup> ,	sustainability		por los productos españole
Spanish Cement-Based Materials. Metrials 2004, 17, 326. https:// doi.org/10.3390/ma17020326 Academic Editors: Paulo Santos and	1. Introduction Within the wider context set by t		Abstract: The worldwide cement indu- challenge. Brazil's cement industry c capacity of 94 million tons per year an carbon-neutral cement sector by 2050 concrete carbonation is subtracted fr	<ol> <li>Department of Geological and Mines E. Technical University of Madrid (UPM).</li> <li>Oficement, C/lose Abascal, 53, 28003 Ma</li> <li>Correspondence: masanjuan@isca.es; T</li> </ol>	Article Updating Carbon Storage Capacity of		Pedro Mora Miguel Ángel Sa
Daniel Fornindez Wega Received: 18 December 2023 Revised: 4 January 2024 Accepted: 5 January 2024	climate neutral by 2050, the EU has emissions (GHG) by at least 55% by Climate Law [3] requires Member Stat within the European Union at the late	Filation: da Silva Rom, 1H - Saturda	the calcination of lime, i.e., the calcin adays, the Intergovernmental Panel on Gas (GHG) Inventories to report the 6 consider the mortar and concrete carb	Received: 16 December 2019; Accepted: 14 Featured Application: The Guidelines by the Intergovernmental Panel on C	Spanish Cements Carmen Andrade <sup>1,*</sup> and Miguel Angel Sanjuán <sup>2</sup> () International Center of Numerical Methods in Engineering, CIMNE, Paser General Martínez		El Instituto Español del Cen migón como sumidero de C últimos diez años.
Published: 9 January 2024	date, and to reach negative emission of the global cement output, wherea: 2020) [4]. China continues to honor all its c its carbon dioxide emissions per uni	M.A.; Mora, P.; Zaragova, A.; Visedo, G. Carteon Dioxide Uptake by Brazilian Coment-Based Matorials Appl. Sci. 2023, 11, 10206. https://	Change (IPCC)'s Sixth Assessment Re as carbonation. Brazilian net carbon are estimated considering the carbon secondary usage stages (Tier 1). This	national GHGs emissions. However, the Portland cement clinker (released concrete carbonation). This paper is a	28010 Madrid, Spain <sup>2</sup> Spanish Institute of Cement and its Applications (IECA), C/Jose Abascal, 33, 28003 Madrid, massipamilieccaes * Correspondence: candrade@cimne.upc.edu		Para la elaboración del estu paña, su utilización diferenc los datos de emisián de CO, a obtener el porcentaje de red
Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://	2005 level by 2030 [5]. Recently, Chin: neutrality, by 2060 according to its C Currently, China emits more than 10 worldwide carbon dioxide emissions	Academic Editors: Jose Antonio Correia, Xiaoyong Wang and Xu Yang	changes the current approach to estim clinker production. Even considering t the future and included in the national and concrete carbonation for 30 years i 483 million tons have been released du	Abstract: As the cement industry contin industry has started to calculate its net These emissions are calculated by simpl carbonation from the total CO <sub>2</sub> that is	Received: 9 November 2018; Accepted: 4 December 2018; Published: 17 December 2018; <b>Abstract:</b> The fabrication of coment clinker releases CO <sub>2</sub> due to the calcination of the lin as raw material, which contributes to the greenehouse effect. The industry is involves		Las tipas de cemento y las p mativo, es necesario el desar ñol ya que no son aplicables
creativecommons.org/licenses/by/ 4.0/).	On the other hand, China's Cer of Chinese carbon dioxide emission	Remived: 17 August 2023 Revised: 10 September 2023 Assepted: 14 September 2020 Published: 17 September 2021	Keywords: carbon neutrality; climate capture and utilization; mitigation; nej	However, the procedures given in the Ir for National Greenhouse Gas (GHG) Inv that would grant this calculation met Therefore, some climate models are not uptake due to concrete and mortar c	as raw indernal, winit contraduces to use generative energy remets. The many is involves of reducing his amount liberated to the atmosphere by mainly lowering the amount the cements. The cement-based materials, such as concrete and mortars, combine par by a process called "carbonation". Carbonation has been studied lately mainly due to it induces the corrosion of stell reinforcement when bringing the COs front to the s		En base a lo anterior y una ducción del CO, emitido por etapás de vida en servicio co
		Copyright © 2025 by the authors.	1. Introduction	have improved since the IPCC's Fourth implementing carbon dioxide uptake t	reinforcing bars. Thus, the "rate of carbonation" of the concrete cover is characterized by the length of service life of concrete structures. The studies on how much CO2 is fixed by		1 Automatica
		Licensor MDPJ, Basel, Switzerland, Thin aride is at open access aride identifiated ander the terms ind- conditions of the Croative Commons. Attribution (CC BY) license (https:// madrixeemmons.org/licenses/by/ 407).	The international climate cha forcing citizens, industry, and count do net want to be excluded from the the global cement industry is alwa Carbon dioxide uptake by cor improving the assessment of anthi	easy method of evaluating net CO <sub>2</sub> emi- method. Protuguese net CO <sub>2</sub> emission while taking carbon disxide uptake dur- into account. Following the simplified uptake by motiss and concretes made 37.8 million tors were released due to t- been used to estimate the carbon dioxi that of the simplified method (9.1 milli	phases are scare and even less has been studied the influence of the type of cement. In: 15 cements were used to fabricate paste and concrete specimens withwater/coment ( 0.6 and 0.45 which reproduce typical concretes for buildings and infrastructures. The carbon dioxide uptake was measured through thermal gravimetry. The degree of arbo is defined as the CO <sub>2</sub> fixed with respect to the total theoretical maximum and the ci- capacity (CSC) as the carbonation uptake by a concrete element, a family or the whole' region or country. The results in the pastes where analyzed with respect to the uptake and indicated that (a) the humidity of the pores is a critical parameter that favours th		<ol> <li>Antecedentes</li> <li>In Mirrennion del Gospo Interguiver- comencial de Espertos solave el Combio Umoteco Introd.et de Tanados, Resa, destanda da 11 al 3 de aben de 2016, e encroso al reolacación de uma menjora a pasa de 2006 per contada sobre la val- posación del Inventario Hacegnal de los.</li> </ol>
		/kpil. Sci. 2023, 13, 10396. https://doi.org/10.3390/app131810386		Keywords: climate change; climate mu utilization; cement industry; sustainabi	reaction as higher is the humidity (within the normal atmospheric values). (b) all typ uptake CO <sub>2</sub> in function of the CoA of the dinker except the binders having slags, whi additional CO <sub>2</sub> giving aDoC near or above 100%. The CSC of Spain has been updated w a previous publication resulting in proportions of 10.8–11.2% of the calcination emiss considering a ratio of "surface exposed/Youtume of the element" of 3 as an average Spanish asset of building and infrastructures.	lidad	Saessée Electro Invernatero. El objeto de sost mejora os brana en la pacibilidad de que se pueda facilitar la Incorporación de neas fuentes como para las sumalens de Saess de Efecto Invernaders (ES), pero alla en assellos casos en las que la haja actas sen cutilor, la o dende hajan sui-

 $\bigcirc$ 

#### bsorción de CO.

derivados de los ceme es en el periodo 2005-2

Spain's cement sector: carbon

#### neutrality by 2050



DECARBONISATION 71

Developments in the Built Environment 8 (2021) 100063

Contents lists available at ScienceDirect

Developments in the Built Environment

journal homepage: www.sciencedirect.com/journal/developments-in-the-built-environmen

#### Carbon dioxide uptake by pure Portland and blended cement pastes

Carmen Andrade<sup>a</sup>,<sup>\*</sup>, Miguel Ángel Sanjuán<sup>b</sup>

\* International Center for Numerical Methods in Engineering (CIMNE), C/ Martinez Campos 41, 280310, Madrid, Spain <sup>b</sup> Spanish Institute of Cement and its Applications (IECA), C/ José Abascal, 53, 28003, Madrid, Spain

#### ARTICLE INFO

Keywords: Carbonation Cement type Thermal analysis CO2 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 lifecycle 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 ( $10 \times 10 \times 60$  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 CO2 recombination to be discounted from the emitted one (Sanjuán et al., 2020a). This recombination would be 100% efficient if all the CO2 released during clinker production as captured, that is, if all the CaO of clinker is combined with the CO<sub>2</sub> 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<sub>3</sub>) 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<sub>2</sub>. 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 (CO2) 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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<sup>\*</sup> Corresponding author. E-mail addresses: candrade@cimne.upc.edu (C. Andrade), masanjuan@ieca.es (M.Á. Sanjuán).

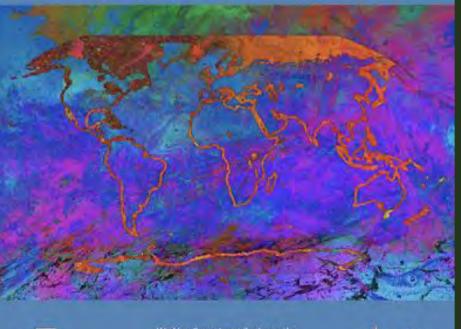
# Sixth Assessment Report (AR6)

**p.19** (full report 1171) • PgC yr-1. p. 5-20 (full report 1172)

**IOCC** INTERGOVERNMENTAL PANEL ON CLIMATE CHARGE

#### Climate Change 2021 The Physical Science Basis

Summary for Policymakers





**Sixth Assessment Report** 

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

# In 2019, fossil CO2 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

Direct CO2 emissions from carbonates in cement production are around 4% of total fossil CO2 emissions and grew at 5.8% yr-1 in the 2000s but a slower 2.4% yr-1 in the 2010s. The uptake of CO2 in cement infrastructure (carbonation) offsets about one half of the carbonate emissions from current cement production (Friedlingstein et al., 2020).

# Sixth Assessment Report (AR6)

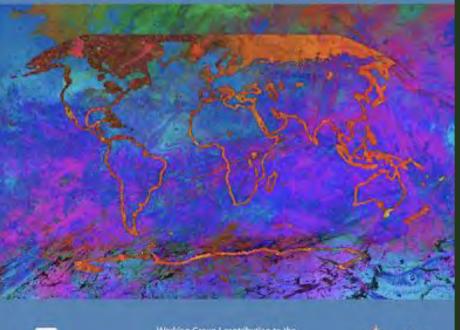
**p. 5-32** (full 1184) Since AR5 (Ciais et al., 2013), a number of improvements have led to a more constrained carbon budget. Some new additions include: (i) the use of independent estimates for the residual carbon sink on natural terrestrial ecosystems (Le Quéré et al., 2018a), (ii) improvements in the estimates of emissions from cement production (Andrew, 2019) and the sink associated with cement carbonation (Cao et al., 2020).

**IDCC** INTERGOVERNMENTAL PANEL ON CLIMATE CHARGE

C V D

#### Climate Change 2021 The Physical Science Basis

Summary for Policymakers





**Sixth Assessment Report** 

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

INTERGOVERNMENTAL PANEL ON CLIMBTE CHARGE

#### Climate Change 2021 The Physical Science Basis

Summary for Policymakers

INTERGOVERNMENTAL PANEL ON CLIMATE CHARGE

### **Climate Change 2022** Impacts, Adaptation and Vulnerability

Summary for Policymakers



IPCC

#### Climate Change 2022 Mitigation of Climate Change

Summary for Policymakiers





Internet Sector & Contract of Sectors



Sixth A 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** 

# Sixth Assessment Report (AR6)

### Sixth Assessment Report (AR6) - WG III

# Sixth Assessment Report (AR6)



## INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

### **Climate Change 2022** Mitigation of Climate Change





Working Group III contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change



Working Group III contribution to the IPCC Sixth Assessment Report - Registratio Expert Order ipc:

### 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<sub>2</sub>** into hardening concrete, both to dispose of the CO<sub>2</sub> and more importantly reduce the need for binder (Lim et al. 2019).

# Tier 1



carbonation

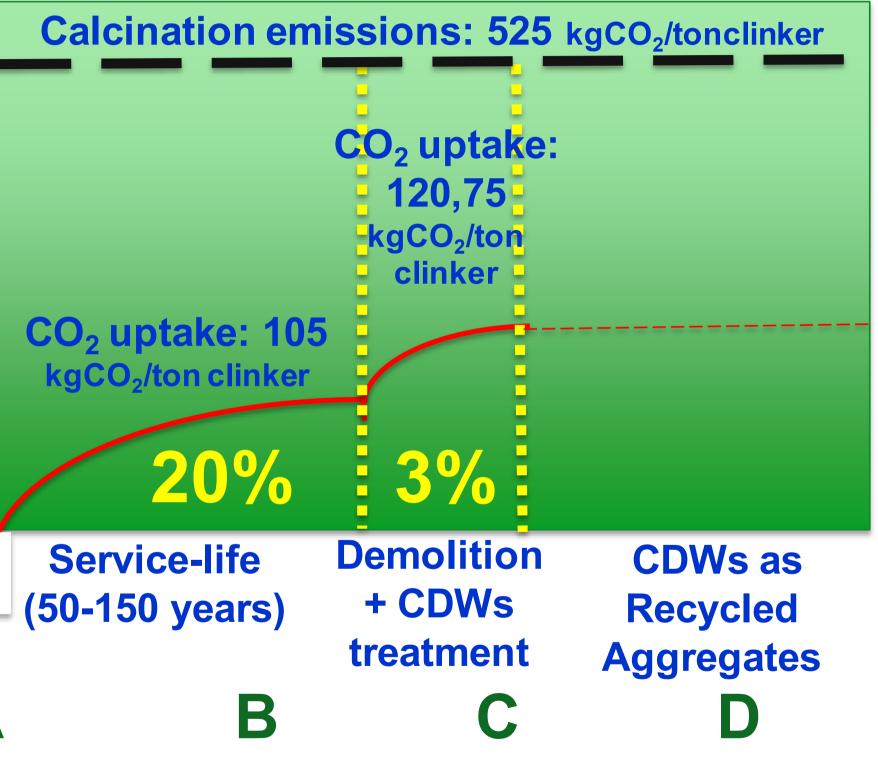
<mark>by</mark>

uptake

02

### **Modules: A**









#### Article Carbon Dioxide Uptake by Brazilian Cement-Based Materials

Tier 1

Joao Henrique da Silva Rego <sup>1</sup>, Miguel Ángel Sanjuán <sup>2,\*</sup>, Pedro Mora <sup>3</sup>, Aniceto Zaragoza <sup>4</sup> and Gonzalo Visedo <sup>5</sup>

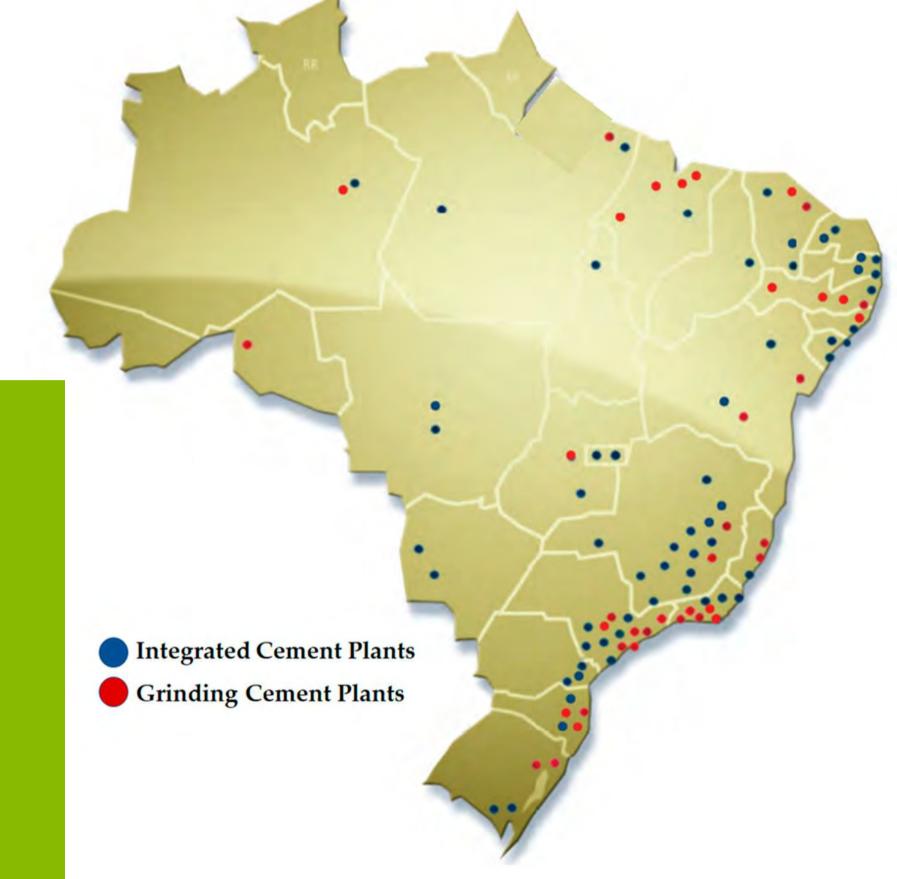
<sup>1</sup> Department of Civil and Environmental Engineering, Universidade de Brasília, Brasilia 70910-900, Brazil; jhenriquerego@unb.br

**MDPI** 

- <sup>2</sup> Spanish Institute of Cement and its Applications (IECA), C/José Abascal, 53, 28003 Madrid, Spain
- <sup>3</sup> Department of Geological and Mines Engineering, Mine and Energy Engineering School,
- Technical University of Madrid (UPM), C/Ríos Rosas, 21, 28003 Madrid, Spain; pedro.mora@upm.es
- <sup>4</sup> Oficemen, C/José Abascal, 53, 28003 Madrid, Spain; azaragoza@oficemen.com
- <sup>5</sup> Environment and Sustainability, National Cement Industry Association (SNIC), Av. Torres de Oliveira, 76-Jaguaré, São Paulo 05347-902, Brazil; gonzalo@snic.org.br
- \* Correspondence: masanjuan@ieca.es

### $CO_2$ 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. <u>https://doi.org/10.3390/app131810386</u>

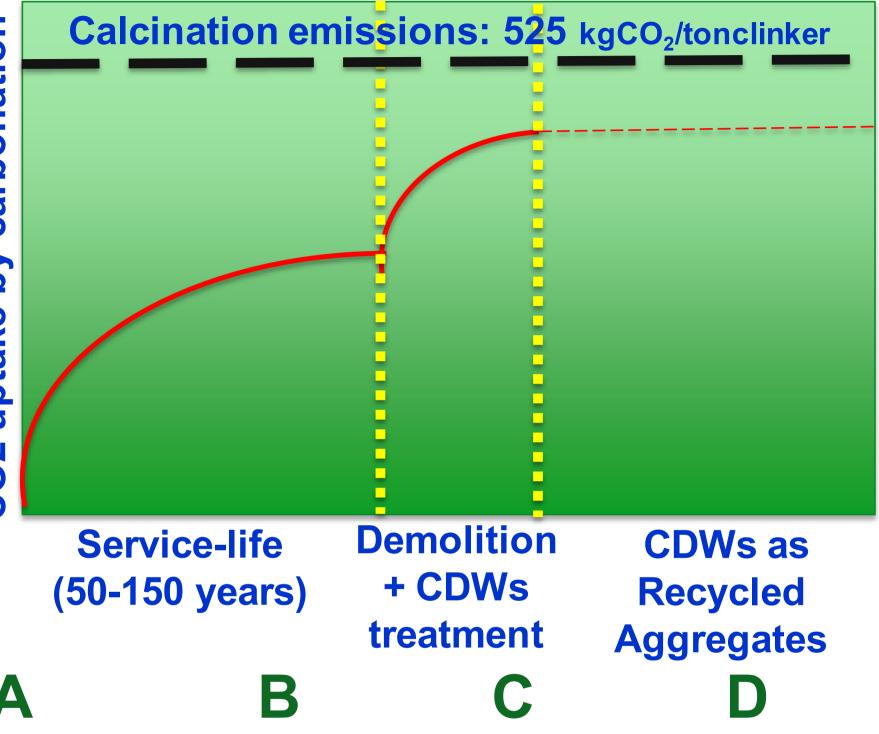
# Tier 2



24

# **Modules: A**

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



### **Tier 2: Advanced Methodology**

# Tier 3



### geoscience

#### Substantial global carbon uptake by cement carbonation

from industrial processes

Cumulative cement proces

38.2 Gt CO<sub>2</sub> from 1930 to :

However, the calcium over time, and cement 1

atmospheric CO<sub>2</sub> throu

carbonation<sup>3-4</sup>. Carbonati

pores of cement-based mail

in the presence of pore w

starts at the surface of th

moves inwards. Although

civil engineers due to the

structures<sup>4,10</sup>, the resultin

been quantified. In contra-

during manufacture of o

that takes place througho

materials<sup>3,15</sup>. The CO<sub>2</sub> u

materials is thus propor

consumption. Previous stu

to estimate concrete cas

timescales<sup>4,1,1,2</sup>. However,

materials in specific regio

in other types of cement

cement mortar, construc-

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, a

the sensitivity of our upt

dust worldwide.

(see Methods).

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

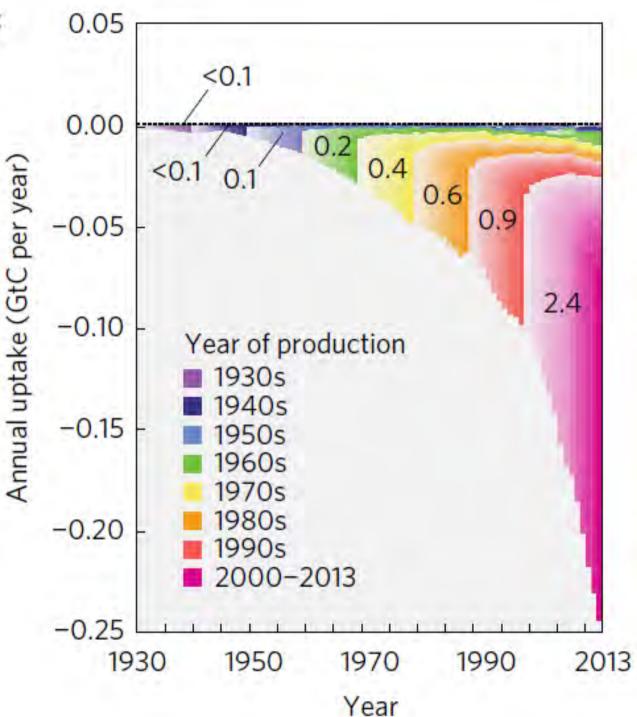
Calcination of carbonate rocks during the manufacture of cement produced 5% of global CO<sub>2</sub> emissions from all industrial process and fossil-fuel combustion in 2013<sup>12</sup>. Considerable attention has been paid to quantifying these industrial process emissions from cement production<sup>2,2</sup>, 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, 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<sub>20</sub> increasing from 0.10 GtC yr<sup>-1</sup> in 1998 to 0.25 GtC yr<sup>-1</sup> 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 CO2 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<sup>1,2,4</sup>.

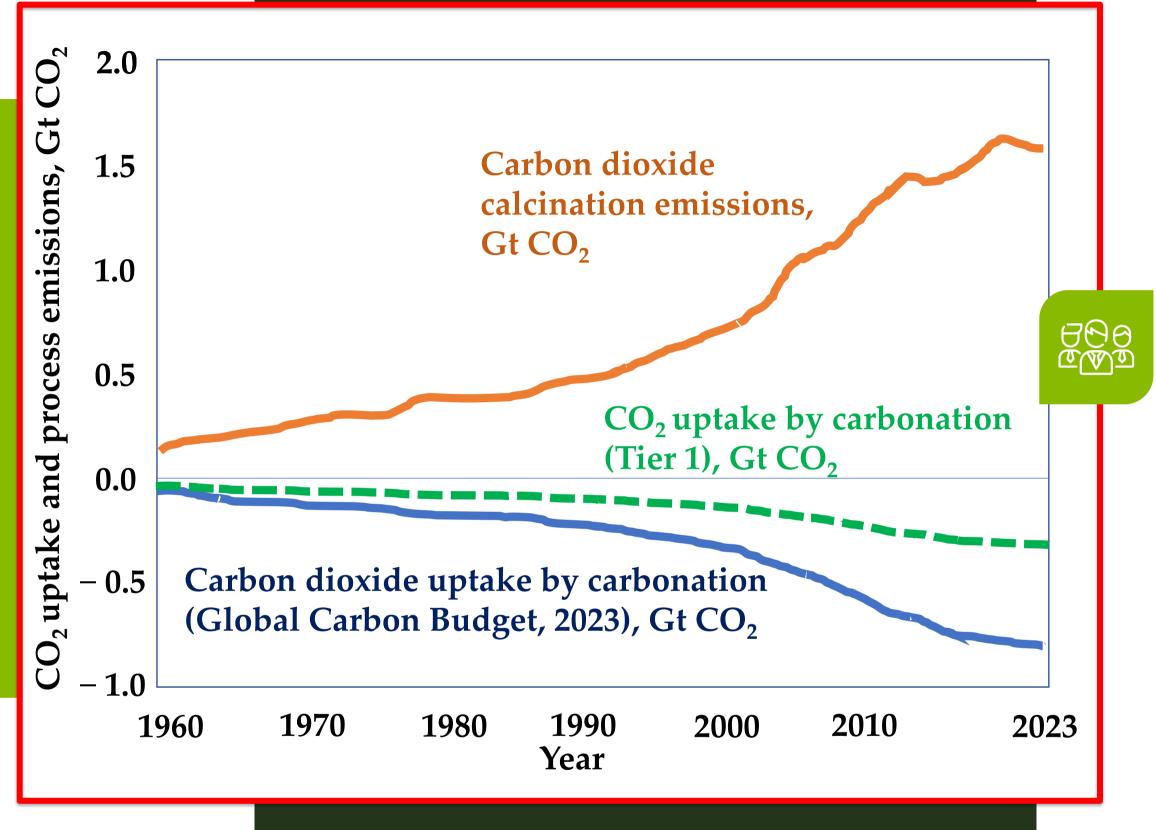
A tremendous quantity of cement has been produced workby defor the construction of buildings and infrastructure, namely: 76.2 billion tons of cement between 1930 and 2013, and 4.0 billion tons in 2013 alone'. When making cement, the high-temperature calcination of carbonate minerals (for example, limestone rocks) produces clinker (mainly calcium oxide), and CO<sub>2</sub> is released into the atmosphere from this process. These 'process' CO<sub>2</sub> 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<sub>2</sub> emissions from all industrial processes and 5% of global CO<sub>2</sub> emissions

<sup>1</sup>Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110016, China. <sup>2</sup>Key Laboratory of Poll Chinese Academy of Sciences, Shenware 110016, China. <sup>3</sup>Collage of Architecture and Urban Planning, Shenware

### 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). <u>https://doi.org/10.1038/ngeo2840</u>





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

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### Global Carbon Budget de 2023

2.  $CO_2$  emissions-absorption (cement 1. Background 3. "Concrete  $CO_2$  sink" Project 4. Sixth Assessment Report (AR6) 5. Conclusion > AR7 & Inventories State of the art on the quantification of natural carbonation of cement-based materials as a CO<sub>2</sub> capture mechanism



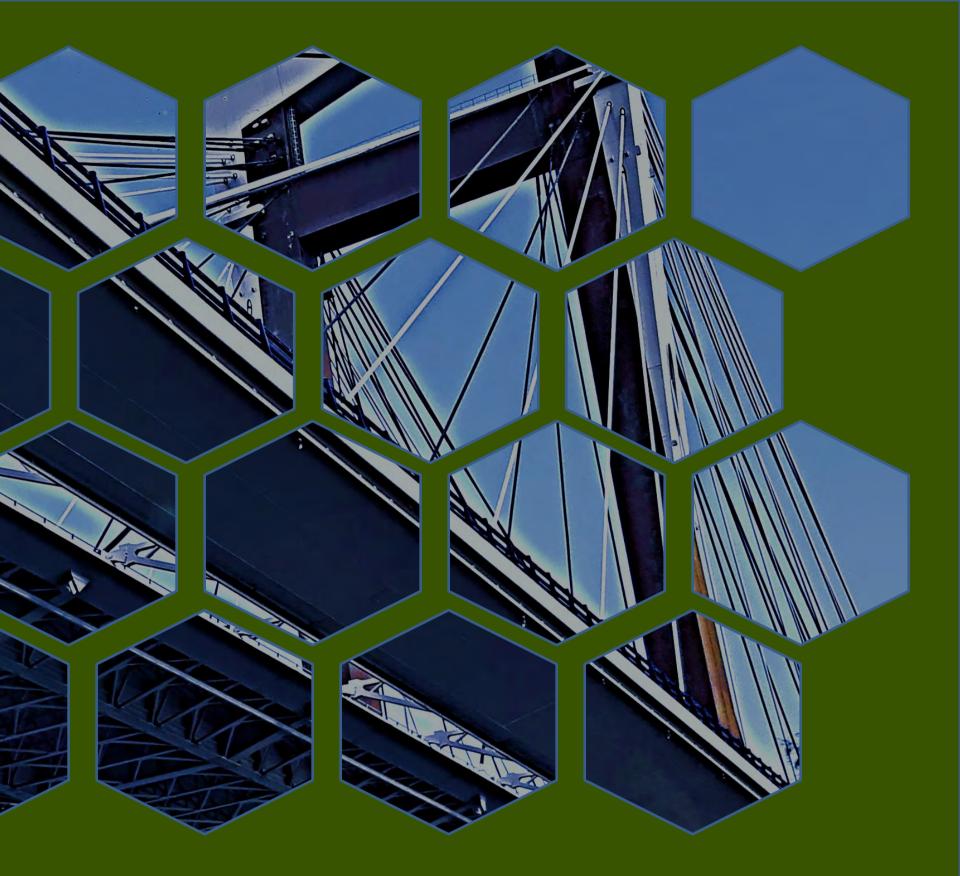
# Conclusion

Natural carbonation of cementbased materials is a wellknown process.

The rate of carbonation ranges from 1 to 9 mm/year<sup>0.5</sup>.

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



IPCC Expert Meeting on Carbon Dioxide Removal Technologies



Vienna, Austria

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

Miguel Ángel Sanjuán <u>masanjuan@ieca.es</u>



