039/11
rendering mortar from the arena wall

040/11
pointing mortar from the arena wall

041/11
bedding mortar from the arena wall

042/11
mortar from the core of the city wall

Nikolic et al (2016). Mortars from the amphitheatre masonry, Viminacium.

Chopped straw in plaster and pointing mortars.
Low level pozzolanic addition to pointing mortar (probably zeolite); higher level of same pozzolan in bedding mortars (25-30%, perhaps).
All displayed high porosity, although compressive strength higher, and porosity lower in bedding mortars.
Masonry of limestone. Lime content highest in plaster mortars (43%, with 2.4MPa; 45% porosity); then Pointing (29%; 2MPa; 47% porosity). Bedding only 13%; 2.7 Mpa; 33% porosity. City wall core mortar 21%; 5.3MPa; 25% porosity.

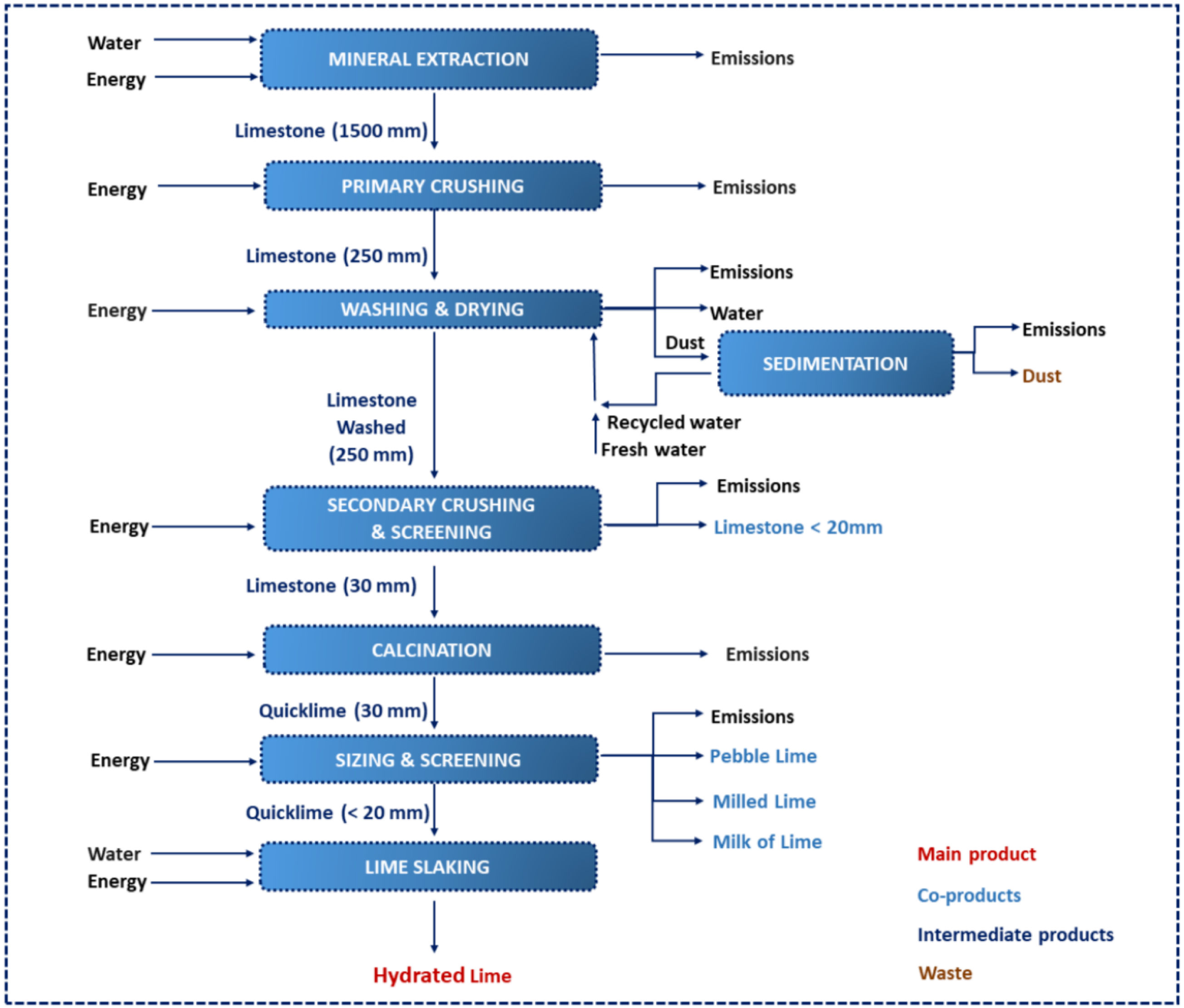


Figure 1. Industrial process for the production of Hydrated Lime – System boundaries considered in this study.

Agustin Lavegliaa,b *, Luciano Sambataroa, Neven Ukrainczyka, Nele De Belieb, Eddie Koendersa (2022)

Hydrated Lime Life-Cycle Assessment: Current and future scenarios in four EU countries

Aspersion (Z2)

This slake process consists in spreading lumps of quicklime on a wooden raft with an area of 3 ⍰ 6 m2 and 0.4 m height, rejecting those stones apparently under- cooked and the impurities. Quicklime was then thoroughly watered, as shown in Fig. 1a and the biggest clods were crumbled using wooden shovels, in order to dis- aggregate the lumps and to facilitate the mixture. More water was then added, until slurry was obtained, leading to the completion of slake process [14]. Agglomerates and impurities were eliminated by continuous sieving and, finally, lime putty was decanted (see Fig. 1b) and classified in two phases according to its sedimentation.

Grande Acqua (Z3)

In this second method, a pit was dug in the ground, roughly 1.2 ⍰ 0.6 m2 and 1 m deep, which was filled up to its half with burned stones form the lime kiln. Approximately 200 l of water were poured into the hole (see Fig. 1c). A few minutes after the entering in contact with the lime the water began to boil and, 400 addi- tional litres of water were added, stirring the lime putty as shown in Fig. 1d). Quick- lime-to-water ratio was roughly 1:2 in terms of weight. In some previous experiences using this slaking method, the exothermal nature of the process pro- duced an explosion of some virulence.

Immersion (Z4)

This third slaking method consisted in filling up a 15–20 l wicker basket with calcined stones and introducing it into a water pit up to its complete immersion [11,14]. As shown in Fig. 1e and f, the basket was removed almost immediately, and then left outdoors while lime was still hydrating, and therefore increasing its volume and temperature in a process that could last several hours.

Aspersion slaking method (Z2)
As shown in Fig. 3, slaking process through aspersion gives rise to heterogeneity in temperatures related to the distribution of the amount of water. In those areas where lime is completely flooded, heat is faster dissipated, thus temperatures are lower. In the areas where lime is not flooded, temperatures are higher, **reaching more than 100 °C in some points.**

Slake process Grande Acqua (Z3)
In this case, slaking **temperatures reach 100 °C due to the reaction between water and quicklime, but the excess of water added to the process causes a decrease of temperature when lime putty is stirred**. This fact is popularly known as lime frosting. After a certain time, temperature stabilizes around 50 °C,

Slake process through short immersion (Z4)
Unlike the two previous cases, the resulting product of this slak- ing process is not a lime putty, but powder lime. The short amount of water involved in the process explains the high temperatures generated inside the mass (up to 350 °C), which are kept above 100°C over the next 3.5h since the beginning of the process

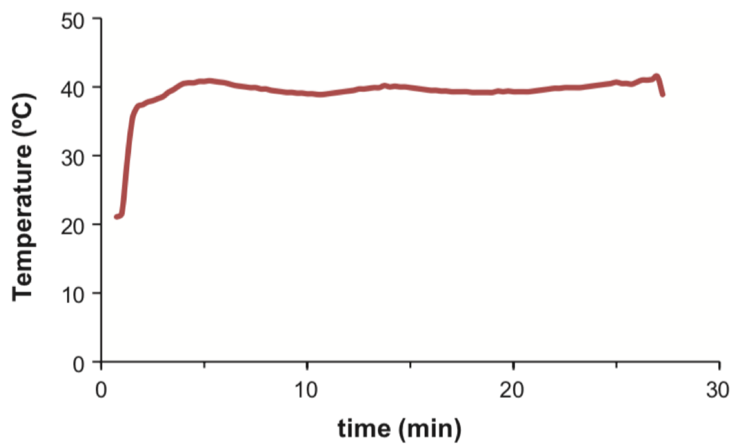


Fig. 5. Temperature follow-up during slaking process through melting in raft.

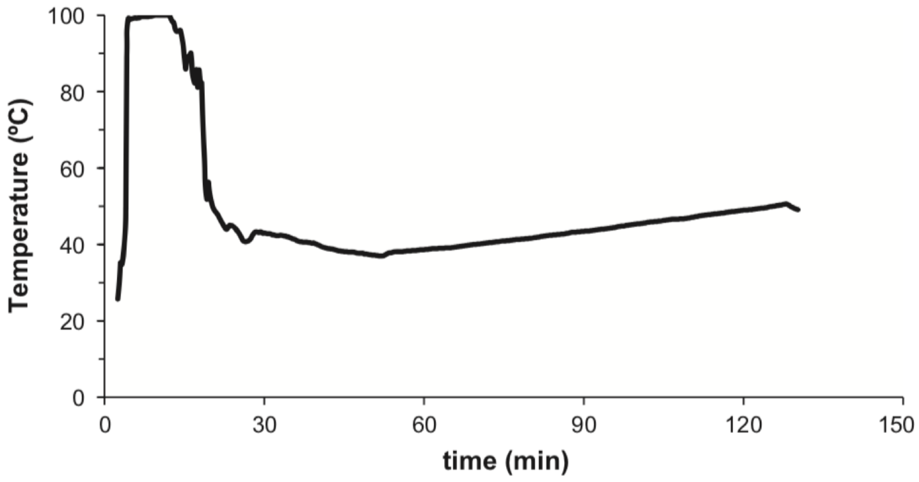


Fig. 6. Graph of evolution of temperature during *Grande Acqua* slaking process.

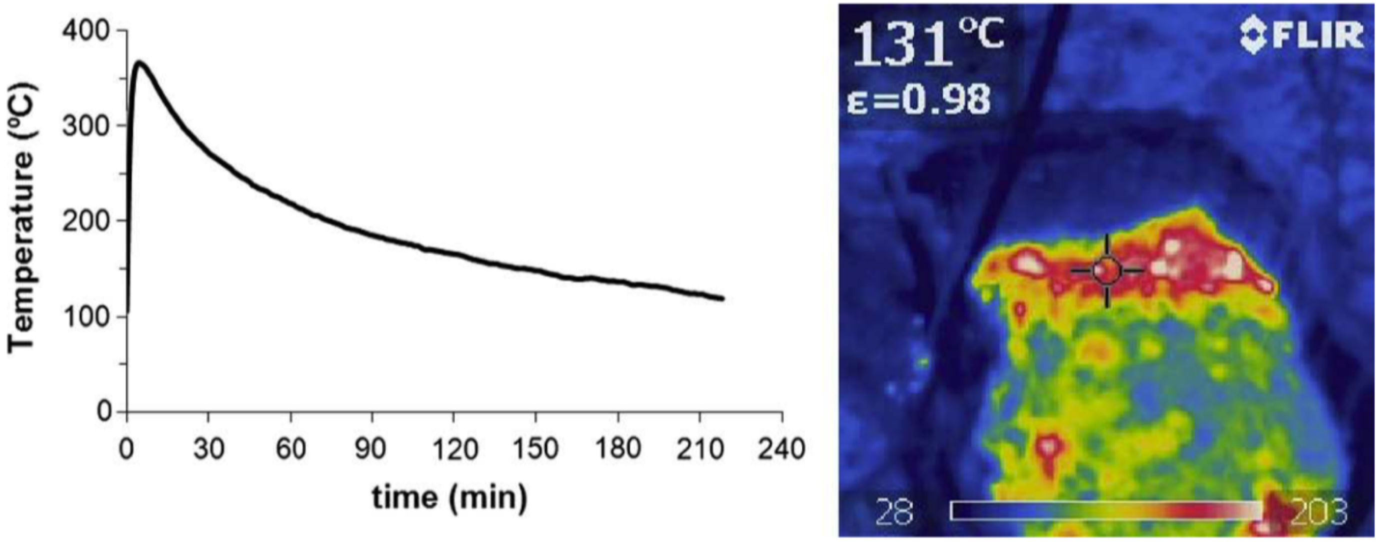


Fig. 7. *Left:* evolution of temperature during short immersion slaking process. *Right:* thermography of the basket.

We observe that portlandite crystal sizes are bigger for the limes slaked in conditions of water excess, and therefore lower temperatures during slaking. Samples Z2 and Z3, slaked with the aspersion and Grande Acqua method respec- tively, show similar crystal sizes for portlandite and brucite. Z4, slaked by the immersion process where temperatures raised above 300 °C, exhibits a remarkably smaller portlandite crystal size of around 400 Å….. bigger portlandite crystals for the limes slaked with higher water-to-lime ratios.

Greater viscosity in the wet-slaked lime.

Joan Ramon Rosell⇑, Laia Haurie, Antonia Navarro, Inma R. Cantalapiedra (2014) Influence of the traditional slaking process on the lime putty characteristics

Conclusions

1)As for the curing time, a vast increment of the compressive and flexural strengths between 28 and 365 curing days was determined (compressive strength increases twice or more from 28 to 365 days).

(2) The period to exhibit a maximum strength has been determined as a function of the binder content: lower B/Ag ratio mortars have shown a slight decrease in the strength when the curing time increased. The maximum strength has been related to the presence of a certain amount of uncarbonated portlandite.

(3) A correlation between binder amount and mortar strength was observed: a binder content increase improves strength within a limit. Binder amounts beyond (2:1) B/Ag ratio have shown a strong strength reduction. It is stated that a large binder content produces an interlocked structure, while the aggregates cause discontinuities in the structure. The porosity increase due to the binder makes carbonation easier, so mortar strength improves. However, in case of binder excess, the increase in voids leads to a strength reduction.

(4) A suitable grain size distribution of the aggregate has allowed higher mortar strengths.

(5) The type and shape of the aggregate influence the mortar strength. Angular limestone has been shown to improve strength. The lack of discontinuity between the binder matrix and the aggregate of the same nature improves the strength, as well as a good packing of the aggregate with angular edges. Limestone aggregates have shown medium and large radius pores that allow carbonation, avoiding stress during drying and the crystallization process.

Lanas & Alvarez (2003) **MASONRY REPAIR LIME-BASED MORTARS: FACTORS AFFECTING THE MECHANICAL BEHAVIOR.**

Table 7. Open porosity (%) in mortars tested after 365 days.

	B/Ag	Ag-1	Ag-2	Ag-3	Ag-4
Lime A	**1:1**	24.11	27.09	26.05	27.27
	1:2	20.51	24.24	22.91	24.25
	1:3	19.08	21.72	20.94	21.03
	1:4	17.90	19.88	20.26	19.30
	1:5	16.51	19.68	18.79	19.35
Lime B	**1:1**	28.42	30.63	29.70	30.45
	1:2	23.89	25.41	25.51	26.51
	1:3	22.23	23.25	24.50	24.61
	1:4	18.40	20.30	21.28	22.72
	1:5	19.79	21.06	20.80	21.35

In 2019, approximately 24 % (14 Gt CO_2-eq.) of the net global anthropogenic emissions originated from industrial sources, **and lime production was the second highest industrial source after cement production** (IPCC, 2021; Shan et al., 2016).

According to Renforth (2019), approximately 34 % of lime can directly or indirectly remove CO2 from the atmosphere and absorb CO2 during the utilization stage…..carbonation can be considered a mineral- ization technology for carbon capture, utilization, and stor- age (CCUS) (Lai et al., 2021; Snæbjörnsdóttir et al., 2020).

MOR = LIME MORTAR

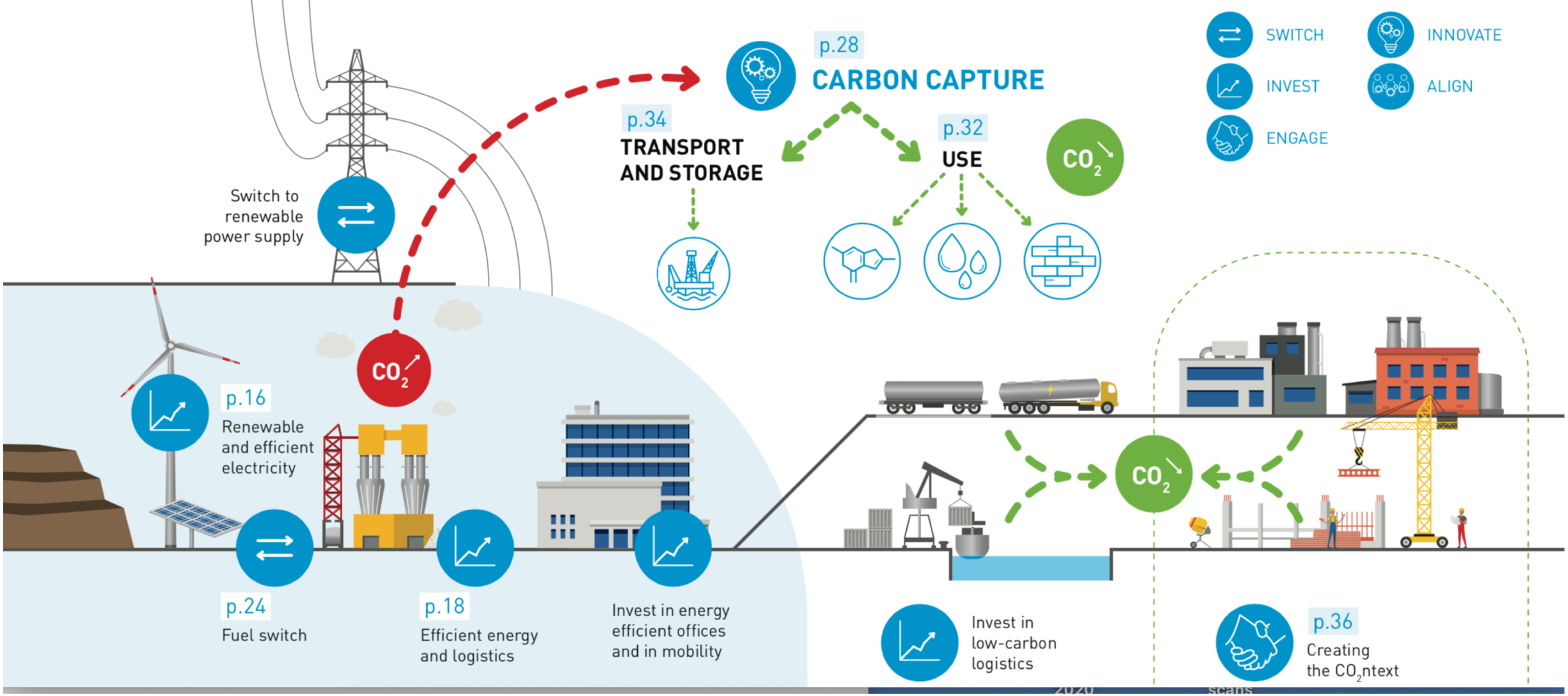
Table 1. Summary of the global uptake of CO_2 by lime-containing materials in different stages of its cycle.

Stage	Types of lime materials	CO_2 uptake in 2020 (Mt C)	Cumulative CO_2 uptake from 1930 to 2020 (Mt C)
Production	LKD	0.76	36.95
Service	LSS	13.96	629.43
	MOR	6.88	316.89
	PCC	1.73	84.98
	SUG	0.74	45.68
Waste disposal	RM	0.002	0.05
	SS	8.31	225.67
	CS	1.67	73.39
	LM	0.003	0.09

LKD: lime kiln dust, LSS: lime-stabilized soil, PCC: precipitated calcium carbonate, SUG: carbonation sugar, RM: red mud, SS: steel slag, CS: carbide slag, LM: lime mud.

Bing L, Ma M, Liu L, Wang J, Niu L, Xo F (2022) **An investigation of the global uptake of CO2 by lime from 1930 to 2020**

Our carbon roadmap



Lhoist 2021.

The mixed air-lime mortars consist of air-lime and Ordinary Portland Cement (OPC), that is the most commonly used hydraulic binder. The substitution of 20% of the binder amount with cement is sufficient to decrease the porosity and consequently the diffusivity of CO2 in the mortars' pores. Thus, the CR decreases. Since K of OPC is about 0.25 mm/(day)1/2, i.e. 4 times lower than in air-lime mortars partially due to the decrease in pore size, it was estimated that partial substitution of air-lime with hydraulic binder causes a reduction of CRs by a factor of 2 to 5 compared to pure air-lime mortars….

In conclusion, CR of mixed air-lime mortars is one fourth of the pure air-lime mortars one for an application with the same thickness, i.e. 20-23% after 100 years. The values of 20% and 23% as natural carbonation, are well aligned with a recent study conducted by Anderson et al. [10] on annual CO2 uptake from concrete and mortar.

Lime Based Construction Materials as a Carbon Sink
Francesco Pietro Campo and Mario Grosso (2022)