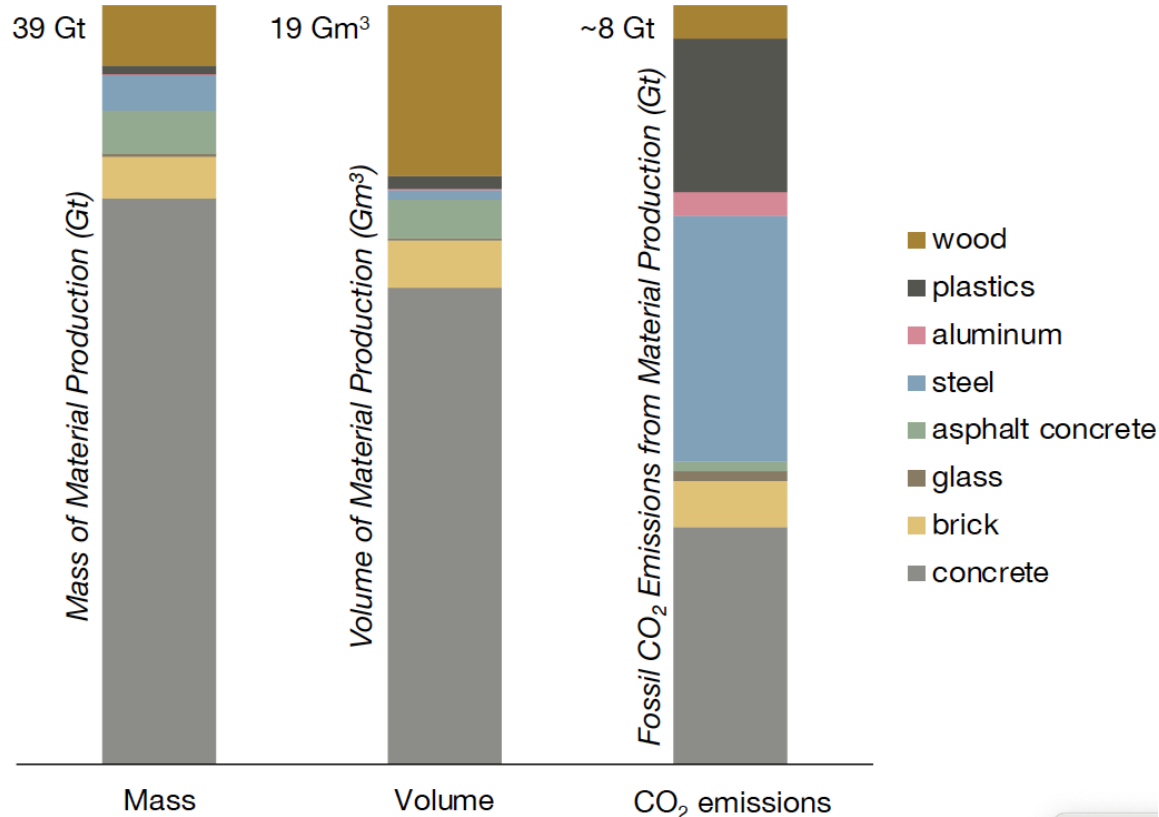


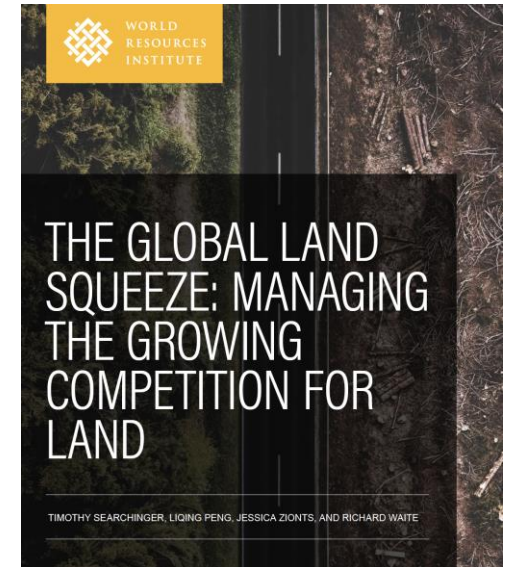
Decarbonisation pathways for cement and concrete

Karen Scrivener, FREng
EPFL
Switzerland

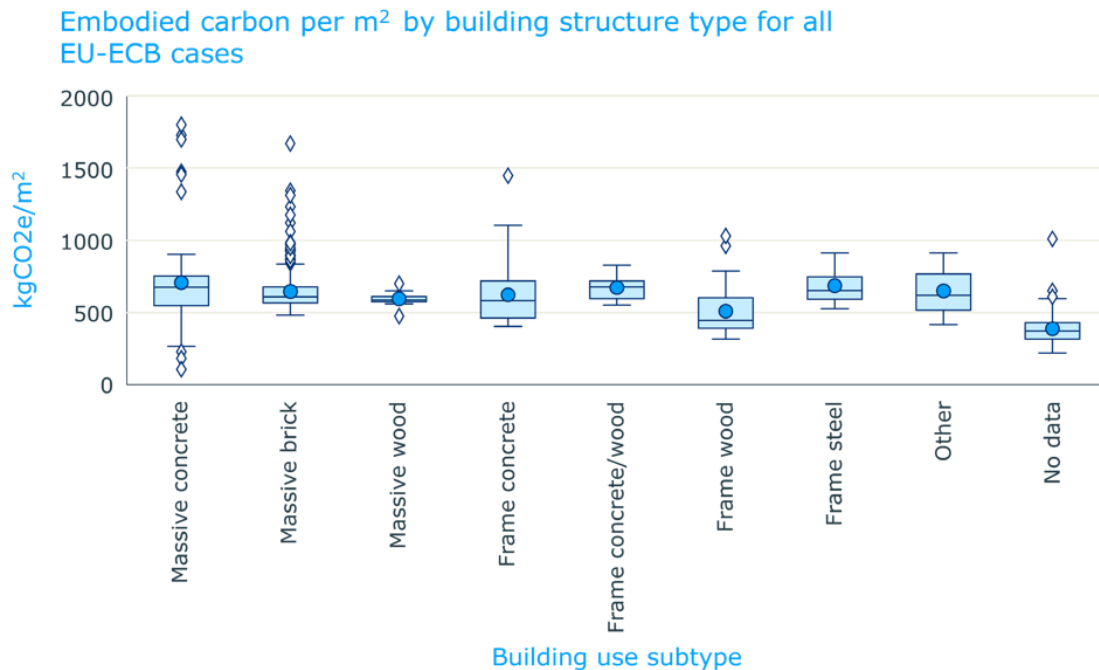
90% construction



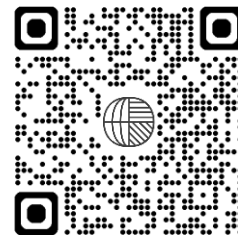
Replacing just 25% of concrete with wood sustainably would require new forest 1.5 times the size of India



Would it help to replace concrete by other materials?



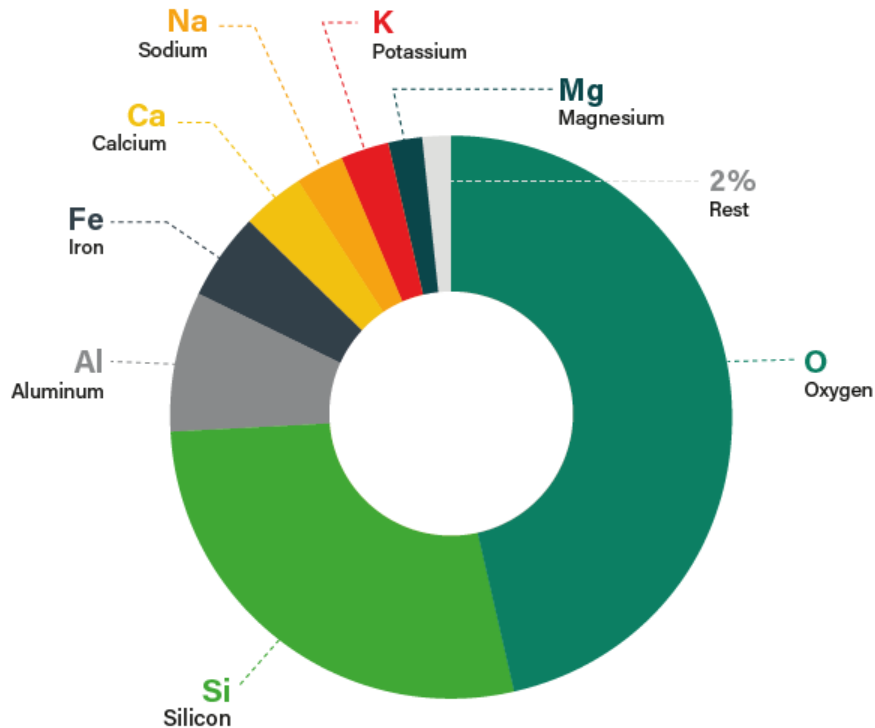
Global Building
Data Initiative



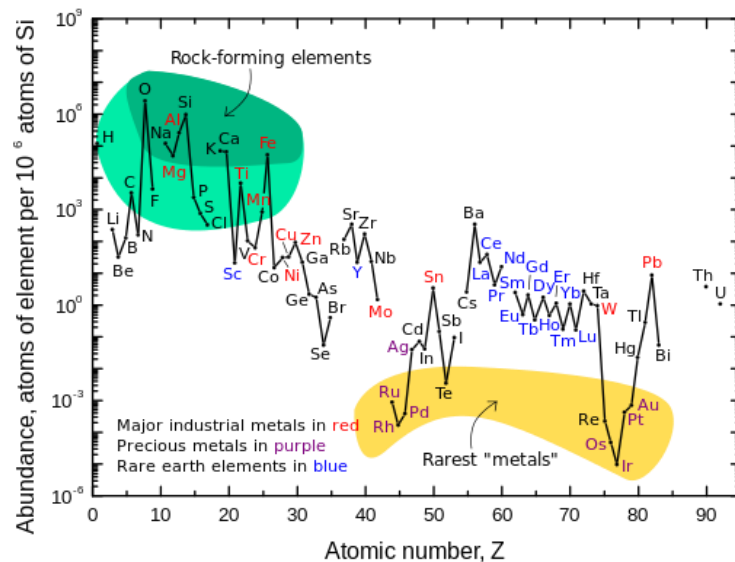
It is not by chance Portland cement is the most used material on earth

It is a direct consequence of chemistry and geology

What is available on earth?



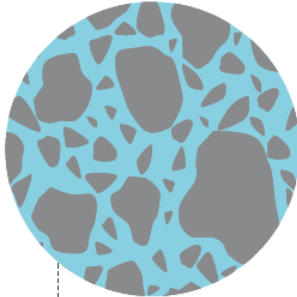
8 elements make up more than **98%** of the earth's crust



Due to the processes of forming elements in stars other rocky planets will be similar

How does cements work?

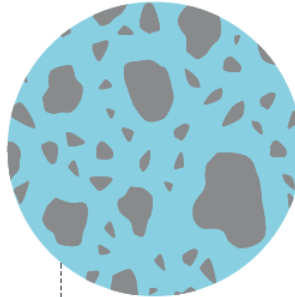
1



We mix the grey cement powder with water.

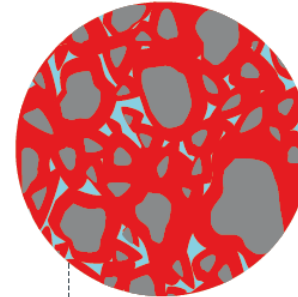
To start with the grains are just floating about in the water and we can cast the concrete into moulds

2



The cement grains dissolve in the water

3



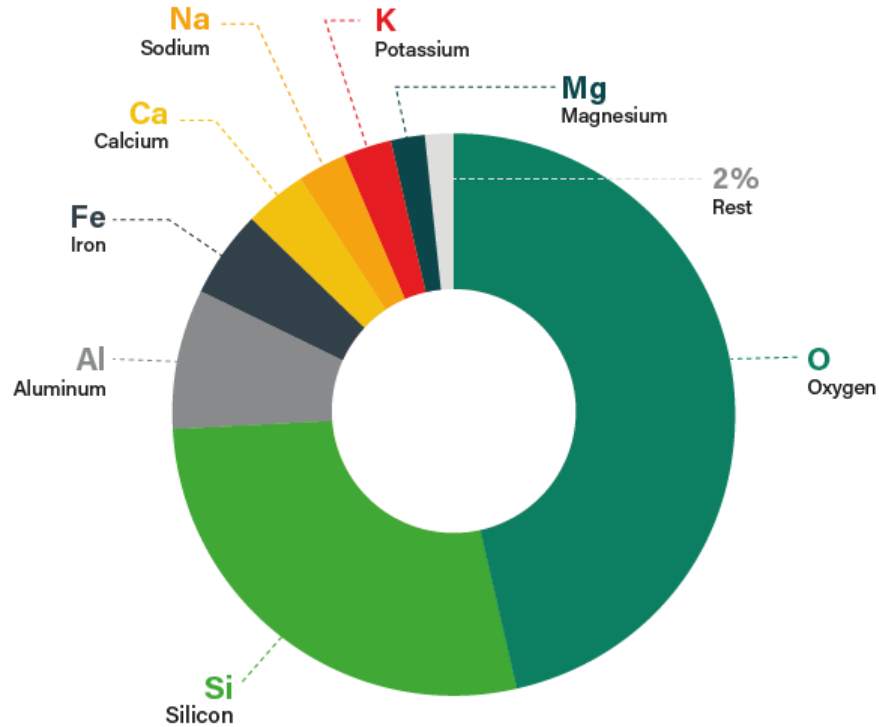
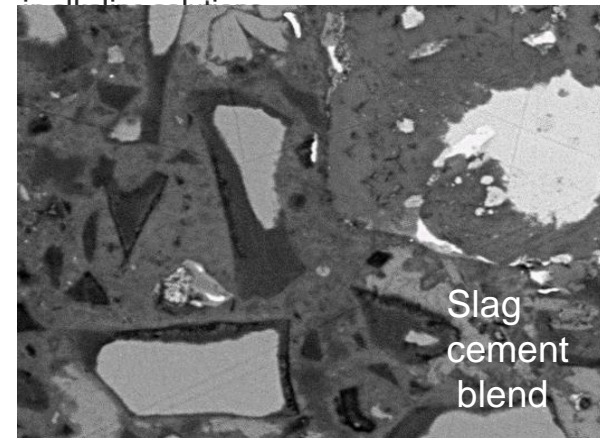
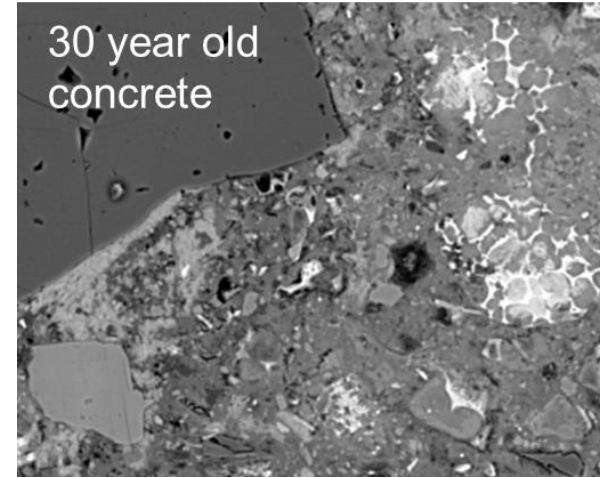
The cement grains dissolve in the water

And then precipitate Hydrates – new solids which have higher volume and hold the grains together: creating a rigid solid

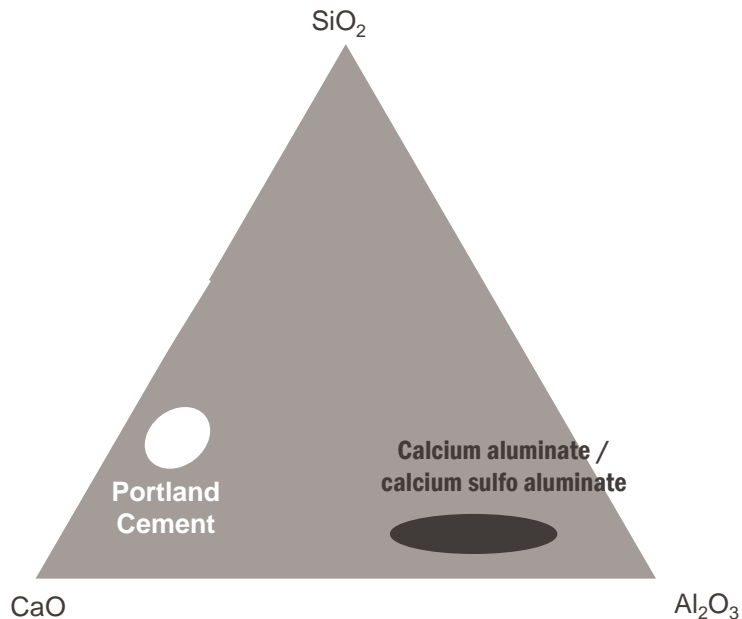
 Cement grain

 Water

What is available on earth?

 Na_2O K_2O Fe_2O_3 MgO CaO SiO_2 Al_2O_3 

Hydraulic minerals in system $\text{CaO-SiO}_2\text{-Al}_2\text{O}_3$



Less CaO > less CO_2

BUT, what sources of minerals are there which contain $\text{Al}_2\text{O}_3 \gg \text{SiO}_2$?

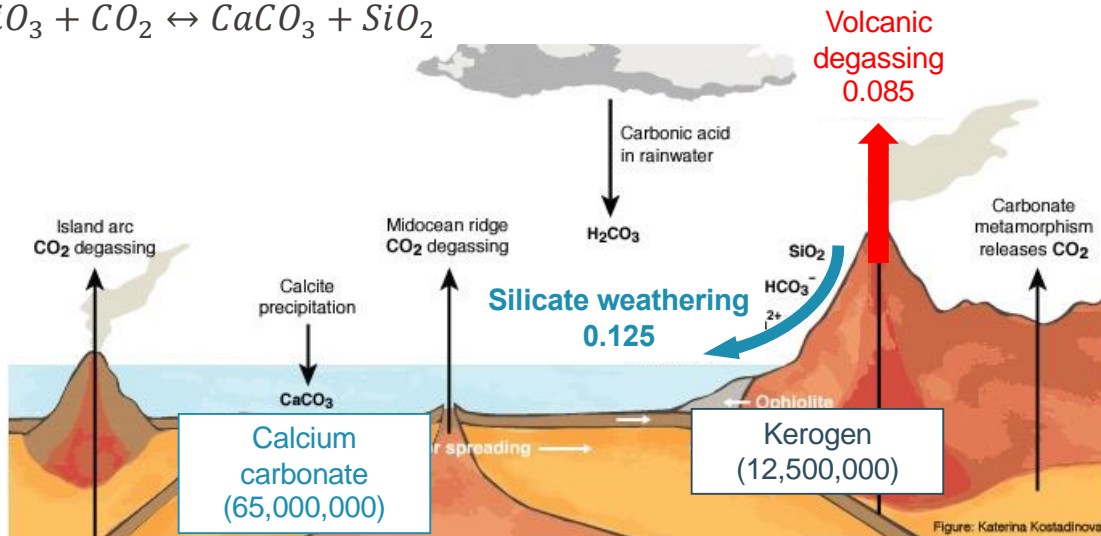
Bauxite – localised,
under increasing demand for Aluminium production,
EXPENSIVE

Even if all current bauxite production diverted would still only replace 10-15% of current demand.

Even after nearly 50 years CSA production in China is <0.1% of OPC

The advantages of limestone

- A concentrated source of calcium due to geological slow carbonate silicate cycle
- Long time scales
 - Lithosphere: Small fluxes, large reservoirs
 - $CaSiO_3 + CO_2 \leftrightarrow CaCO_3 + SiO_2$



[numbers in Gt C per year, number in parentheses in Gt C; source: Kasting, 2019; Hilton & West, 2020]

Slide
from
Ruben
Snellings

KULeuven

- Because of the weathering process, what is not limestone is dominated by aluminosilicate rock, eventually clay

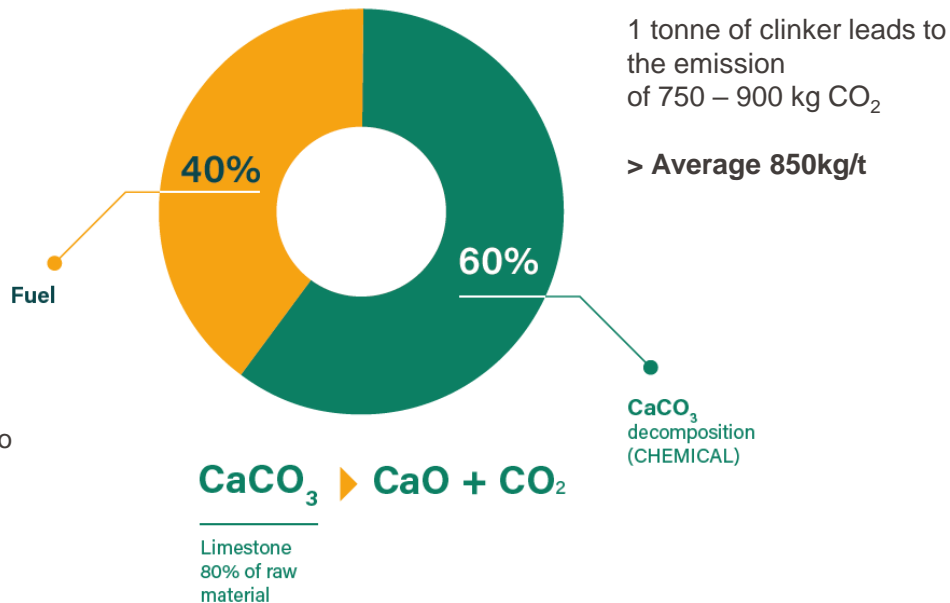


No surprise that the interesting properties of limestone – clay combinations were discovered in Europe about 200 years ago

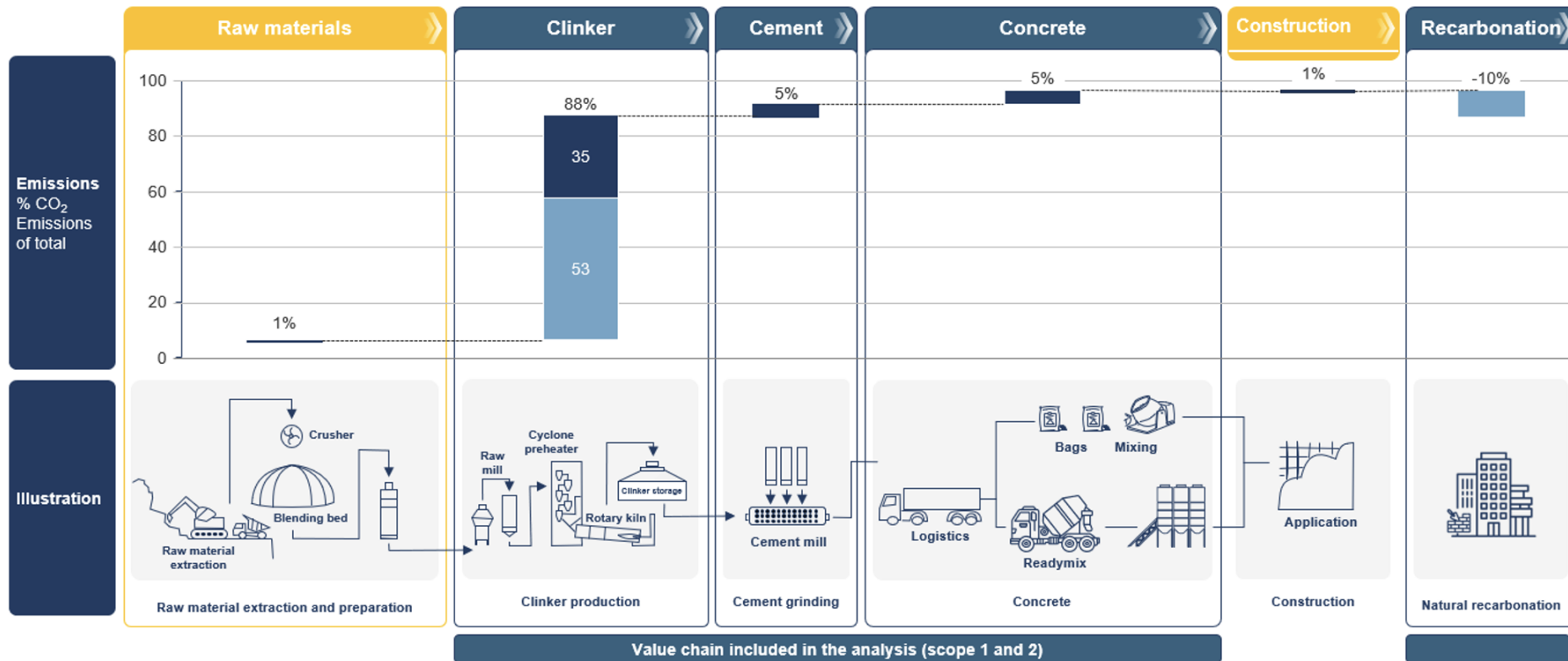
But unfortunately production of cement from limestone leads to substantial CO₂ emissions



- The production process is highly optimised up to around 80% of thermodynamic limit.
- It is estimated that < 2% further savings can be made here
- Use of waste fuels, which can be > 80% reduces the demand for fossil fuels

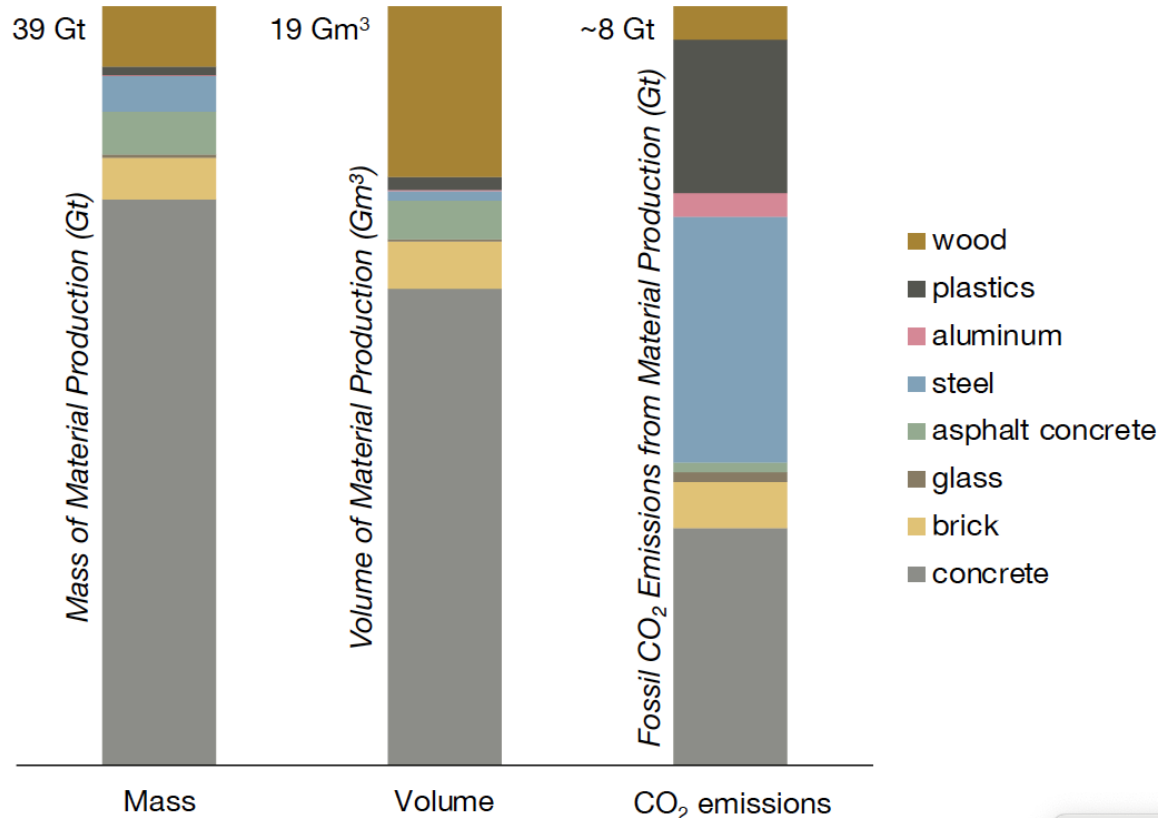


Clinker is responsible for 85-90% of CO₂ emissions for cement-based materials

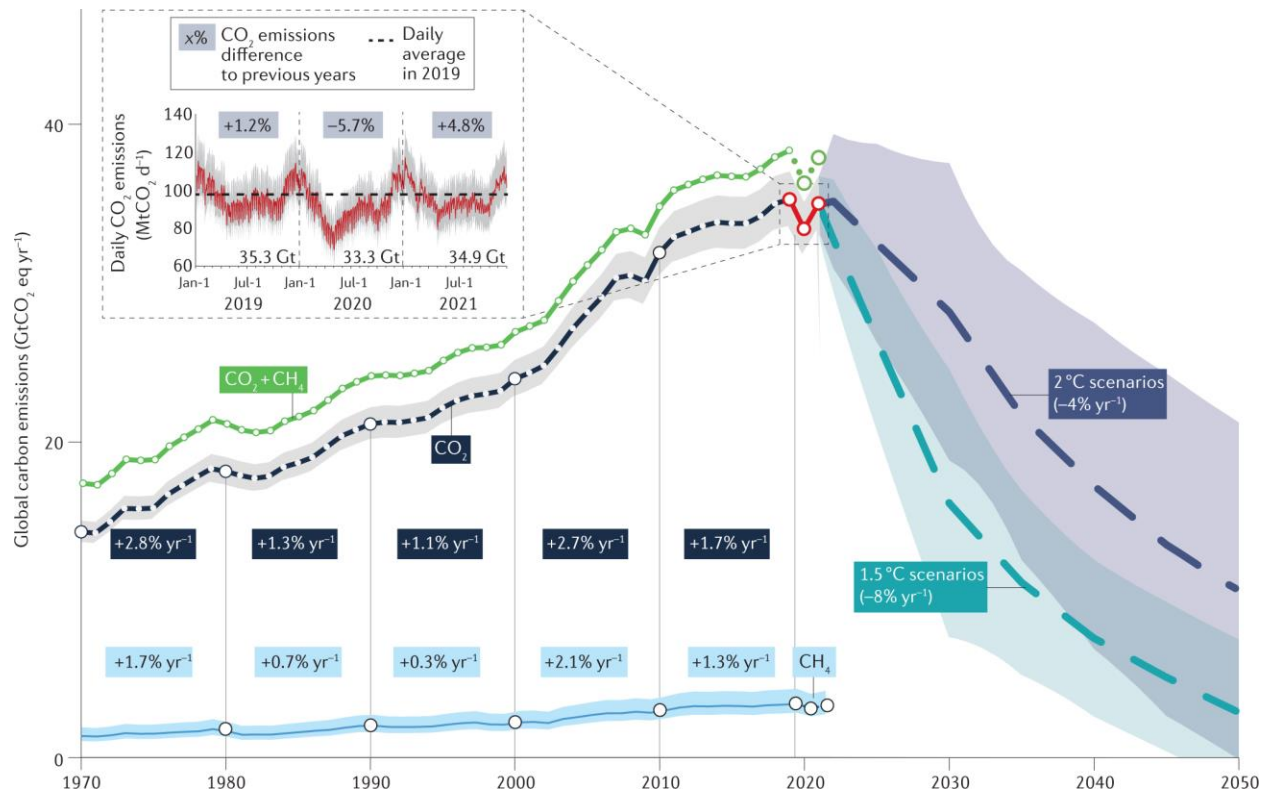


But still very good value for CO₂

World Use of materials: 90% construction



Need to act fast



“

Three-quarters of the infrastructure that will exist in 2050 has yet to be built

– Antonio Guterres – UN SG



“

Up to 2060, the world is expected to add the equivalent of an entire New York City to the world, every month, for 40 years.

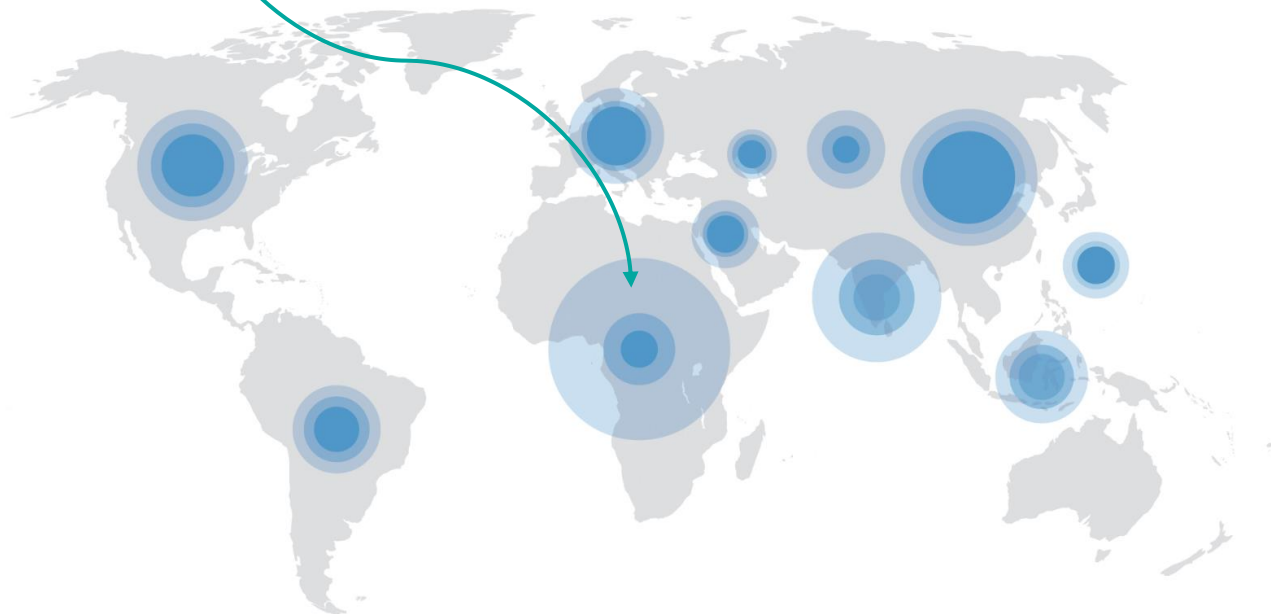
– Architecture2030.org



This will **NOT HAPPEN** in the Global North

It will happen **HERE**

Global building floor area
is expected to **double** by 2060.

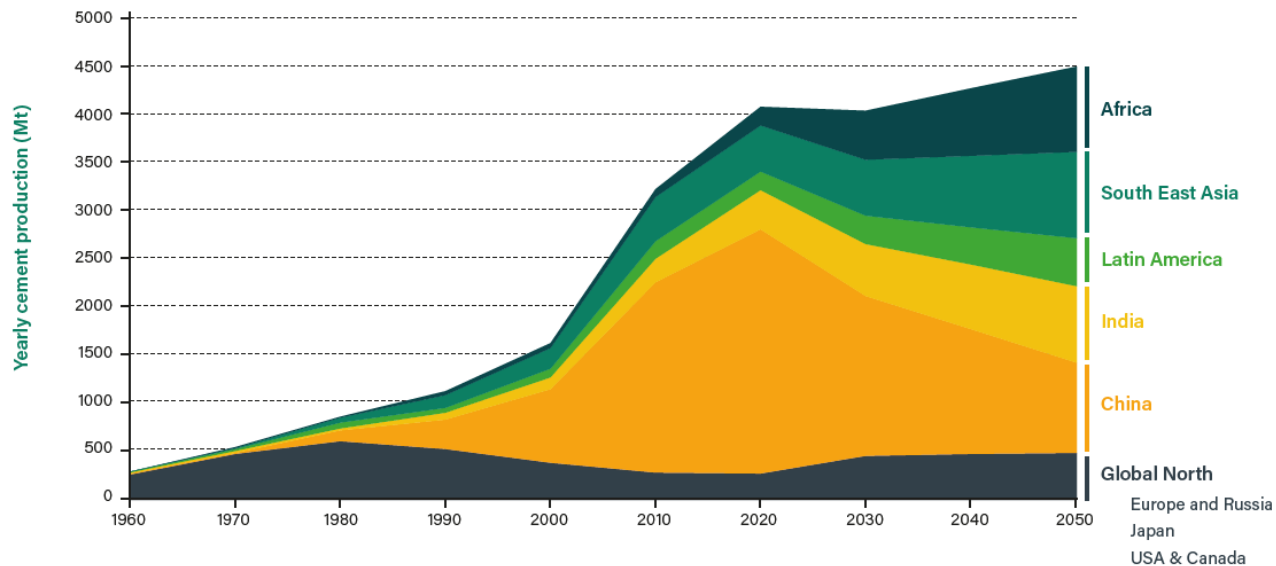


© Architecture 2030. All Rights Reserved.

Data Sources: Global ABC, Global Status Report 2017

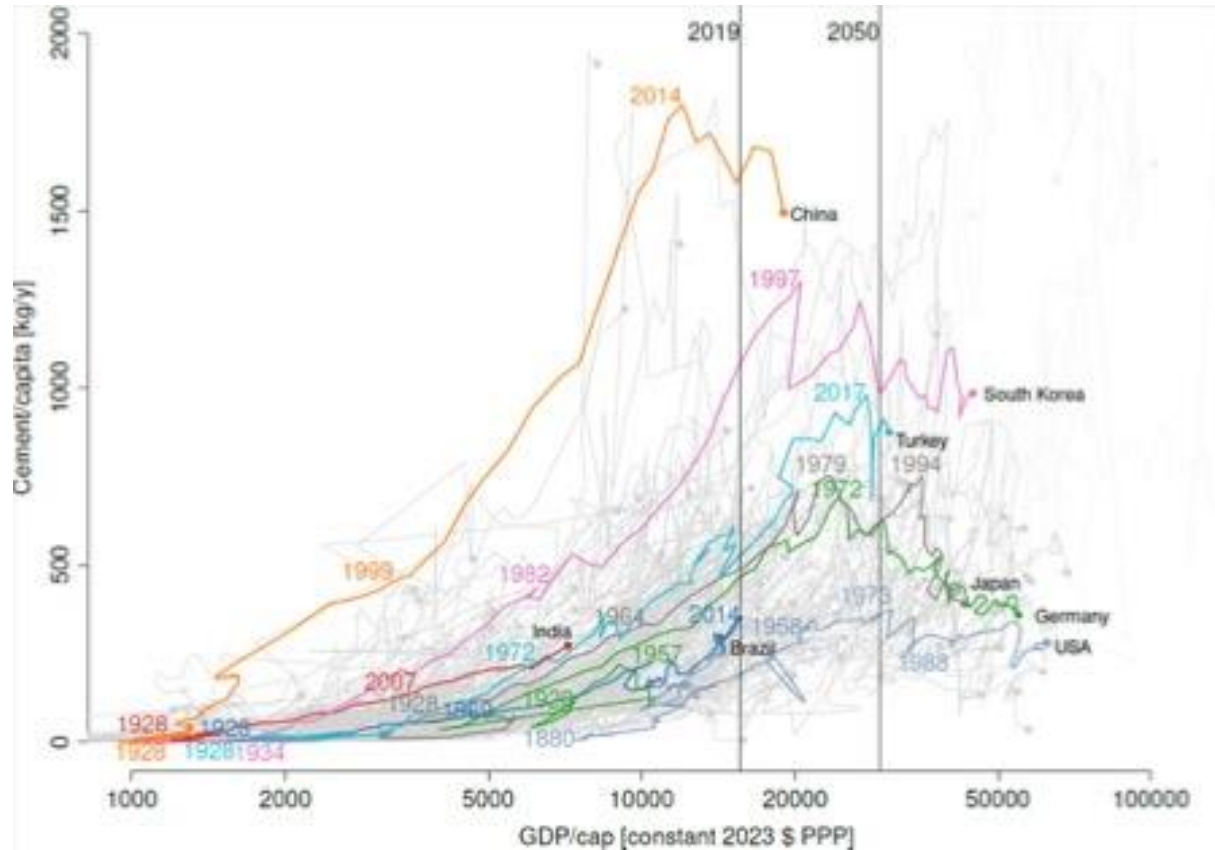
Changing pattern of cement use

Historical and forecast cement supply per region



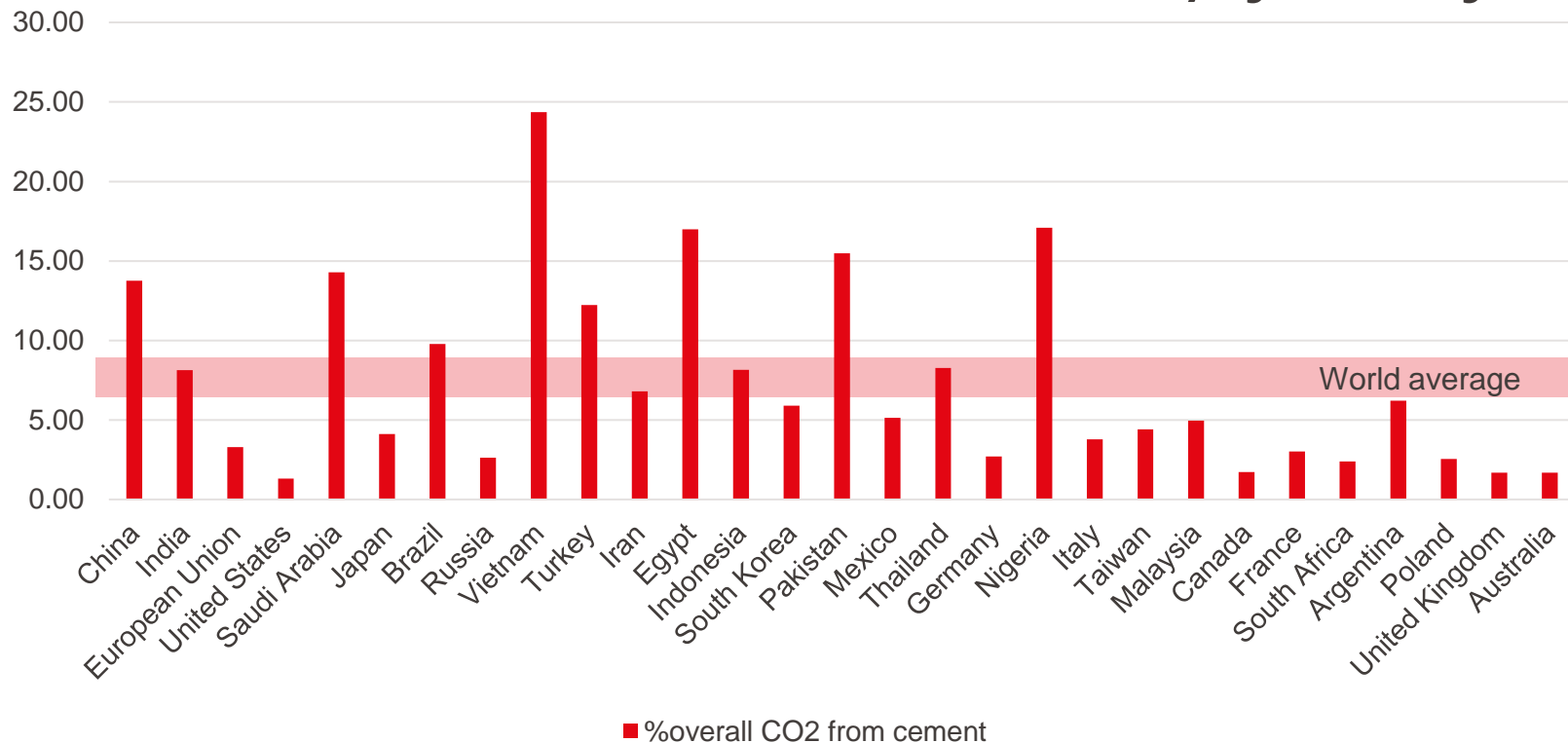
We need solutions for people in developing countries

Concrete “Hump” a normal phenomenon of growth



In China maybe 1000 out 1500 cement plants will close

Contribution of cement to CO2 emissions, by country



Although the USA is the third largest consumer of cement,
it accounts for < 1.5% of the country's emissions

What can be done?

**What about getting Ca
not from Limestone?**

Name of oxide	Content, % by weight
SiO ₂	46.5 – 51.5
Al ₂ O ₃	15.0 – 19.0
MgO	4.0 – 10.5
CaO	7.5 – 11.5
FeO+Fe ₂ O ₃	8.0 – 12.0
K ₂ O+Na ₂ O	3.0 – 6.0
TiO ₂	0.3 – 2.5
Cr ₂ O ₃	0.02 – 0.05
MnO	< 0.1
Other	Up to 100

Dissolve in acid

Precipitate oxide separately

Common technology
in mining industry

**Make clinker with
uncarbonated calcium oxide**

Estimated cost ~ \$800 / ton

Source research gate

>80% reject materials

Ca from Seawater?

400ppm,

Inverse of desalination

- 3 kWh for desalination of 1 tonne of water
 - ~\$300 for seawater containing 1 tonne of Calcium
 - But the desalination residue is still very wet
 - 10X more energy to get a dry residue
 - Then have to separate the elements in the residue
 - Back to situation of basalt
-
- Cost range of \$1000 - \$ 10,000 per tonne of CaO
(remember clinker < \$50, clinker + CCUS < \$150)
 - All the desalination plants in the world today could potentially supply the equivalent of 5-10 clinker plants

No silver bullet

Despite the media interest they attract, most niche technologies – such as alkali activated materials, cement from algae, etc are:

- impractical,
- costly,
- unscalable,
- will take too long to mature

so have little to no possibility of delivering any significant impact.

But there is good news?

We can do a lot if we act through the value chain



Reduce CO₂
from clinker
production

- Efficient plants
- Waste fuels
- Alternate raw materials

Reduce
clinker
in cement

• **SCMs**

Reduce
cement
in concrete

- Aggregate grading
- Good admixtures
- Use filler

Reduce
concrete
in building

More
efficient
(re)use of
buildings

RECYCLE!

Report for
European Climate
Foundation 2017



Near-term pathways for decarbonizing global concrete production

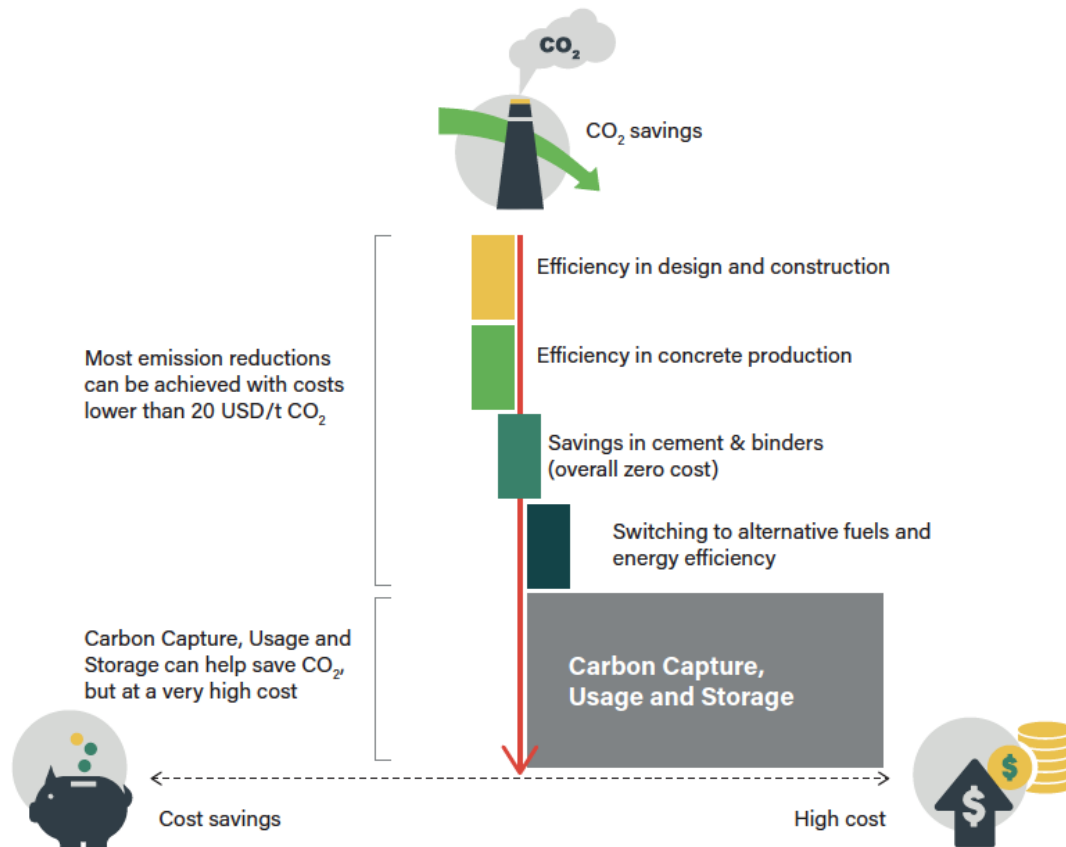
Received: 27 January 2023

Josefine A. Olsson ¹, Sabbie A. Miller ¹ & Mark G. Alexander ²

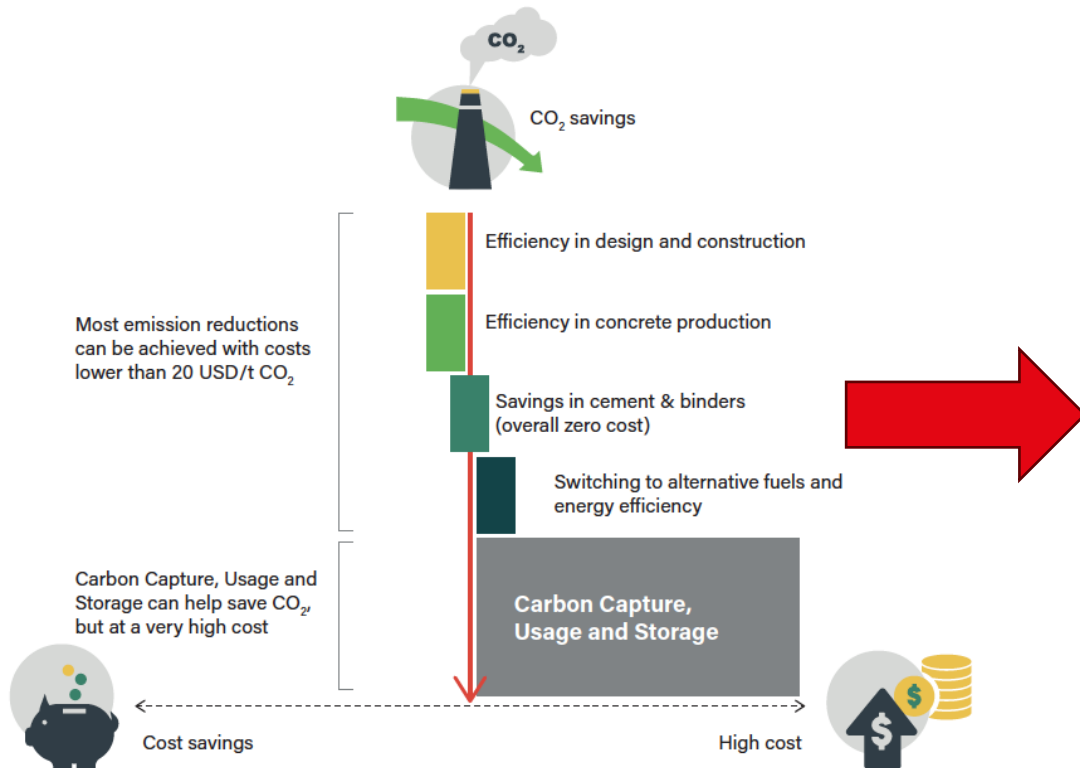
Accepted: 21 July 2023

Calculated **76%** with these strategies

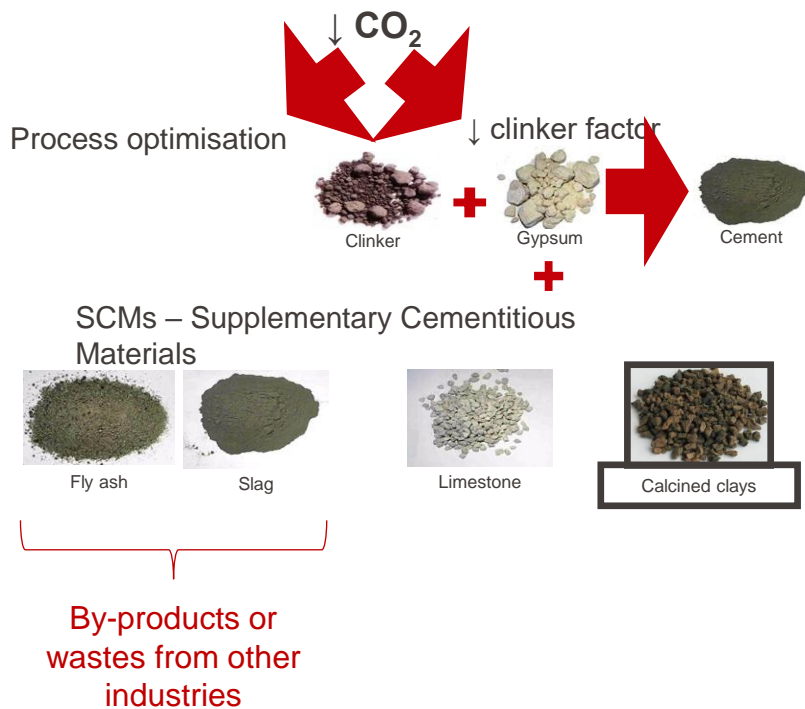
Much of the path to net zero is low cost



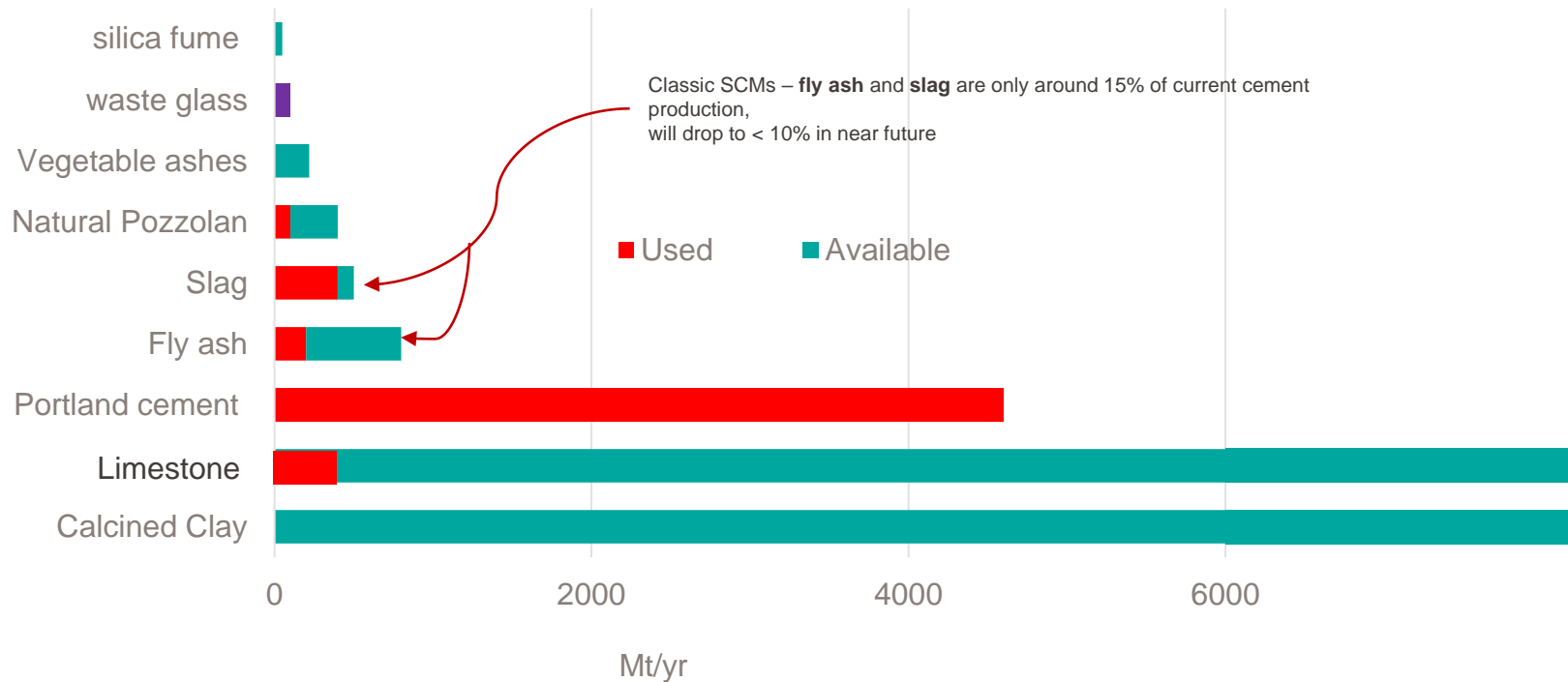
Reducing clinker factor is the most practical to implement



Most promising approach – reducing the clinker factor



Availability of SCMs

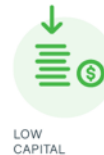


There is no magic solution

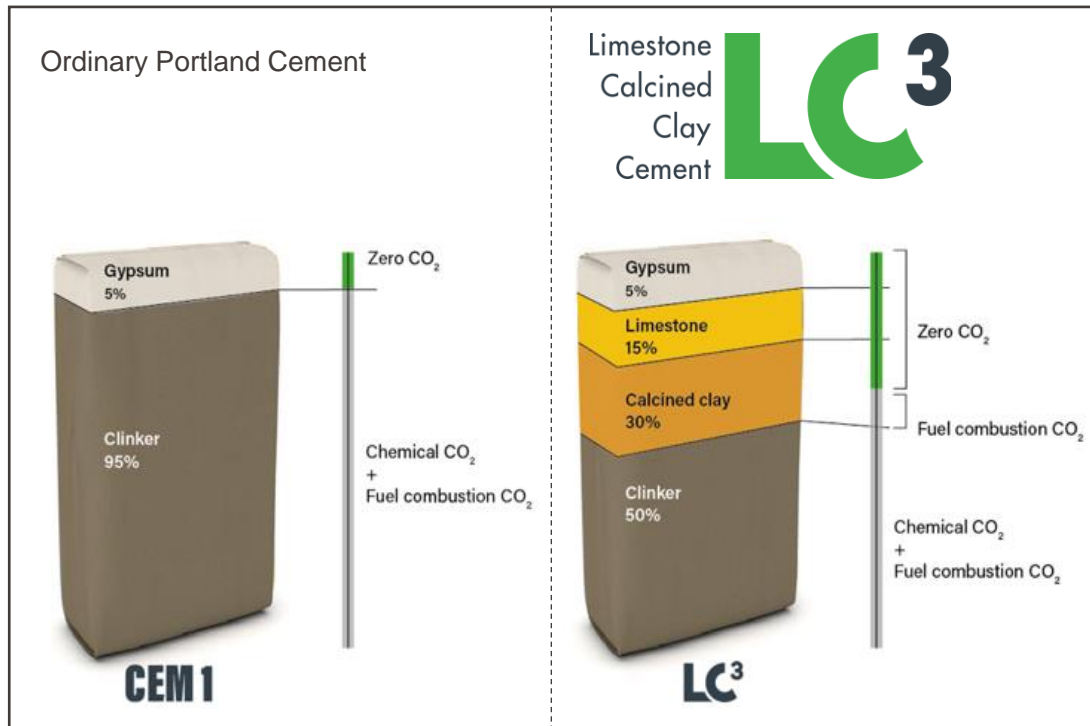
- Blended with SCMs will be best solution for sustainable cements for the foreseeable future.
- **Only material** really potentially available in viable quantities **is clay**.
- **Synergetic reaction** of calcined clay and limestone allows high levels of substitution
- EPFL led the LC³ Project supported by **Swiss Agency for Development and Cooperation (SDC)**, 2013-2022.
- **Climateworks Foundation** supporting the LC³ Project since 2022.



LC³ – Limestone Calcined Clay Cement

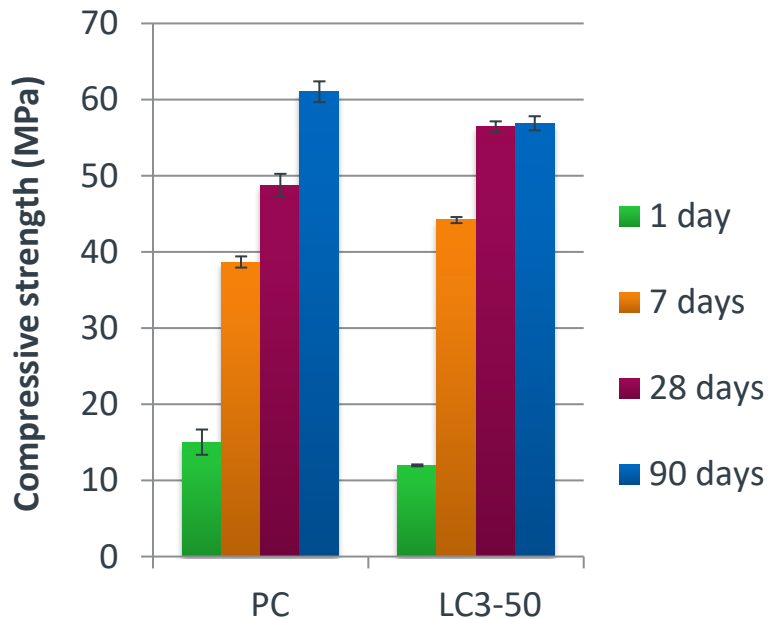
LOW
CARBONLOW
CAPITALHIGH
PERFORMANCE

SCALABLE



- LC³ is a **low-carbon** blended cement type
- **Reduces CO₂ emissions in cement by 40%**

LC³ has comparable strength to OPC



LC3-50 = 50% clinker.

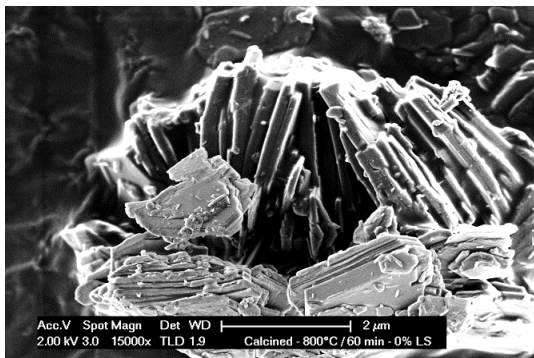
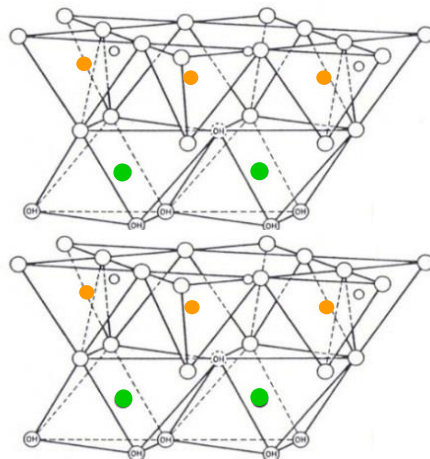
- 50% less clinker
- 40% less CO₂
- Similar strength
- Better chloride resistance
- Resistant to alkali silica reaction



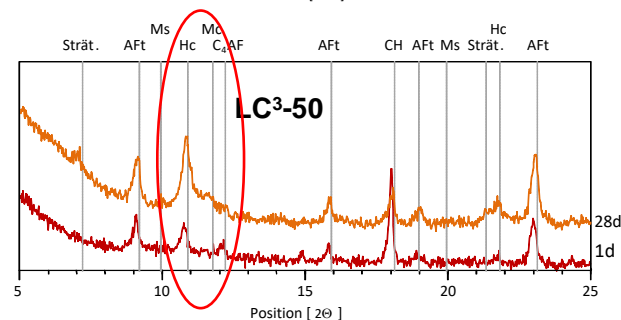
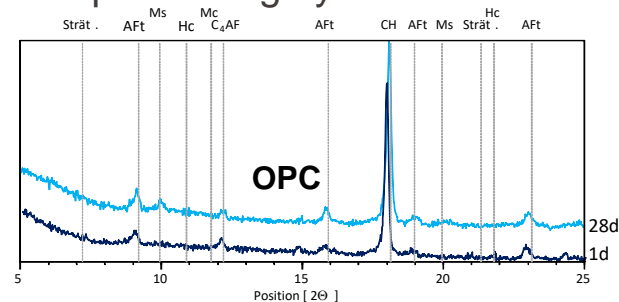
Why can we get such high replacement levels?

- Calcination of kaolinite at **700-850°C** gives metakaolin: much more reactive than glassy SCMs

● aluminium
● silicon

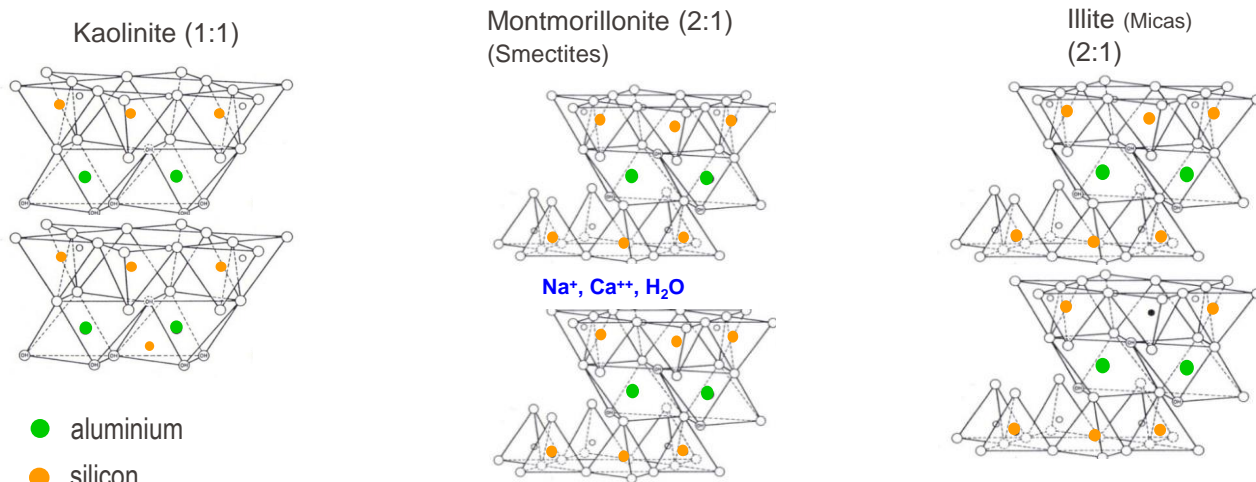


- » Synergetic reaction of Alumina in metakaolin with limestone to give space filling hydrates



**What kinds of clay are
suitable?**

Three basic clay structures



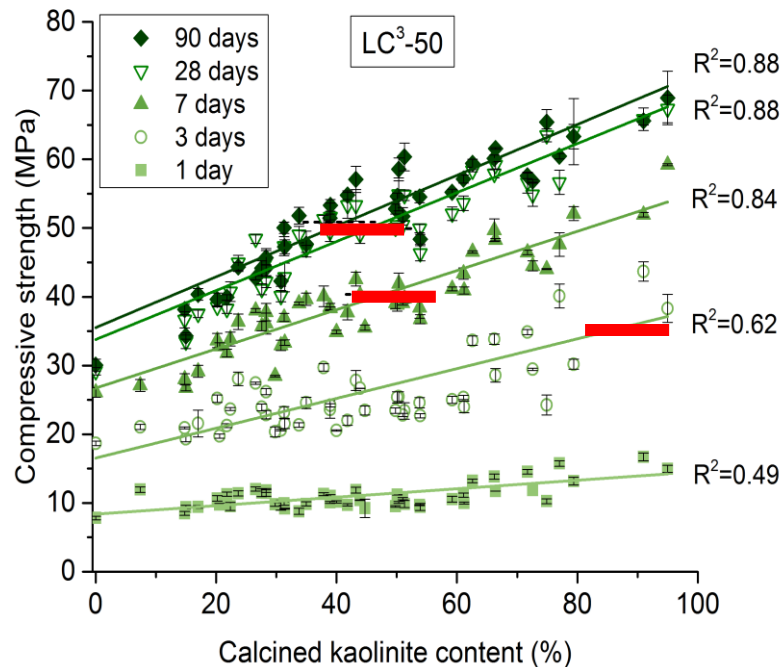
“Metakaolin”, sold as high purity product for paper, ceramic, refractory industries
Requirements for purity, colour, etc, mean expensive 3-4x price cement

Clays containing metakaolin available as wastes
– over or under burden NOT agricultural soil

Much much less expensive often available close to cement plants

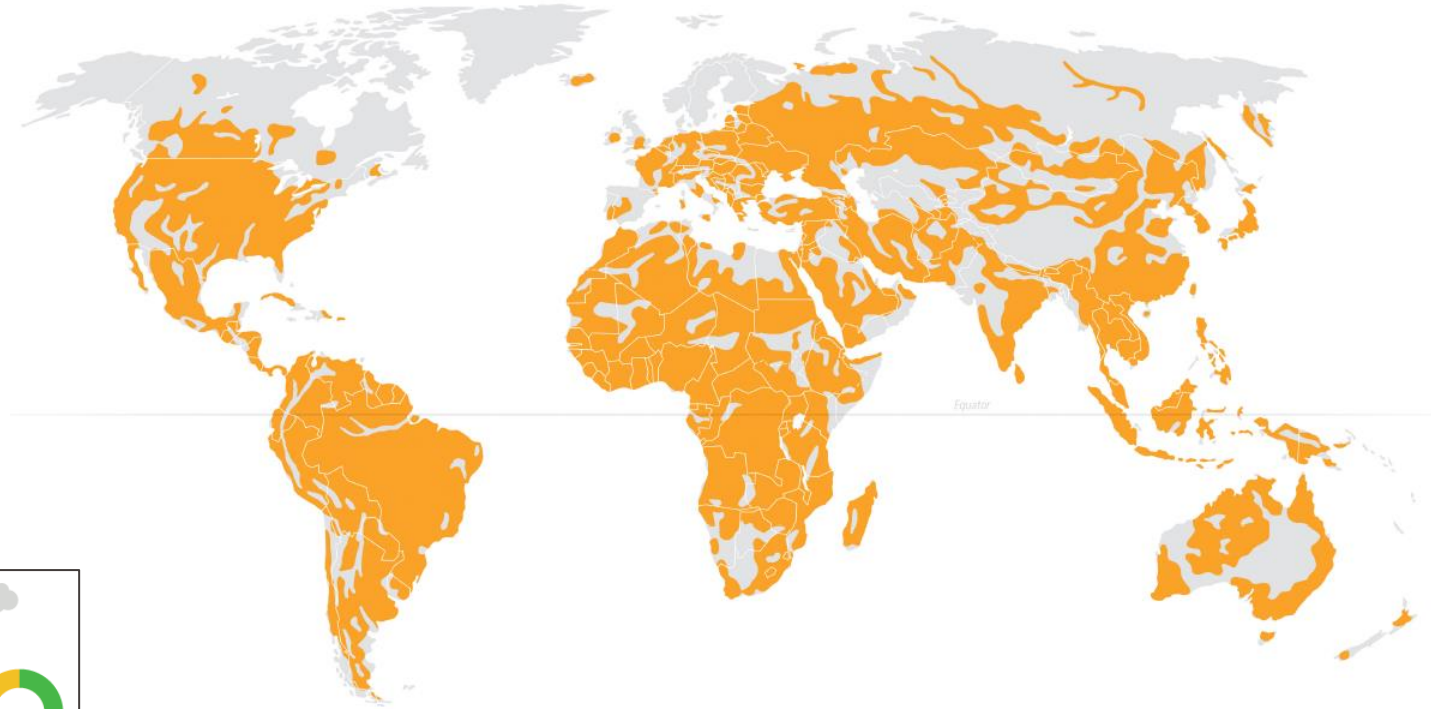
Benchmark test of clay strength

- **Compressive strength EN 196-1 at 1, 3, 7, 28, 90 d**
- **Linear increase of strength with the MK content of calcined clays**
- **Similar strength to PC for blends containing 40% of calcined kaolinite from 7d onwards**
- **At 28 and 90 days, little additional benefit >60%**
- **Minor impacts of fineness, specific surface and secondary phases**

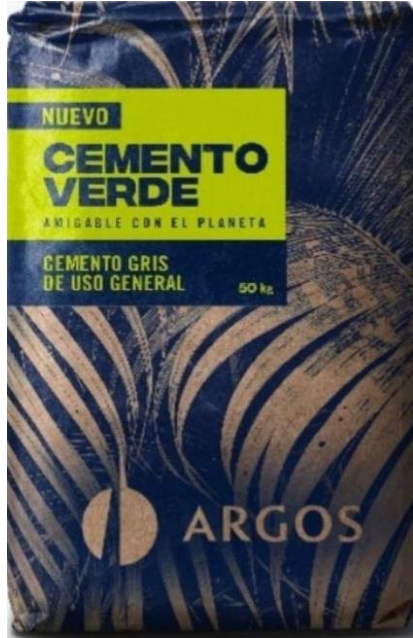


Calcined kaolinite content overwhelming parameter

World distribution of kaolinitic clays

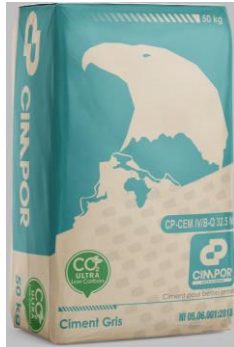
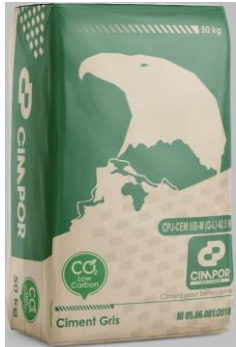


Industrial projects: Cemento Verde ARGOS, Colombia





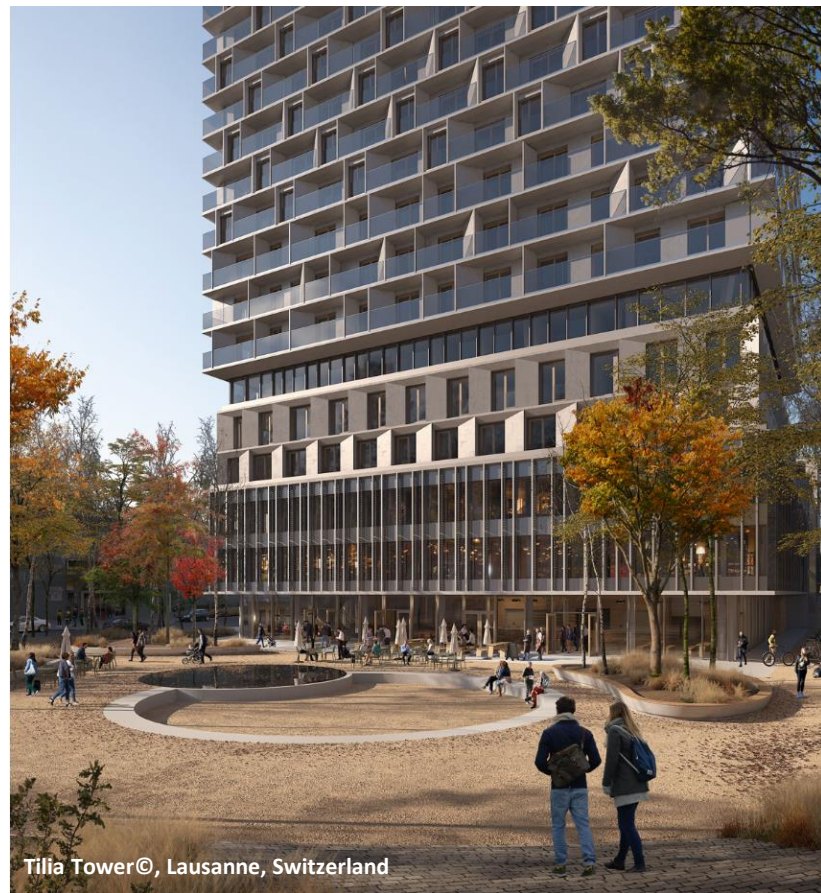
Industrial projects: CIMPOR, Ivory Coast



“people don’t want red concrete”



- Holcim's ECOPlanet LC³-type cement used for constructing a marina in Marseille, France for the 2024 Olympics.
- Tilia Tower©, Switzerland is an ambitious and sustainable high-rise building.
 - Slabs and internal walls are in LC³ from Jura Ciment
 - External façade in wood





- ~15 plants in operation
- >43 plants in progress:
- North America: 10
- Cent&South America: 23
- Europe: 14
- Africa: 14
- Asia: 7



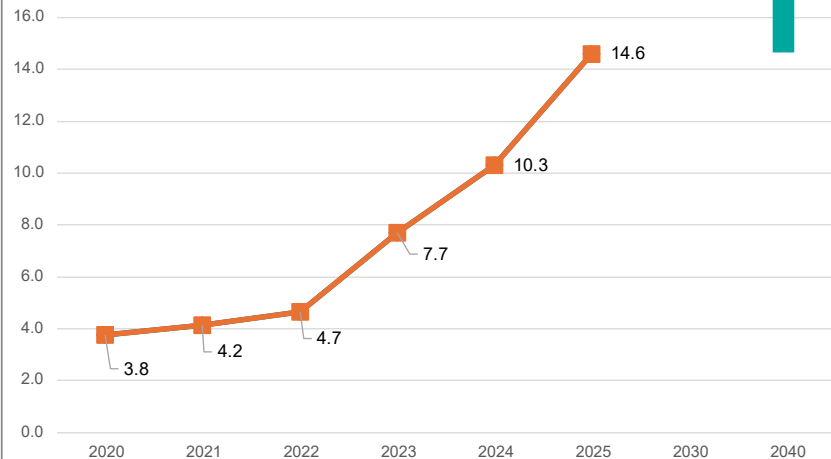
LC³: where are we now

Capacity and cumulative CO₂ savings

400 million



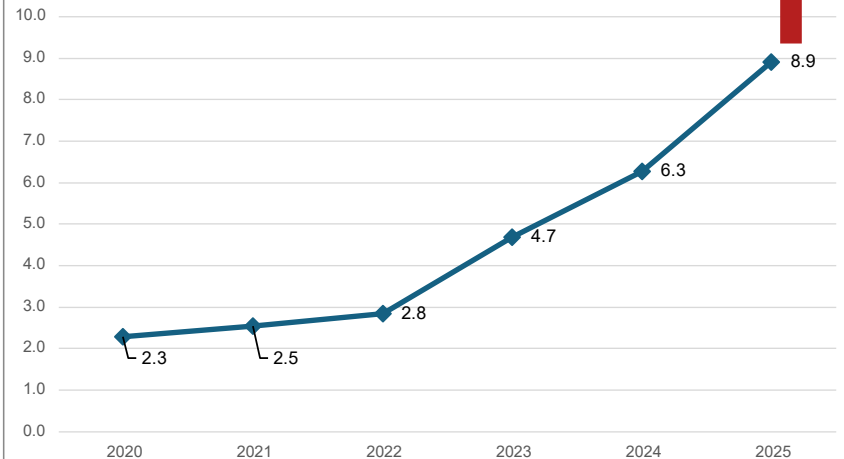
Calcined Clay capacity in place (in Million tons of CC)



> 500/ yr



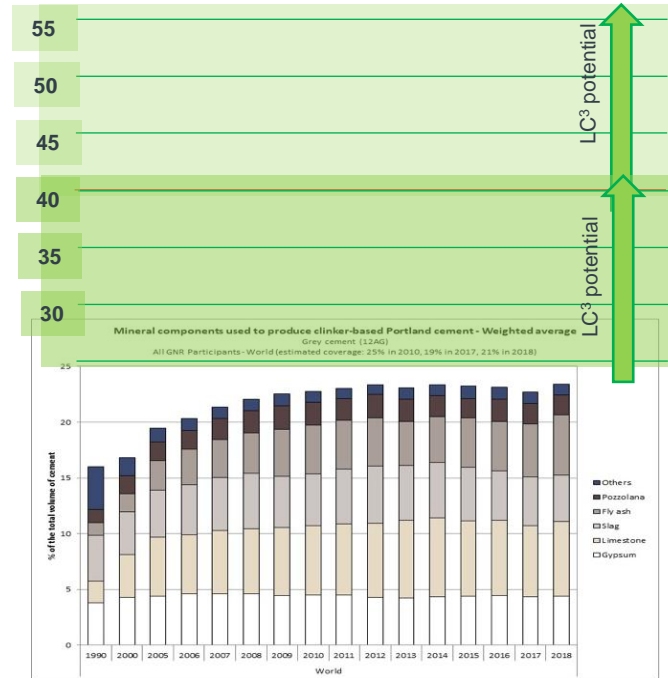
Cumulative CO₂ avoided using LC³ (in Million tons of CO₂)



By 2040, the goal of achieving one-third of global cement production with LC³ would require reaching a calcined clay production capacity of 400 million tons, which means an increase of 25 million tons annually.

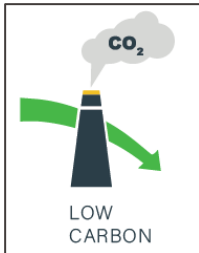
World Potential?

Calcined Clay only SCM which can expand substitution

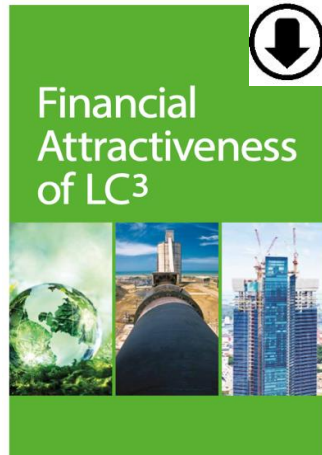


✓ 800 million tonnes CO₂/yr

✓ 400 million tonnes CO₂/yr



Financial Feasibility



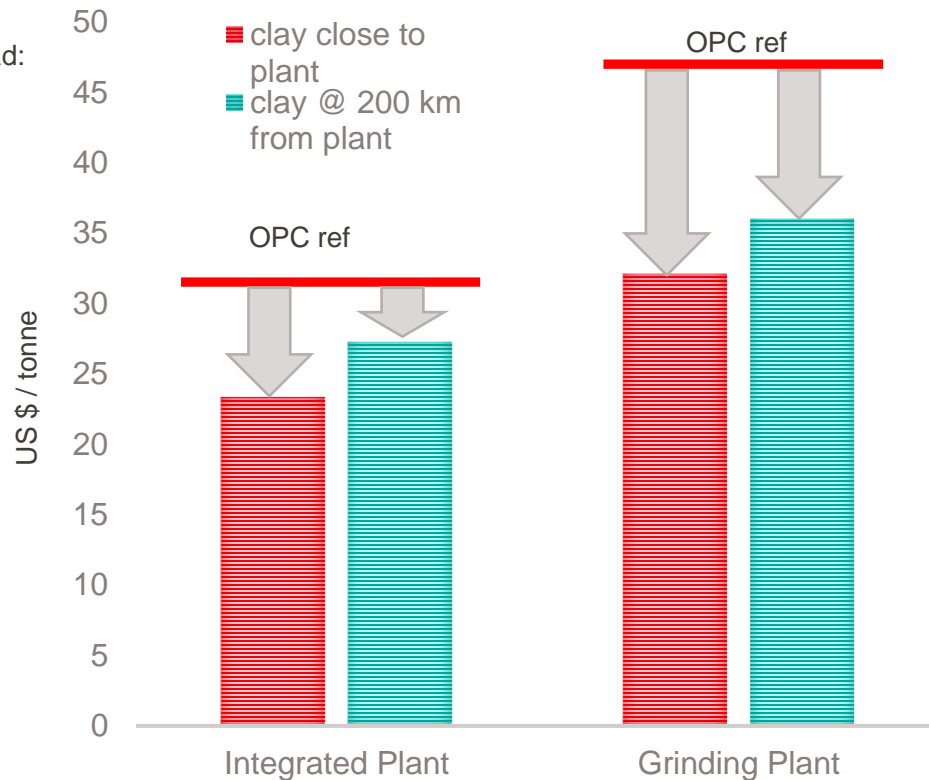
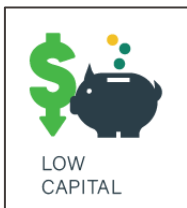
Report available to download:
www.lc3.ch



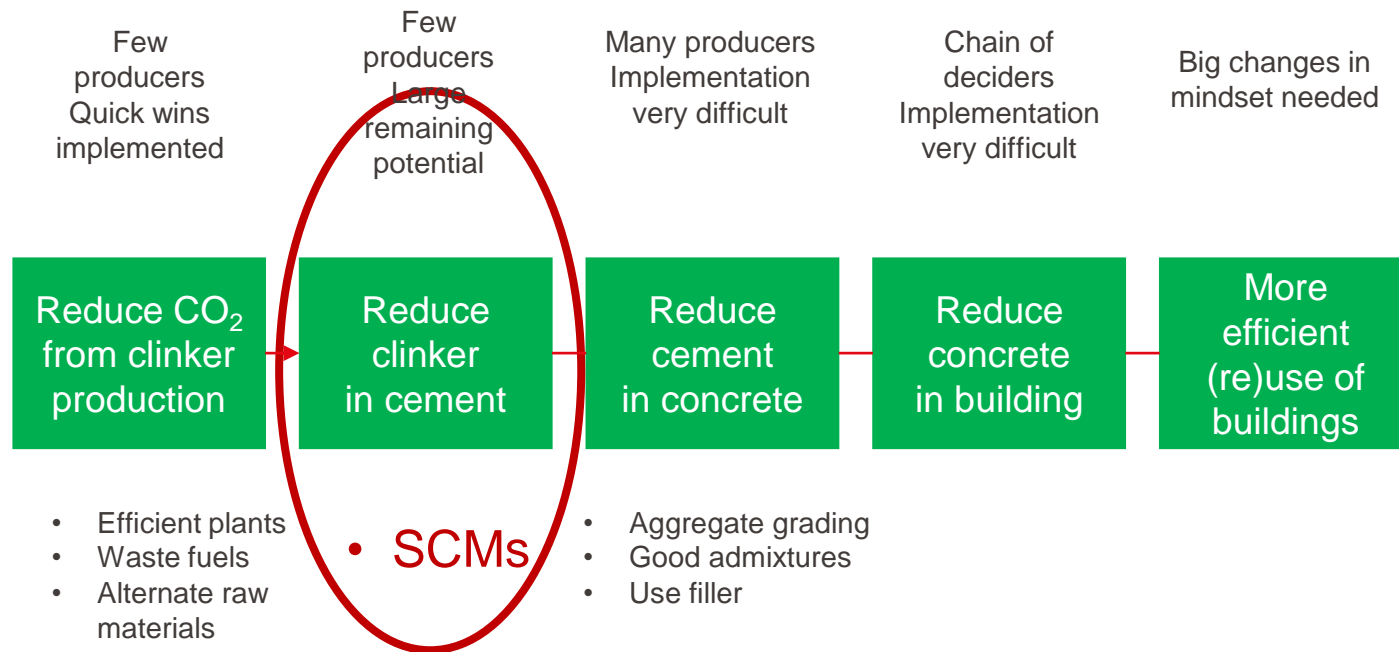
Study by LC3 Project partner



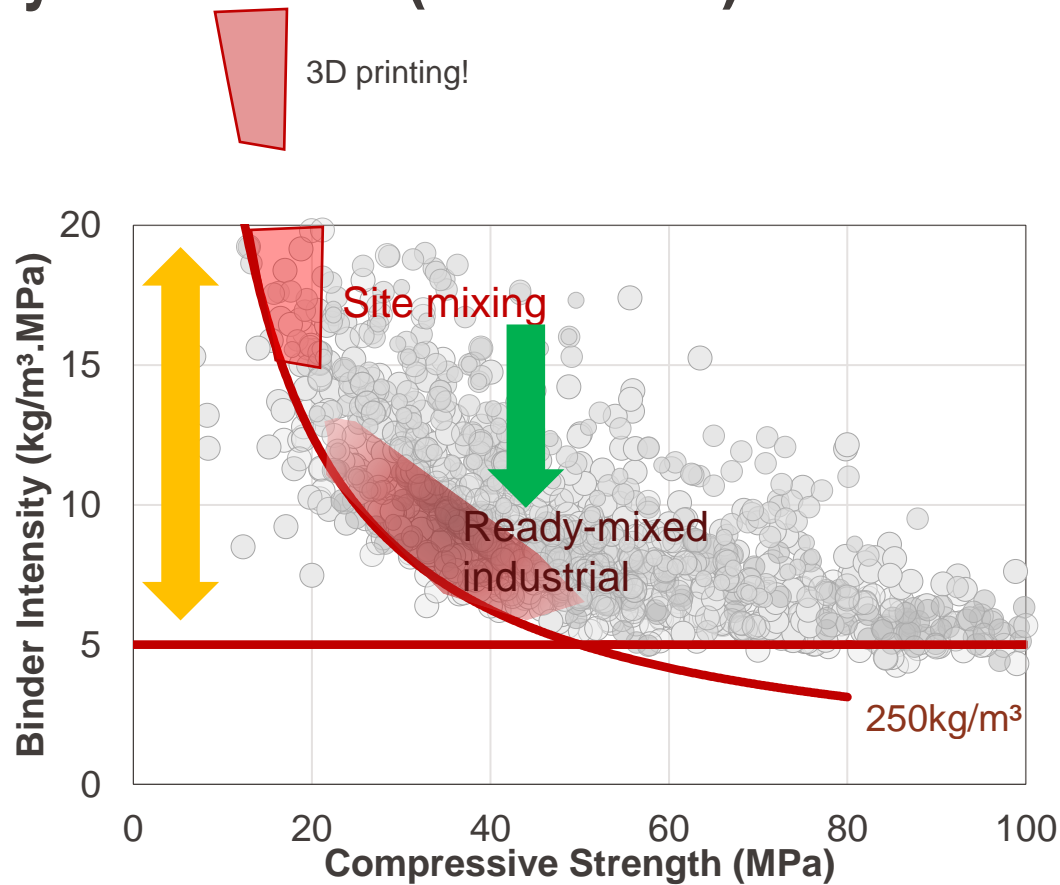
CEMENTIS



Substantial reductions in emissions >70% could be achieved by working through the whole value chain



Efficiency of binder use (29 countries)



DAMINELI, et al.
Measuring the
eco-efficiency of
cement use.
**Cement and
Concrete
Composites**, 32,
p. 555-562, 2010

What are the blockages?

➤ We have solutions:

- At cement level: LC3
- At concrete level: use admixtures, aggregate grading
- At structure level: lean design, stick to codes, do not over design

➤ What are the barriers to implementation?

Cement level

- **No time to do anything new**
- **Cannot find clays**
- **Need to some investment**
- **Lack of awareness: largest companies only make up 30% of market**
- **Allowed in codes and standards**

Concrete level

- **Difficult to incentivise the v.large number of companies**
- **“we’ve always done it like that”**
- **Minimum cement content in codes from days before admixtures**

Structure level

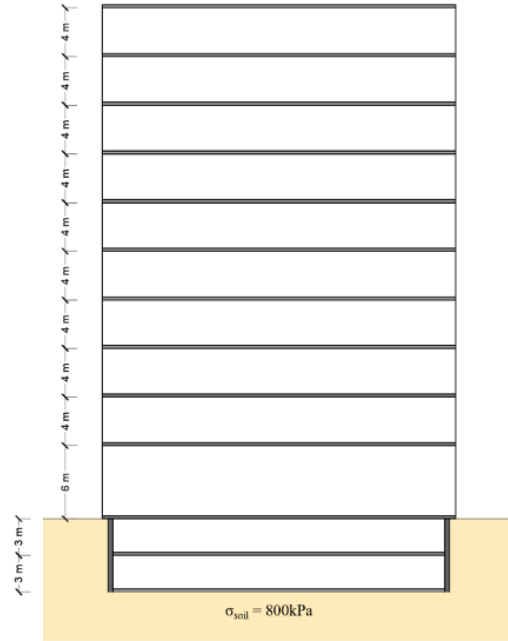
- **An engineer's time costs more than extra concrete**
- **Paranoia about safety**
- **Difficulty to calculate and compare possibilities**

Complexity costs carbon!

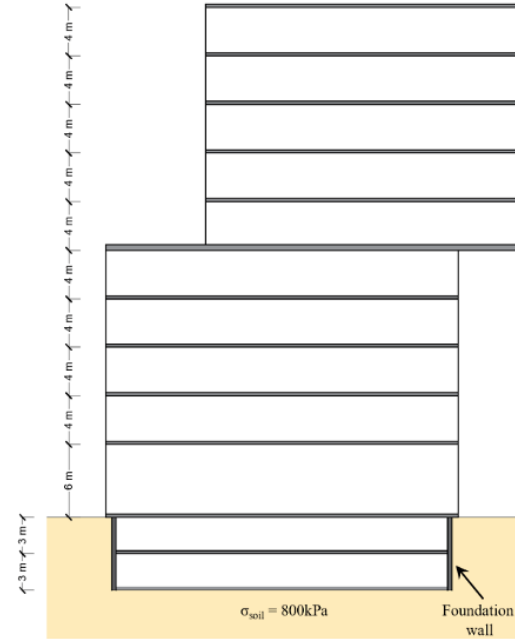
■ THE CASE FOR STRUCTURAL SIMPLICITY IN CONSTRUCTION



Carbon cost of irregularity

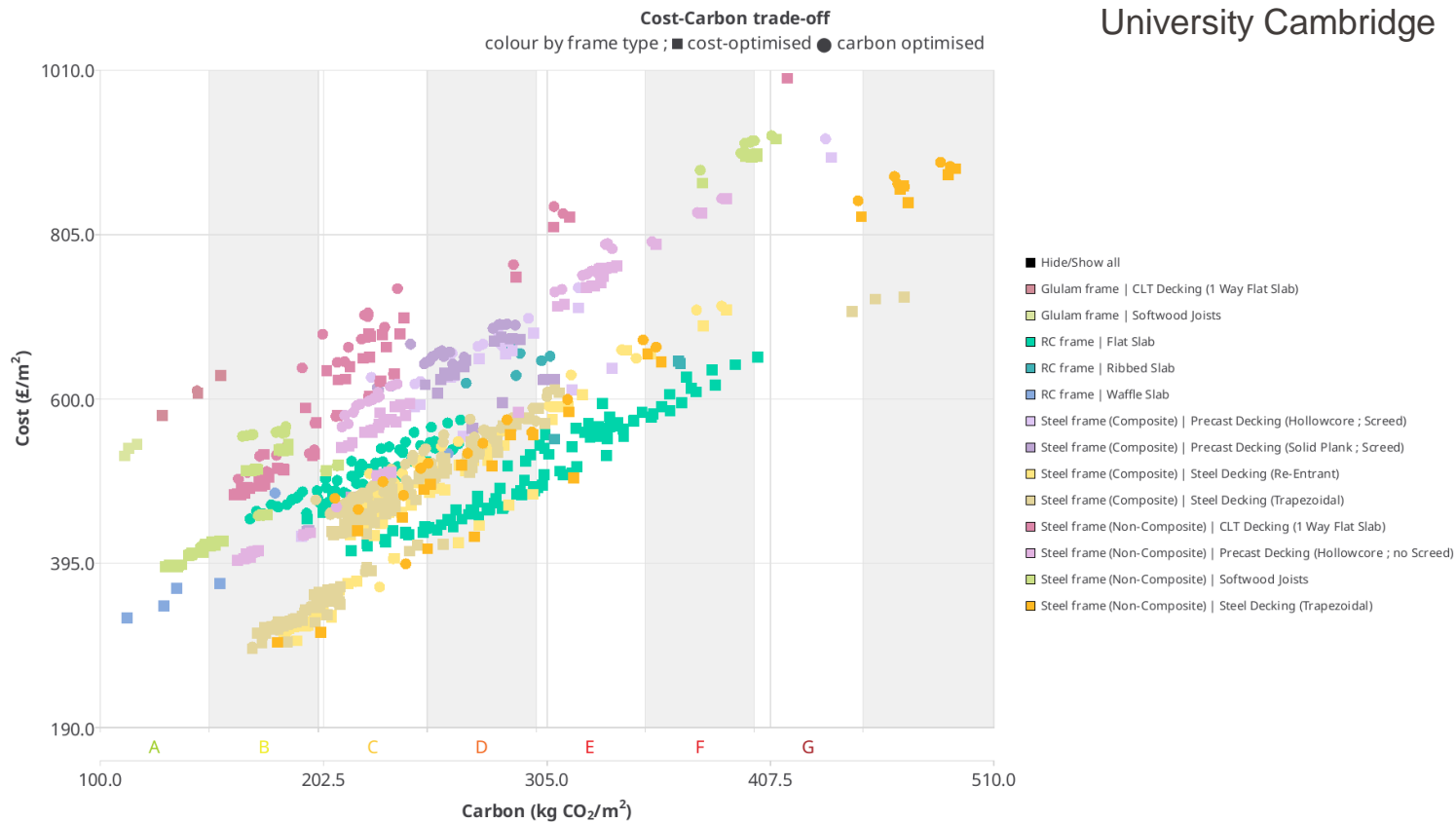


VS.

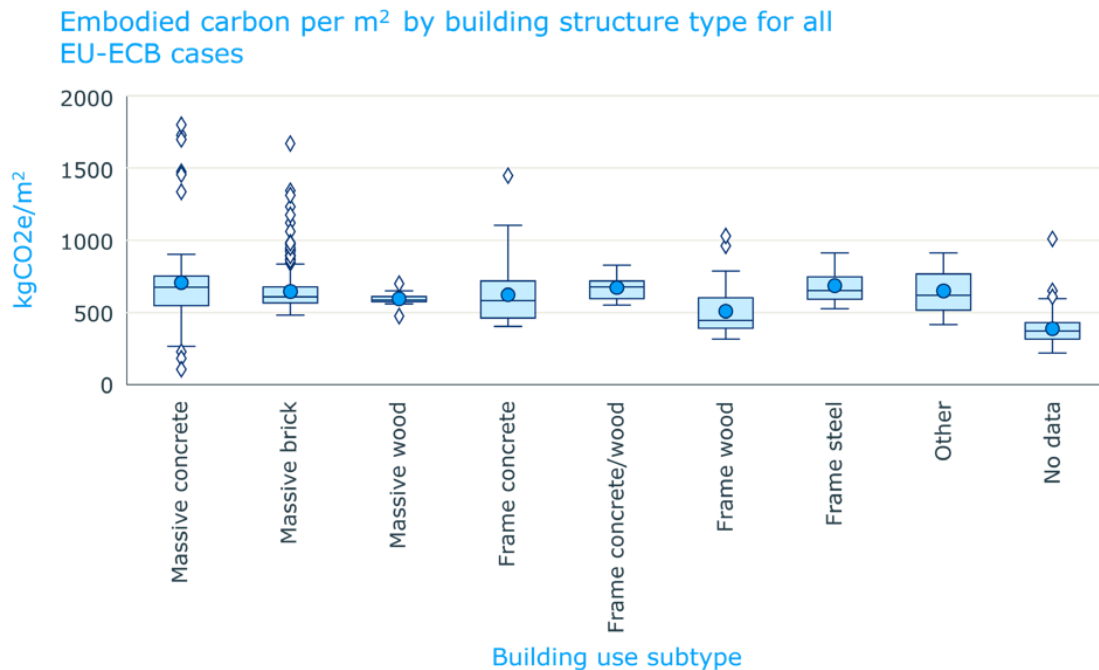


~50% more embodied carbon on average

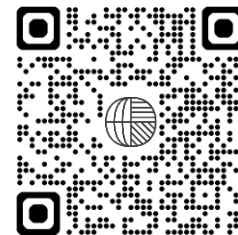
Source: David Ruggiero



Need for metric in applications



Global Building
Data Initiative



Overall

- **Thinking there are miracle alternatives**
- **Wasting time, effort and money on unscalable or ideas of dubious honesty**
- **Getting the different parts of the industry to work together**

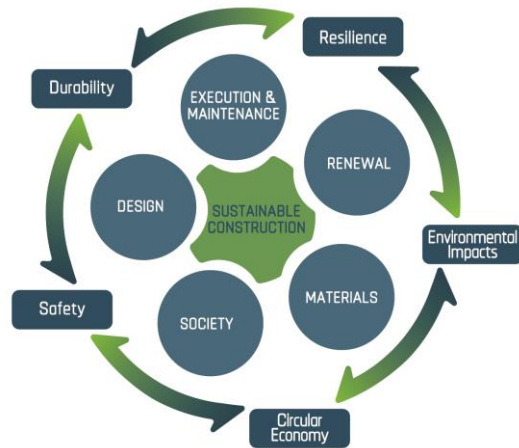


To realise these gains
the industry needs to work together

GLOBE

Global consensus
on sustainability in the built environment

- High level policy advice
- More than 150 nations
- 5000+ experts
- 50+ years of expert networks
- Standards and guidelines
- Research and education
- Innovation



www.globe-consensus.com

See on-line presentation from COP28 for more details



Africa Brick by Brick

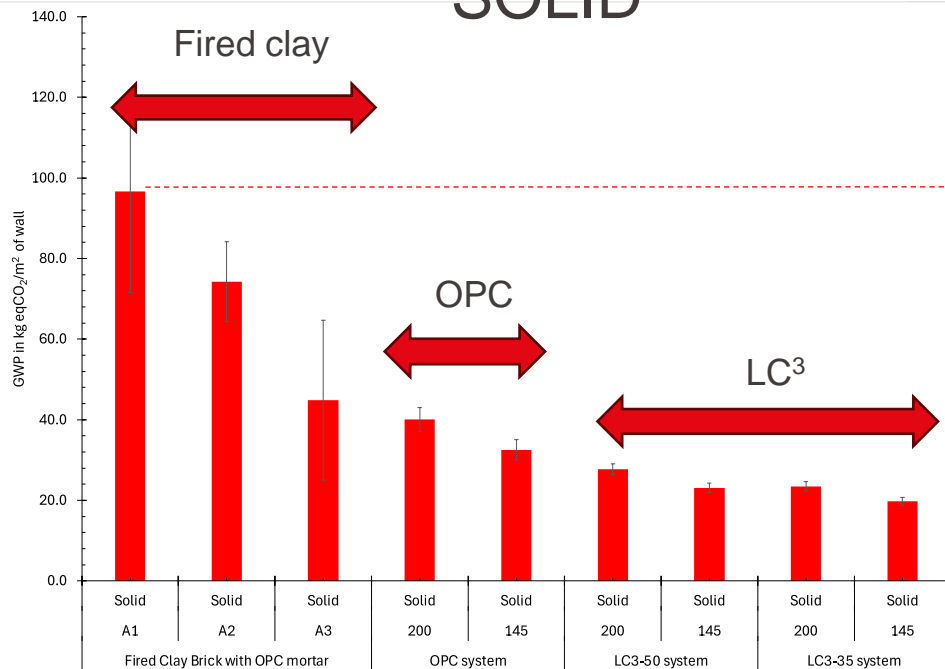




Concrete blocks



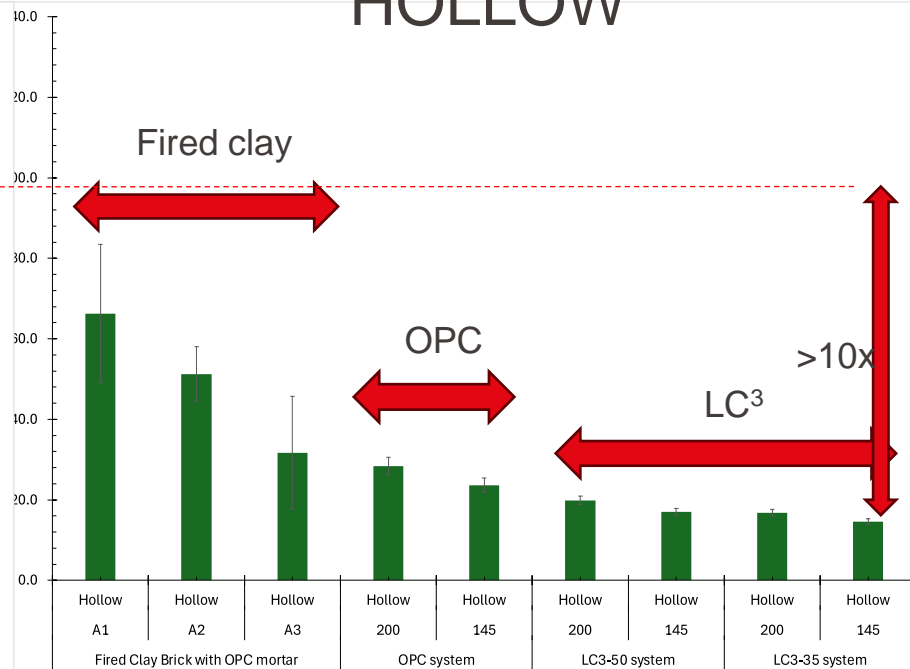
SOLID



A1: Africa Traditional kiln & Down Draught kiln;
A3: Vertical Shaft kiln, Zig-zag kiln & Hybrid Hoffman kiln;

A2: Fixed Chimney Bull's Trench kiln & Tunnel kiln;
200 & 145: Cement content in kg/m³

HOLLOW



A1: Africa Traditional kiln & Down Draught kiln;
A3: Vertical Shaft kiln, Zig-zag kiln & Hybrid Hoffman kiln;

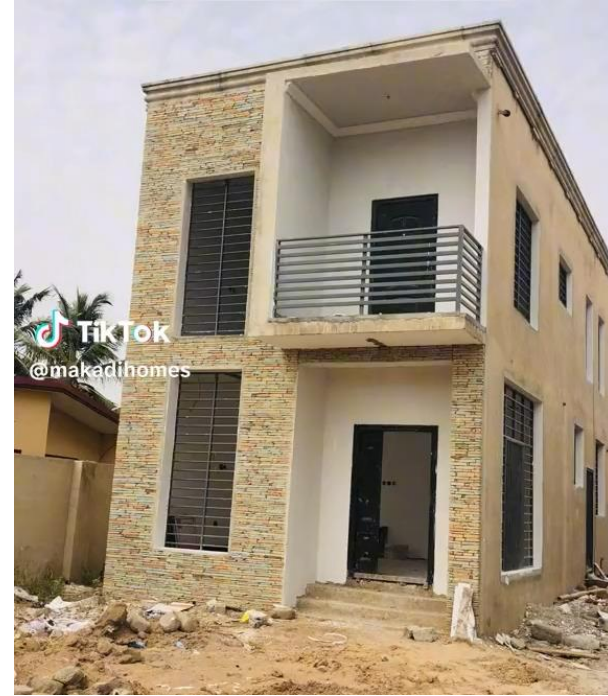
A2: Fixed Chimney Bull's Trench kiln & Tunnel kiln;
200 & 145: Cement content in kg/m³



Dr. Alice Titus Bakera (Civil Engineer)

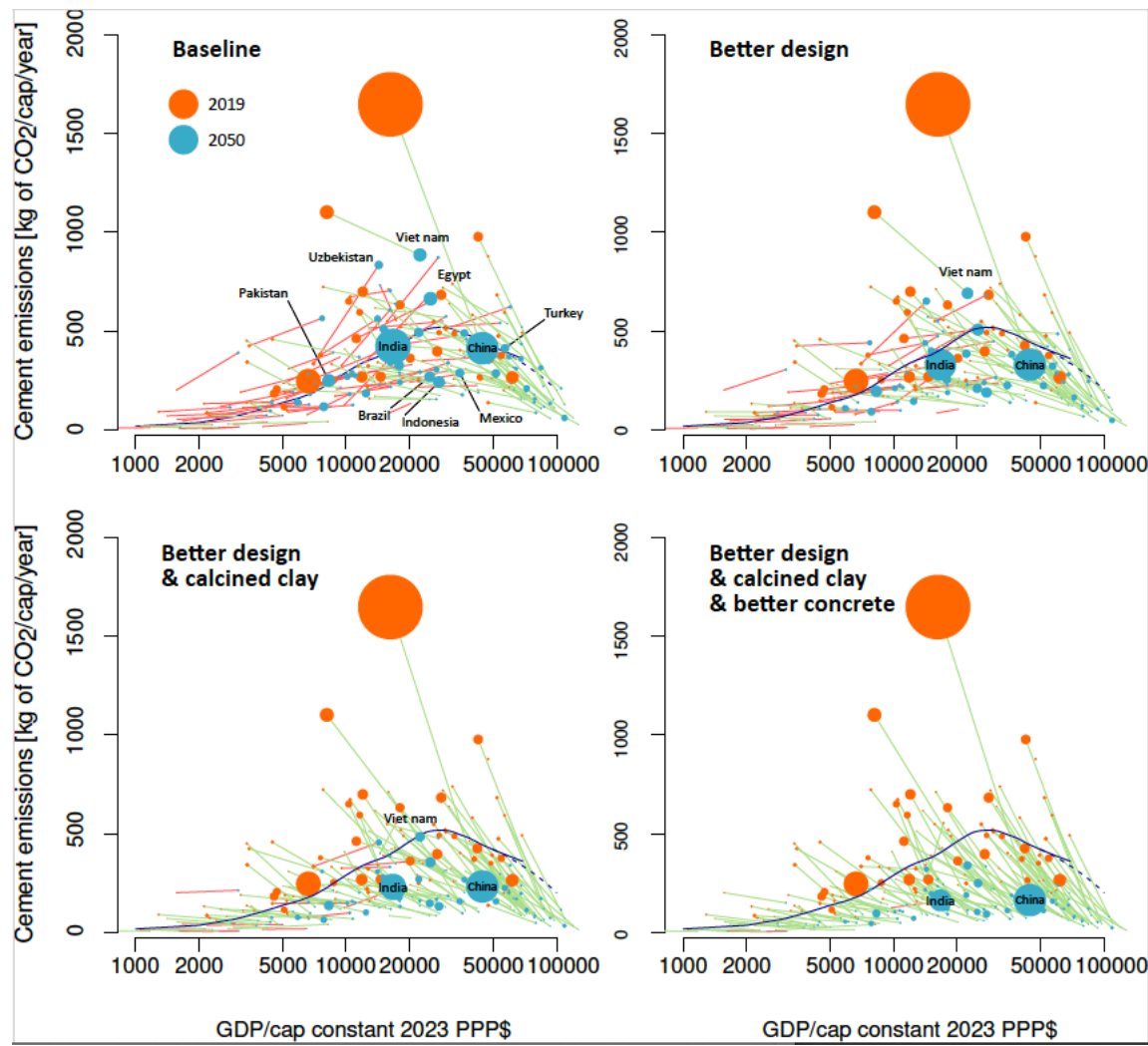
Postdoctoral researcher at EPFL
Lecturer at the University of Dar es Salaam, Tanzania

From cliché to real aspiration!



Can we decouple growth from rising emissions

Deploying these reduction strategies can allow growth without increasing CO₂ emissions



Concluding remarks

- ✓ Portland Based cements are here to stay
- ✓ There is no viable alternative
- ✓ Substantial reductions in CO₂ are possible
 - ✓ At cement level by increasing SCM substitution
 - ✓ At concrete level by minimising cement content
 - ✓ At structure level
- ✓ All of the above will also lower cost
- ✓ Remainder CO₂ can only be dealt with by carbon capture and storage at a high cost, infrastructure not in place.
- ✓ Calcined clays are the only realistic option for extending the use SCMs
- ✓ Can be done FAST and at SCALE





Thank You

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