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Developments and Future trends in Sustainable Cement and Concrete Technolgy

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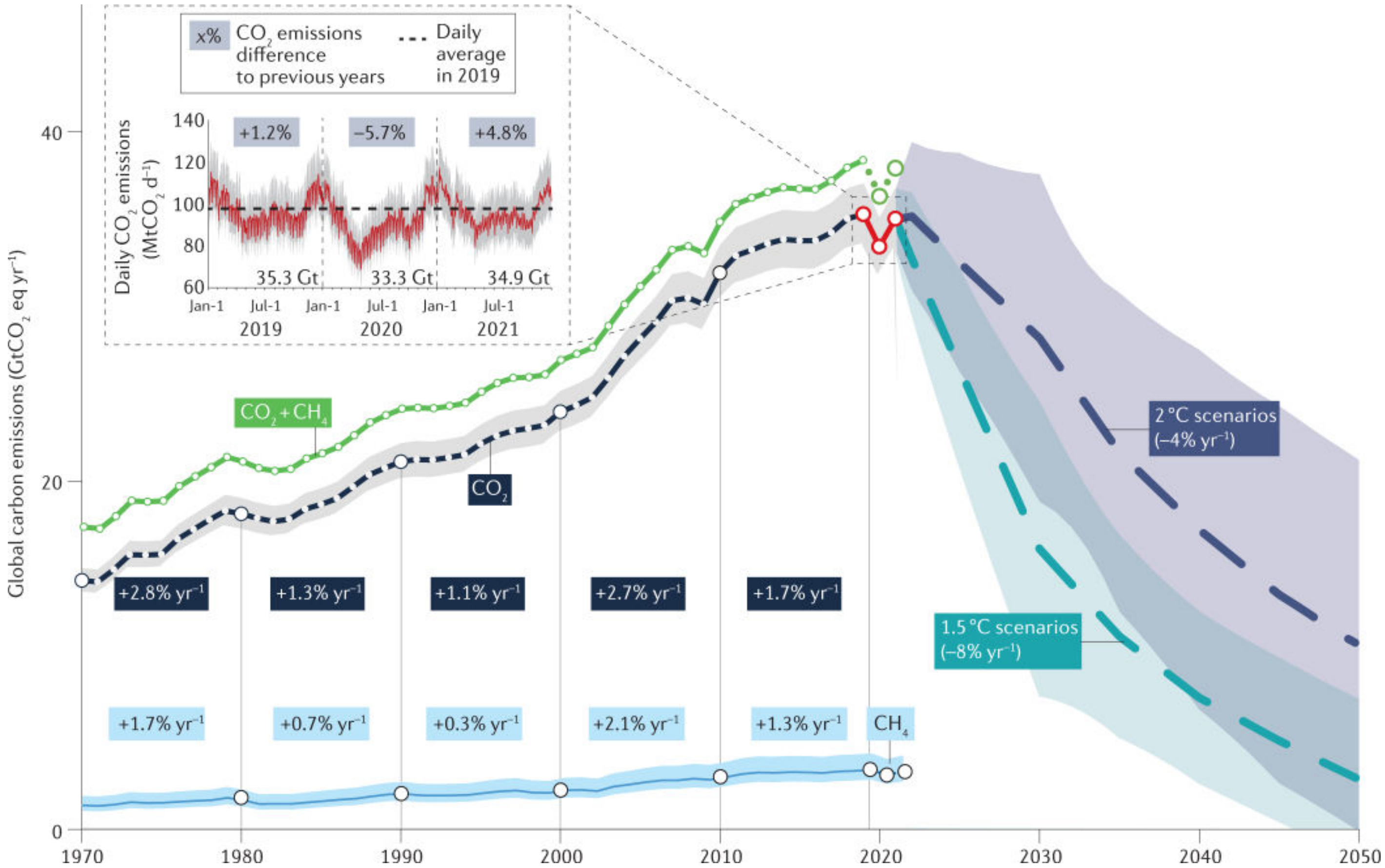
Need to act fast

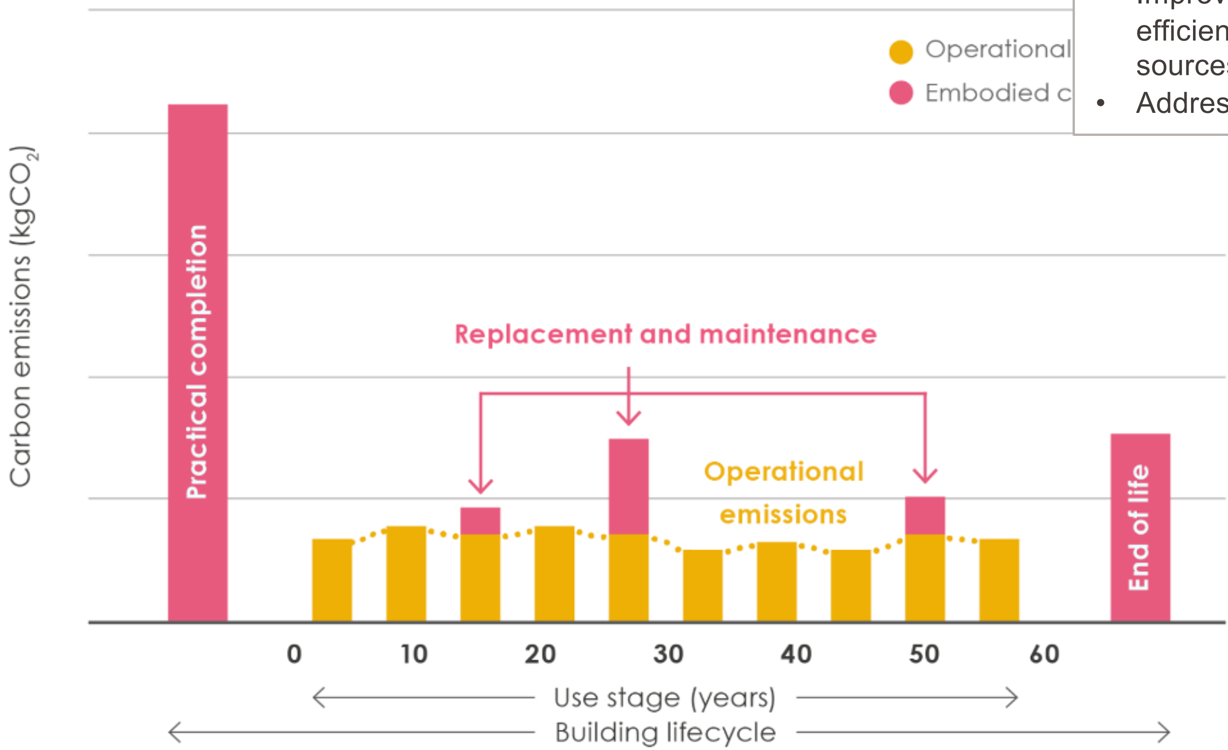


Liu et al. 2022. Nature Reviews Earth & Environment 3, 217-219

Embodied vs operational emissions

Upfront Carbon
- Locked in upon building completion and cannot be improved over time
- Initiatives must be accelerated

Operational Carbon
- Improved over time by shifts to energy efficient technology and renewable sources
- Addressed in various govt schemes



Infrastructure is even more about embodied emissions

Graph: The Institutional Investors Group on Climate Change

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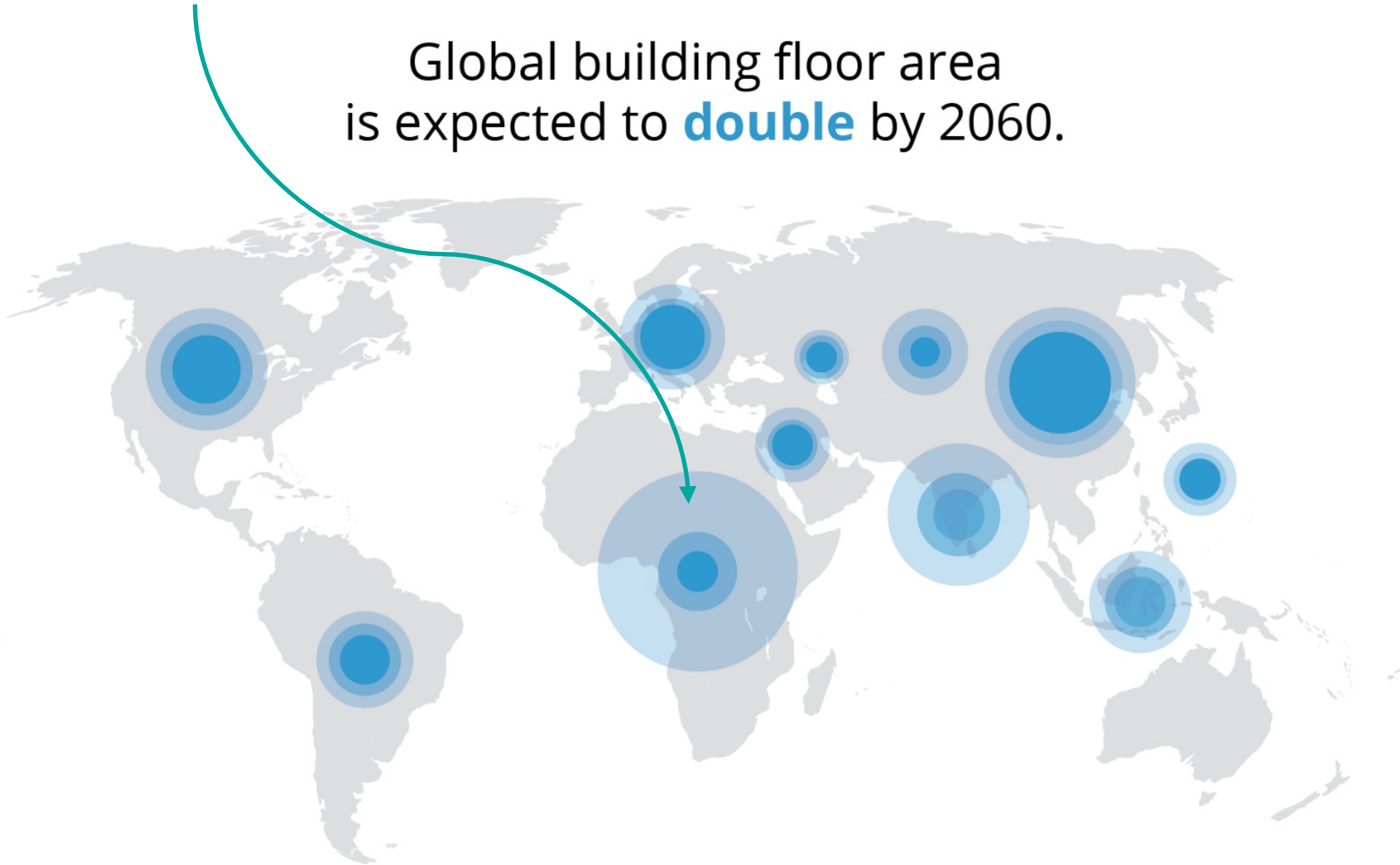
Tomorrow….

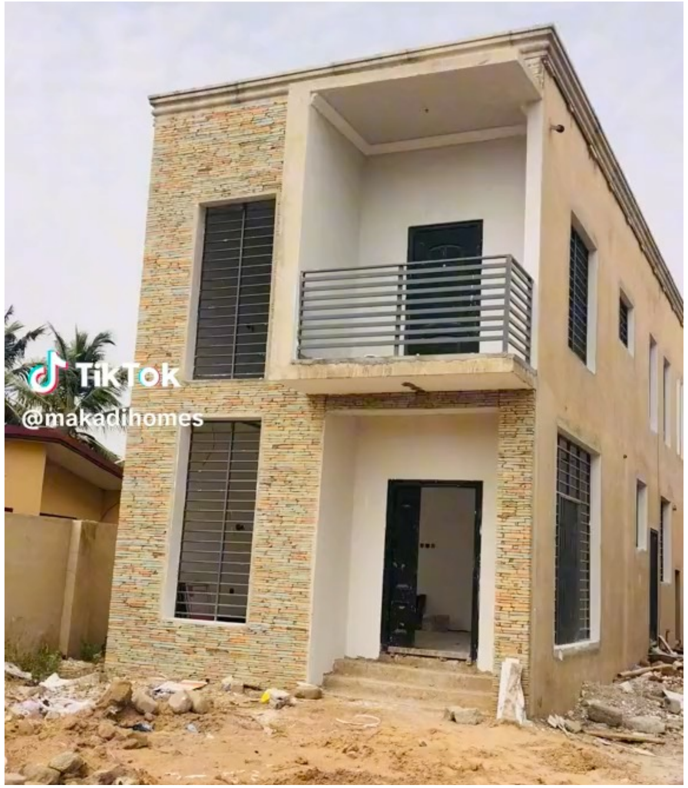
This will **NOT HAPPEN** in the Global North

It will happen HERE

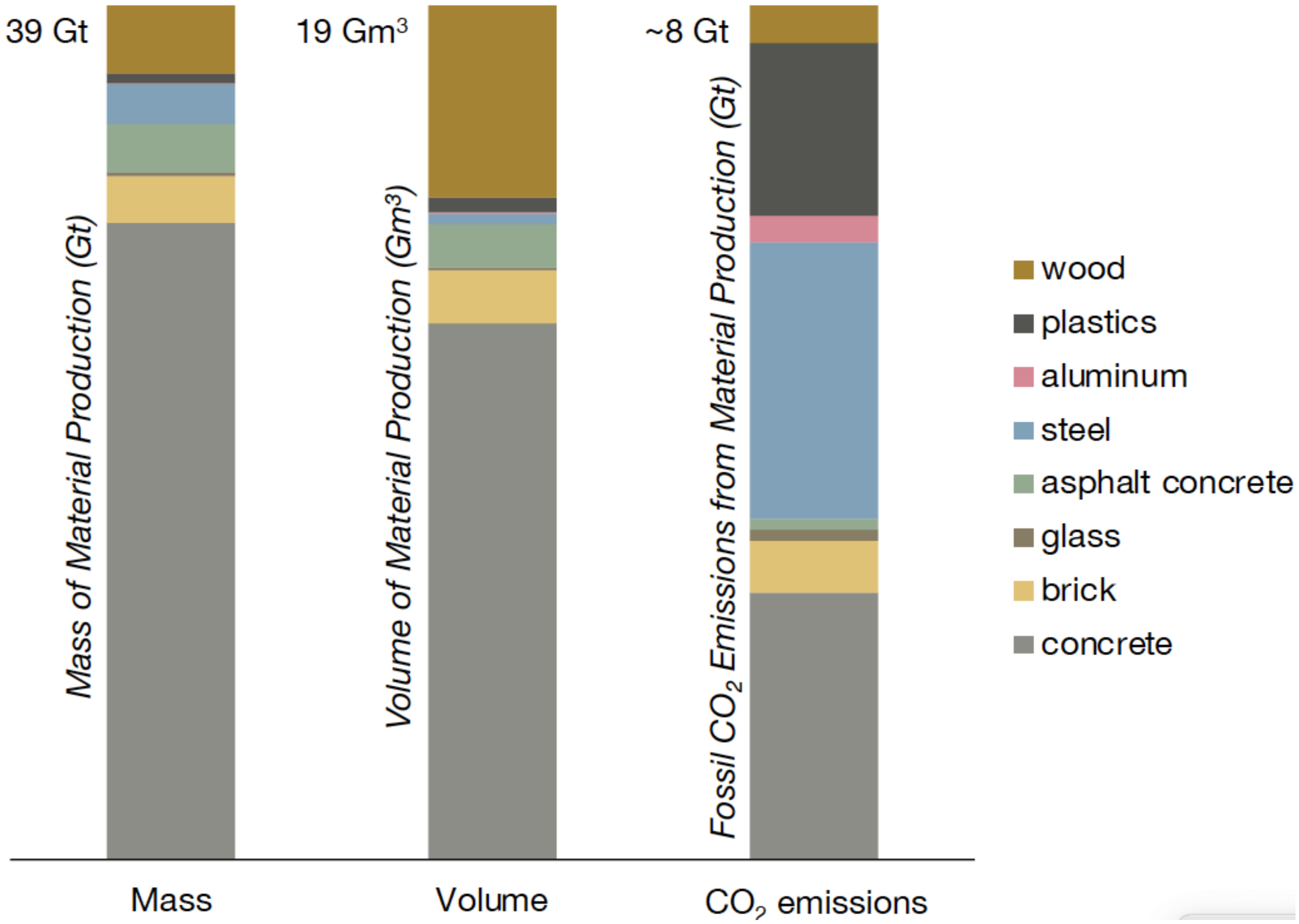


Data Sources: Global ABC, Global Status Report 2017

From cliché to real aspiration!



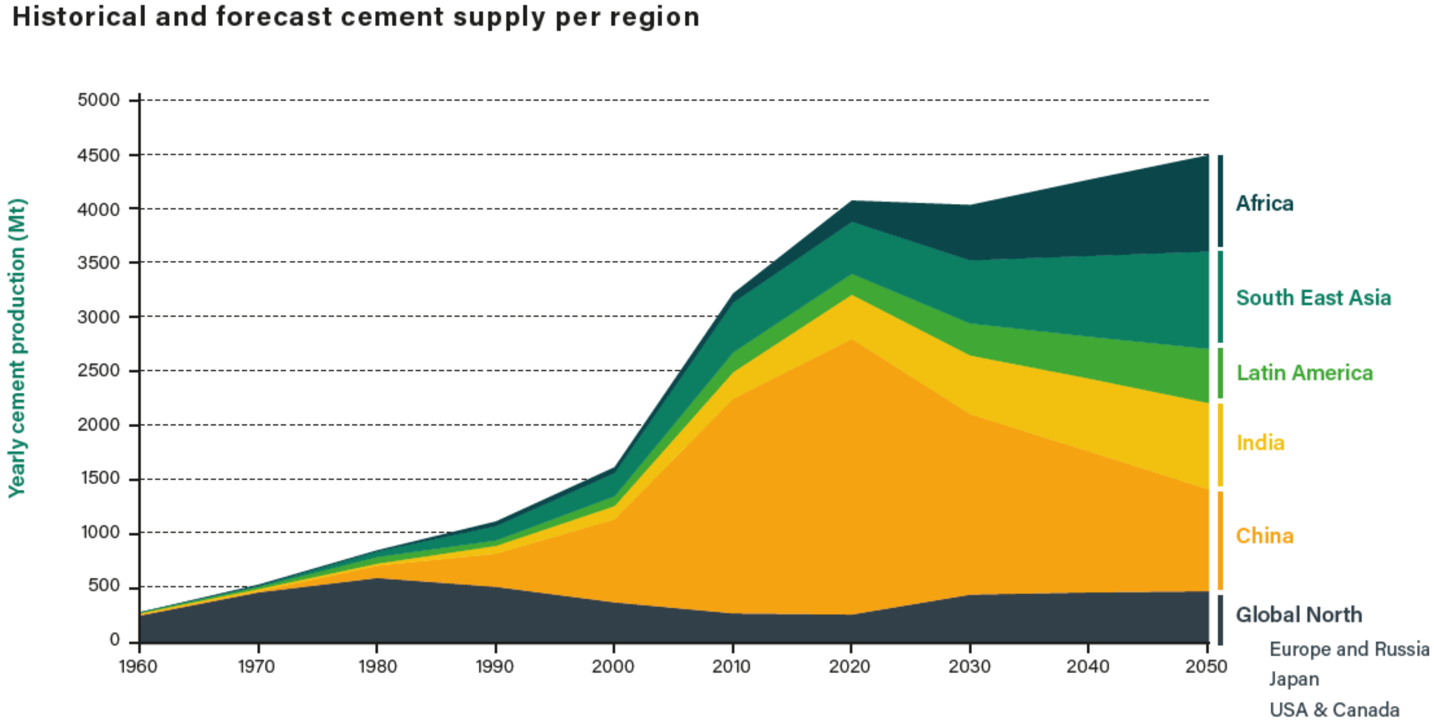
World Use of materials: 90% construction



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

Changing pattern of cement use:

Cement based materials are more than two thirds of all construction



We need solutions for people in developing countries

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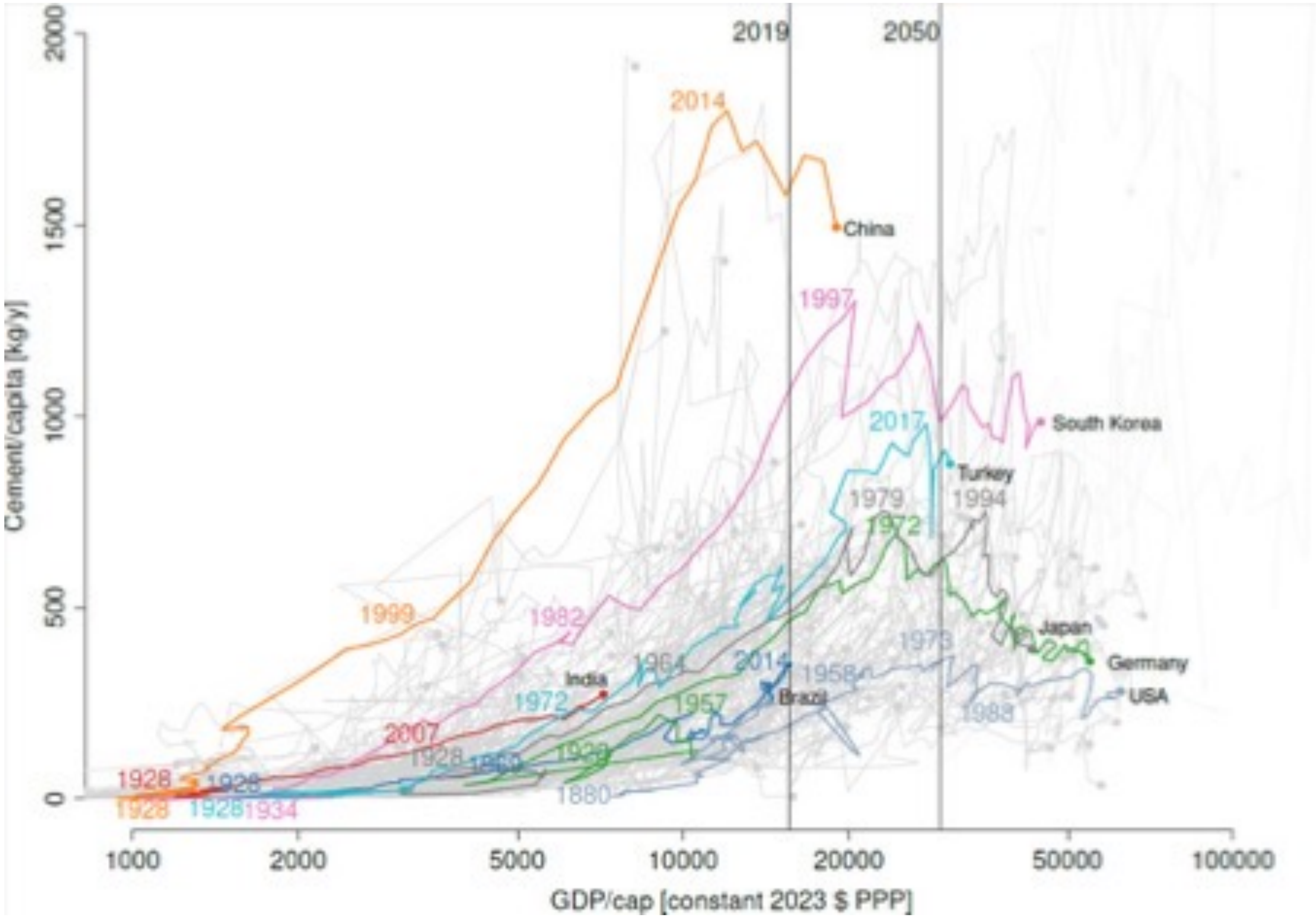
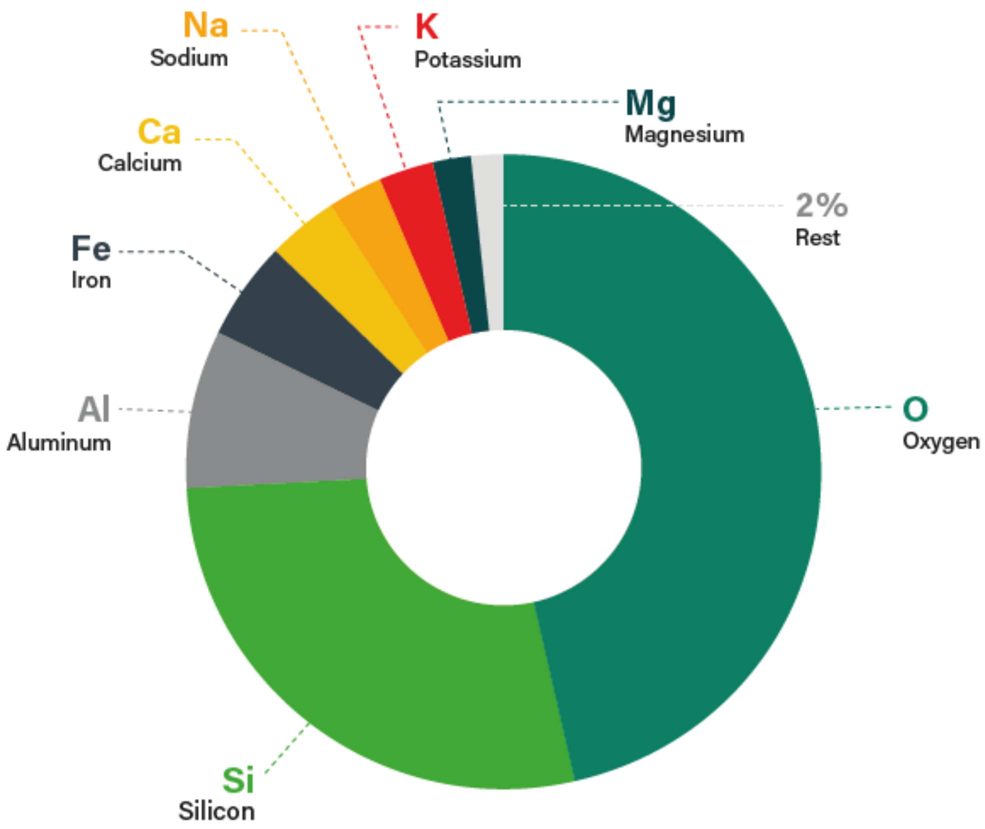
Concrete "Hump" a normal phenomenon of growth



In China maybe 1000 out 1500 cement plants will close

What is available on earth?
No miracle solutions

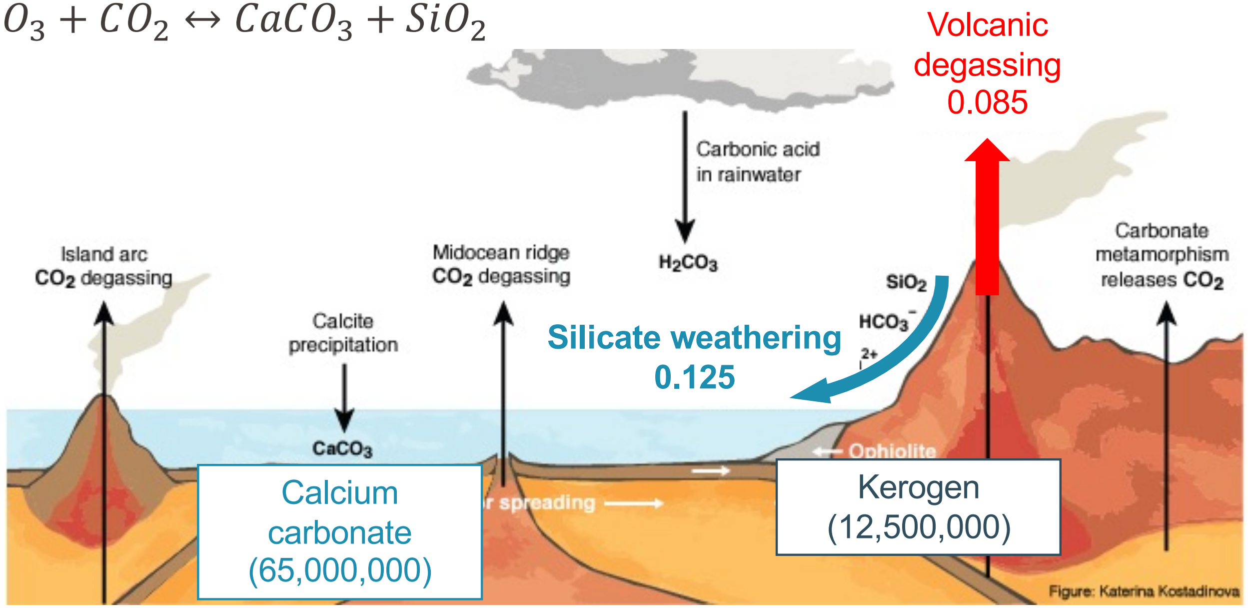


Na_2O K_2O	Too soluble
Fe_2O_3 MgO	Too insoluble in alkaline solutions
CaO SiO_2 Al_2O_3	The most useful

What about getting Ca not from Limestone?

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

Basalt

Name of oxide	Content, % by weight
SiO_2	46.5 – 51.5
Al_2O_3	15.0 – 19.0
MgO	4.0 – 10.5
CaO	7.5 – 11.5
$FeO+Fe_2O_3$	8.0 – 12.0
K_2O+Na_2O	3.0 – 6.0
TiO_2	0.3 – 2.5
Cr_2O_3	0.02 – 0.05
MnO	< 0.1
Other	Up to 100

Source research gate

Dissolve in acid

Precipitate oxide separately

Common technology
in mining industry

**Make clinker with
uncarbonated calcium oxide**

Estimated cost ~ $800 / ton
>80% reject materials

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

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The sustainable construction pathway

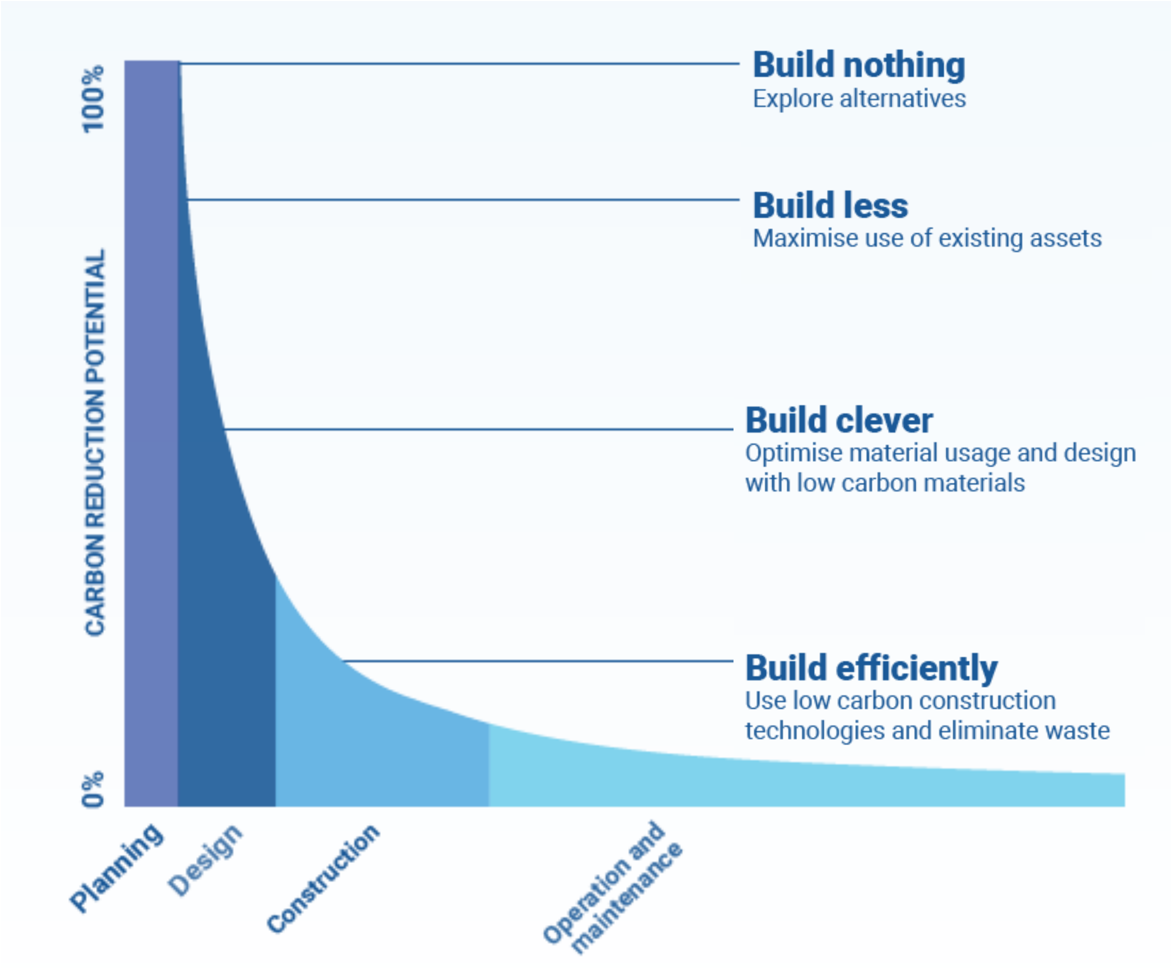
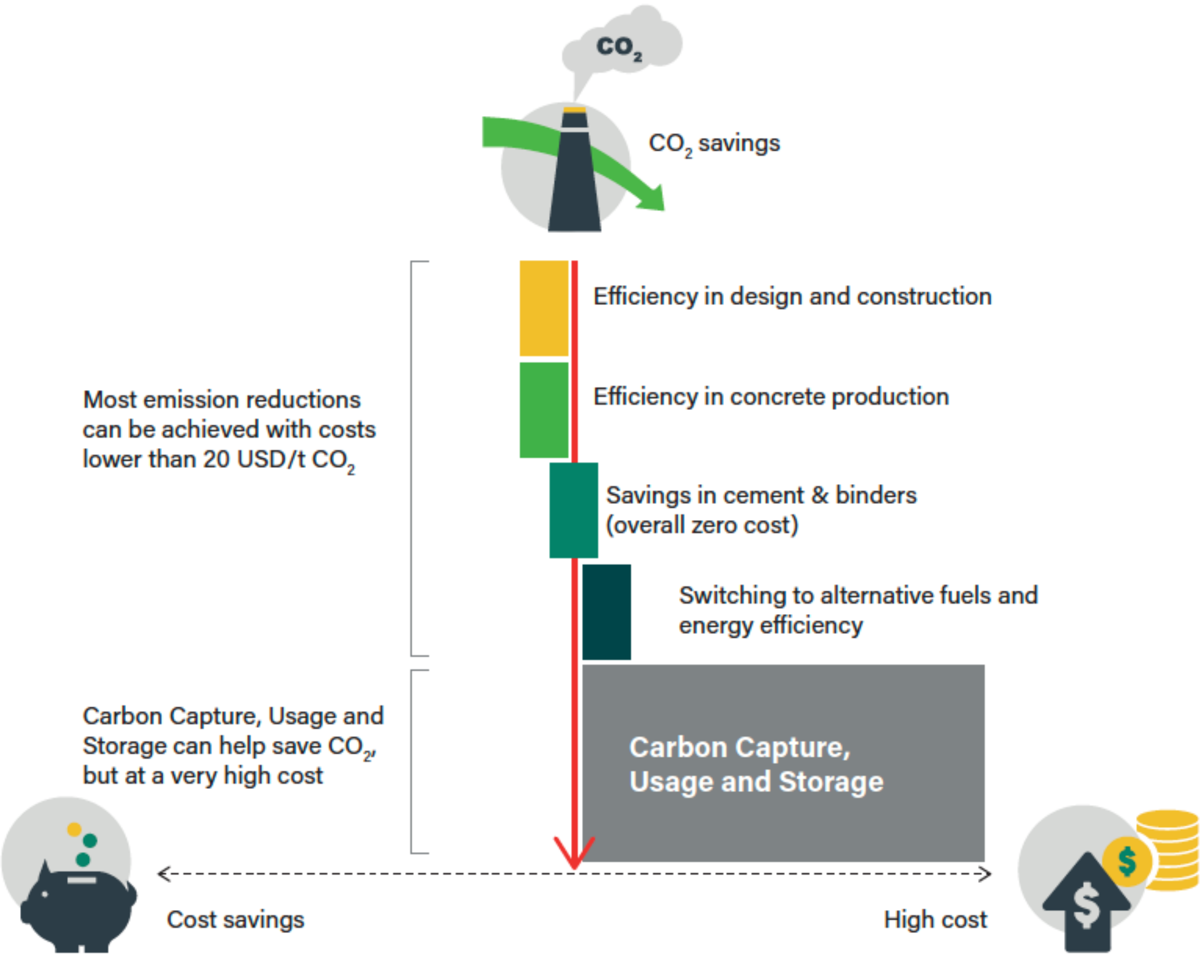


Figure: WorldGBC, 2019

More applicable for the Global North

More applicable for the Global South

Much of the path to net zero is low cost



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

Report for European Climate Foundation 2017

Reduce CO_2 from clinker production → Reduce clinker in cement — Reduce cement in concrete — Reduce concrete in building — More efficient (re)use of buildings

- Efficient plants
- Waste fuels
- Alternate raw materials

- SCMs

- Aggregate grading
- Good admixtures
- Use filler

RECYCLE!

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nature communications

Article

https://doi.org/10.1038/s41467-023-40302-0

Near-term pathways for decarbonizing global concrete production

Received: 27 January 2023

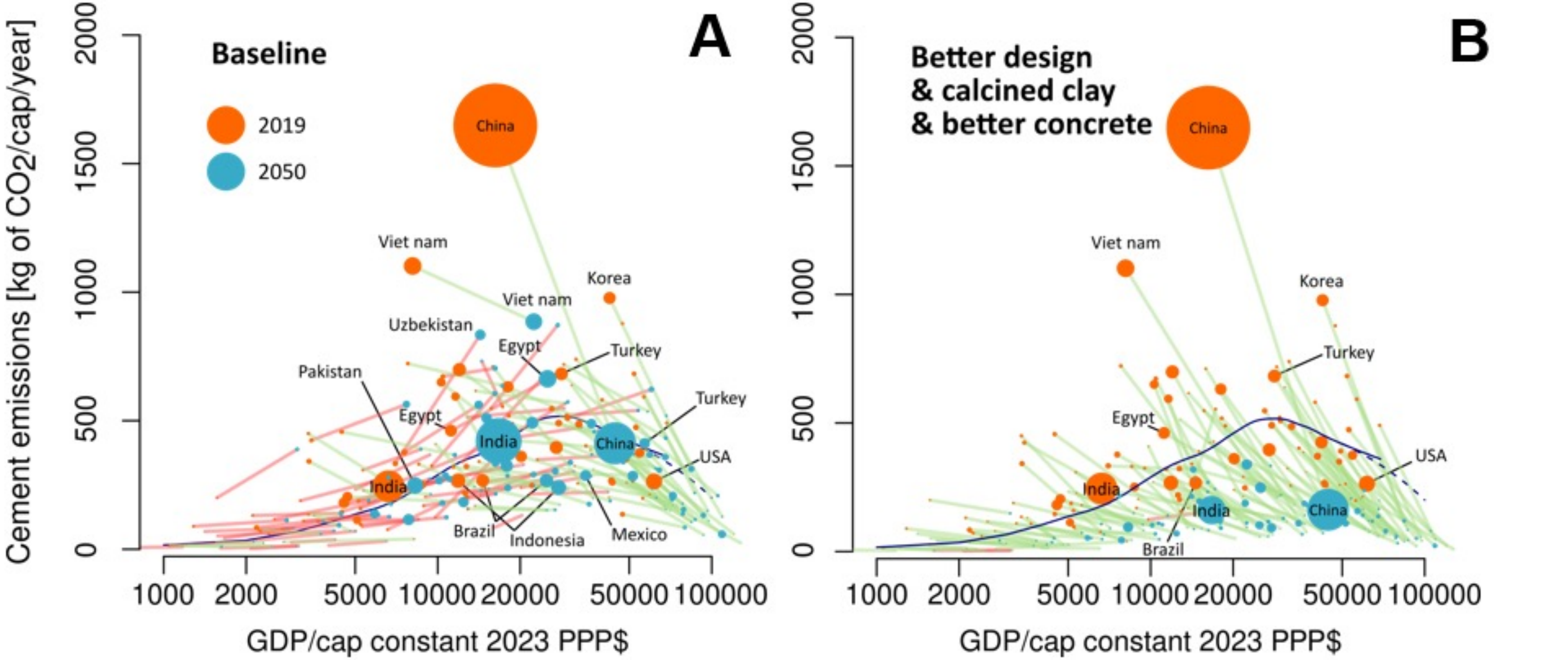
Accepted: 21 July 2023

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

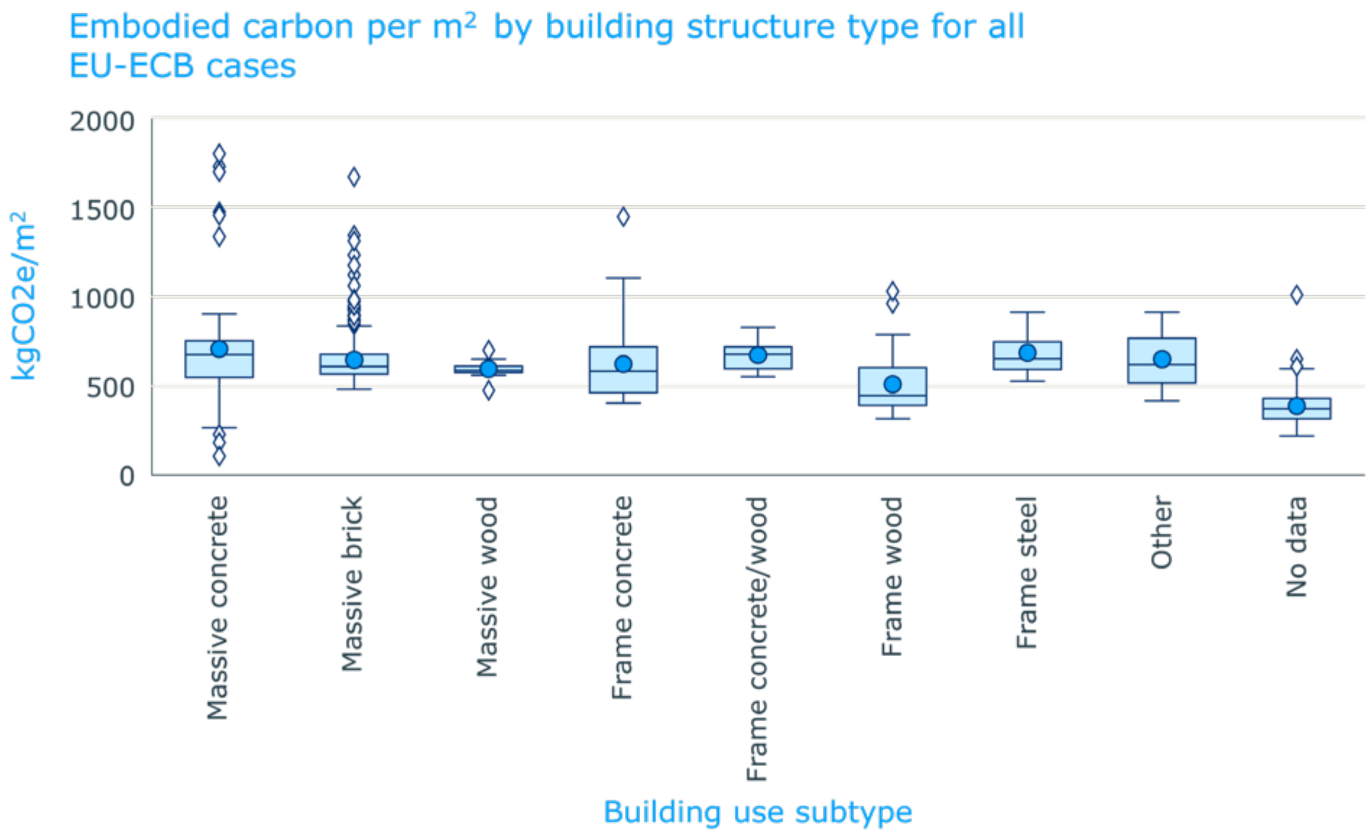
Calculated **76%** with these strategies

Karen Scrivener

Can decouple growth in CO_2 emissions from Growth in GDP



Need for metrics in applications: Not just EPDs but the final use including lifetime



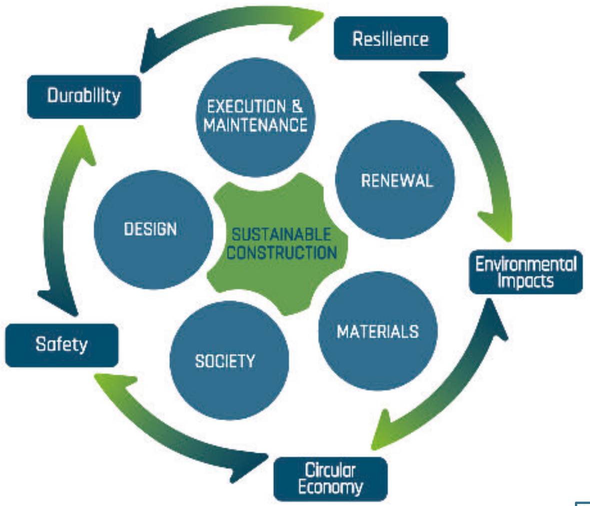
- Röck M, Sørensen A, Tozan B, Steinmann J, Le Den X, Horup L H, Birgisdottir H, Towards EU embodied carbon benchmarks for buildings – Setting the baseline: A bottom-up approach, 2022, https://doi.org/10.5281/zenodo.5895051.

To realise these gains the industry needs to work together

GLOBE

Global consensus on sustainability in the built environment

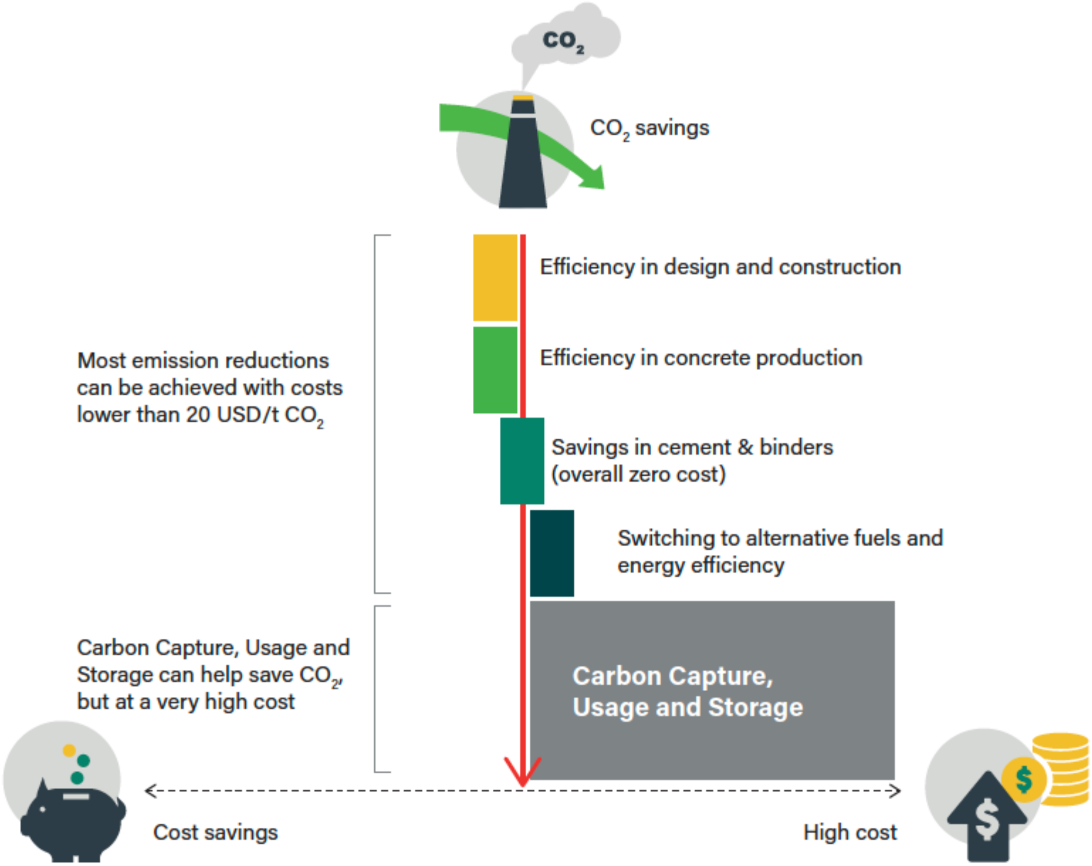
- High level policy advice
- More than 150 nations
- 5000+ experts
- 50+ years of expert networks
- Standards and guidelines
- Research and education
- Innovation



www.globe-consensus.com

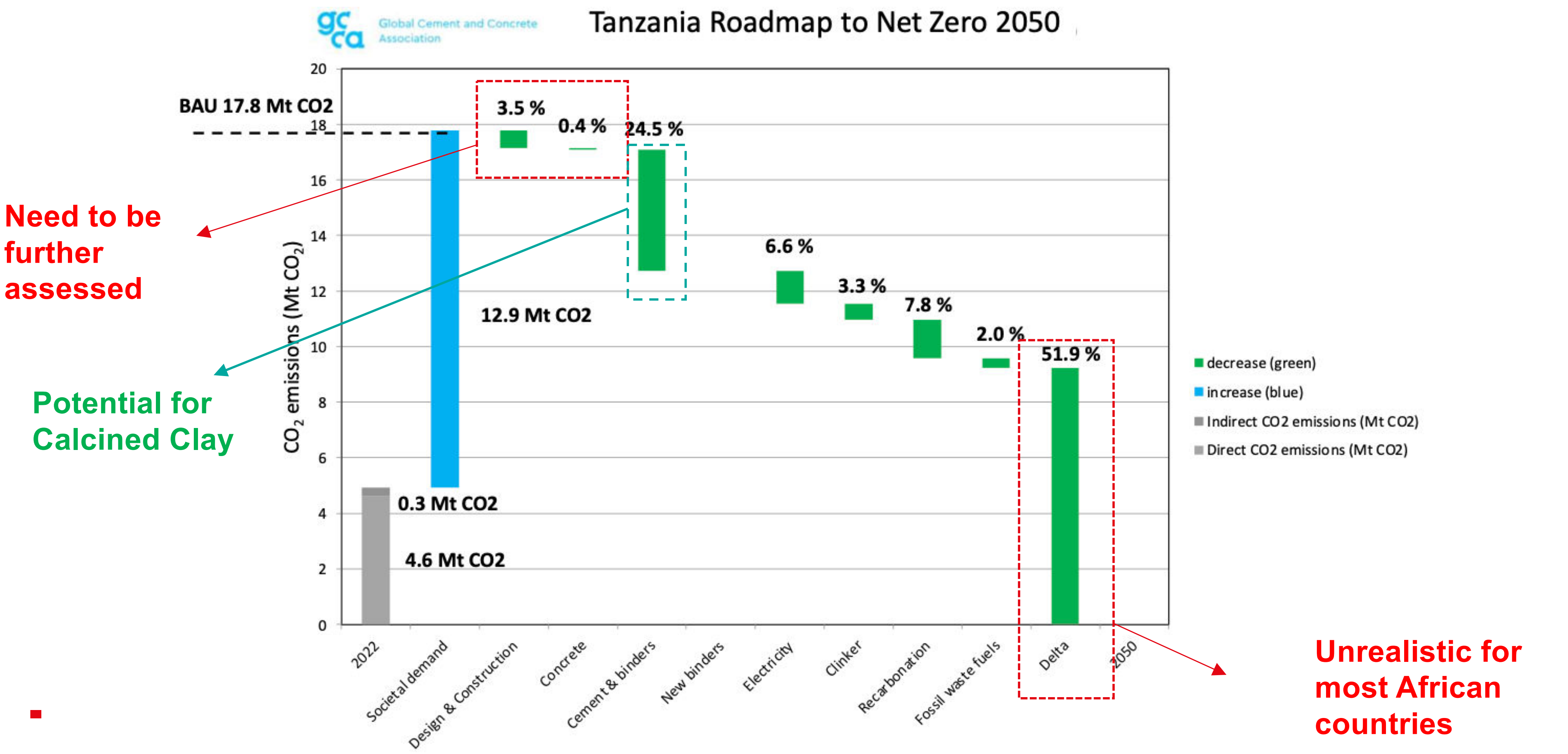
See on-line presentation from COP28 for more details

70-80% possible at low or negative cost. Remainder will need CCUS

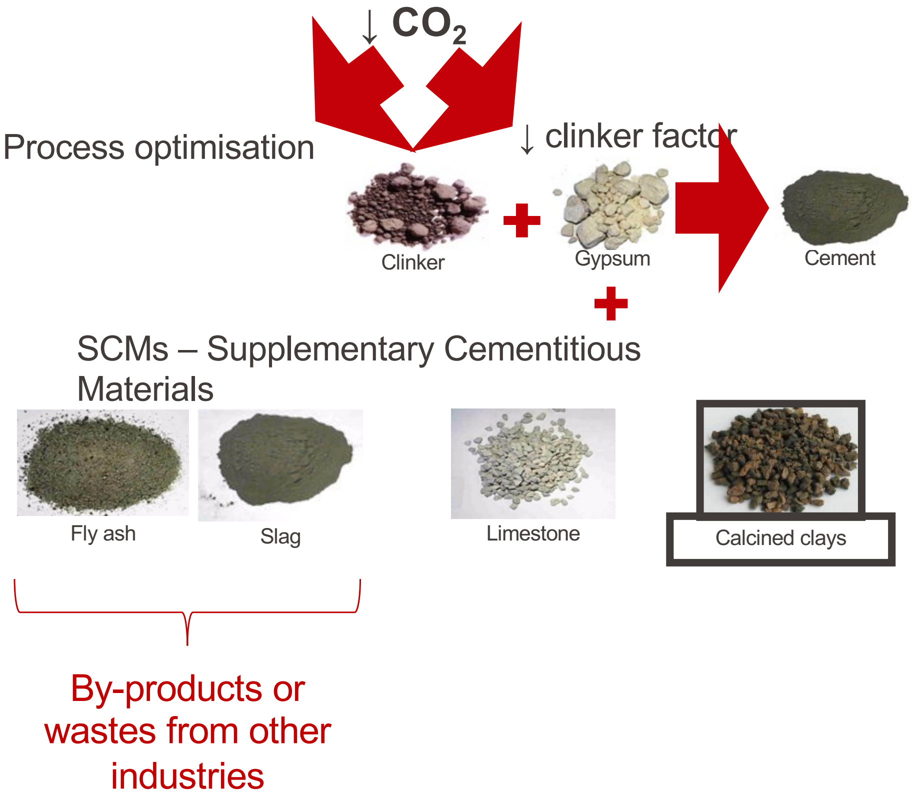


CCUS will increase cost of producing clinker 2-4 times

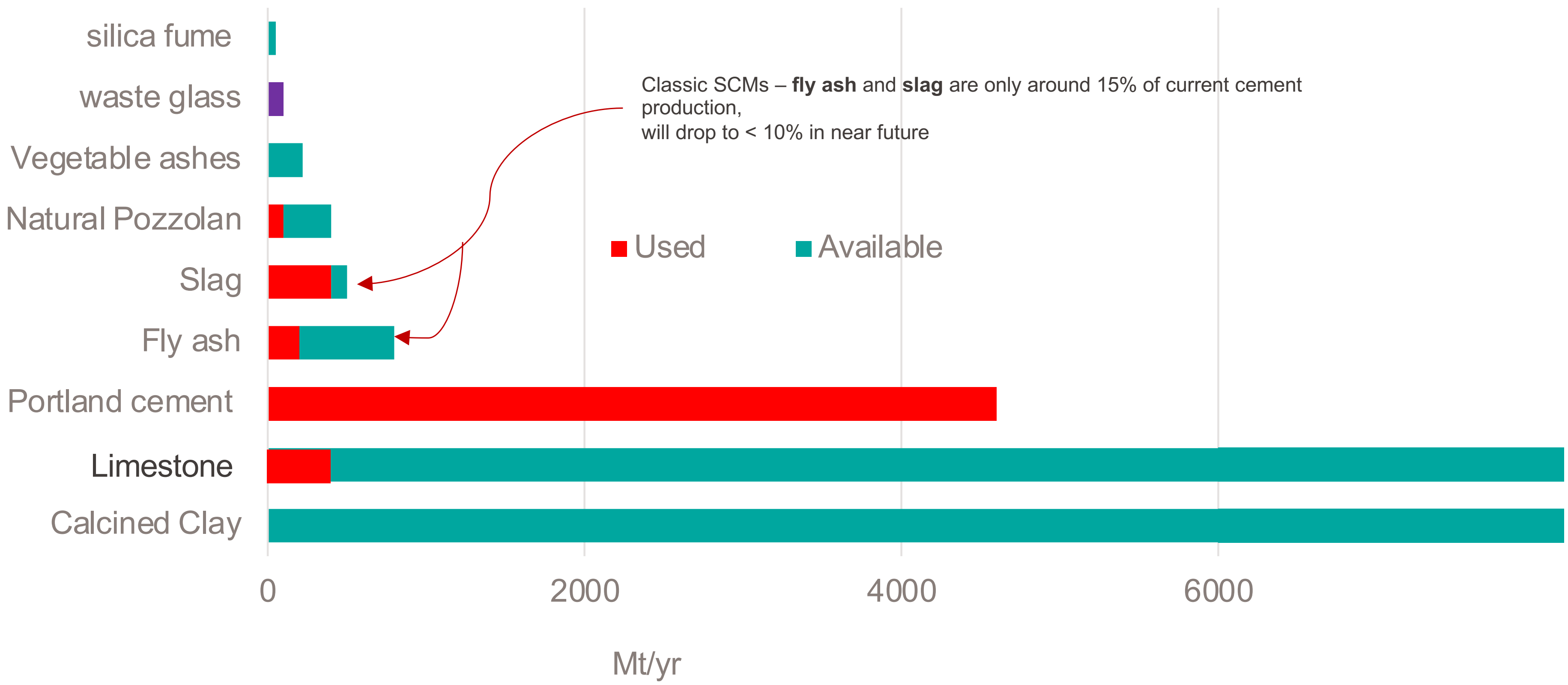
The Materials lever is the easiest to activate



Most promising approach – reducing the clinker factor



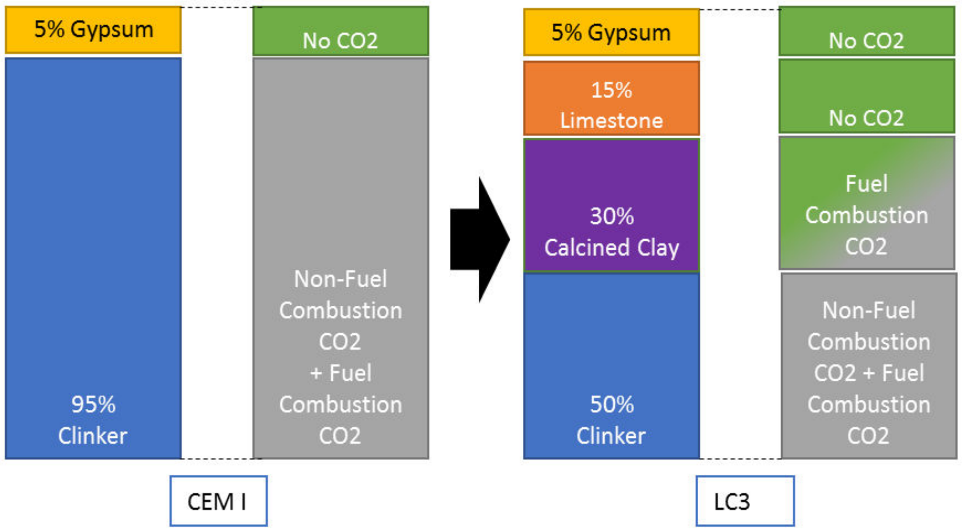
Availability of SCMs

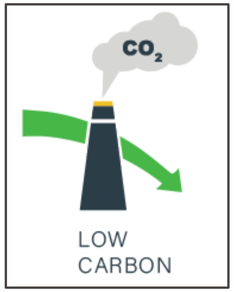


There is no magic solution

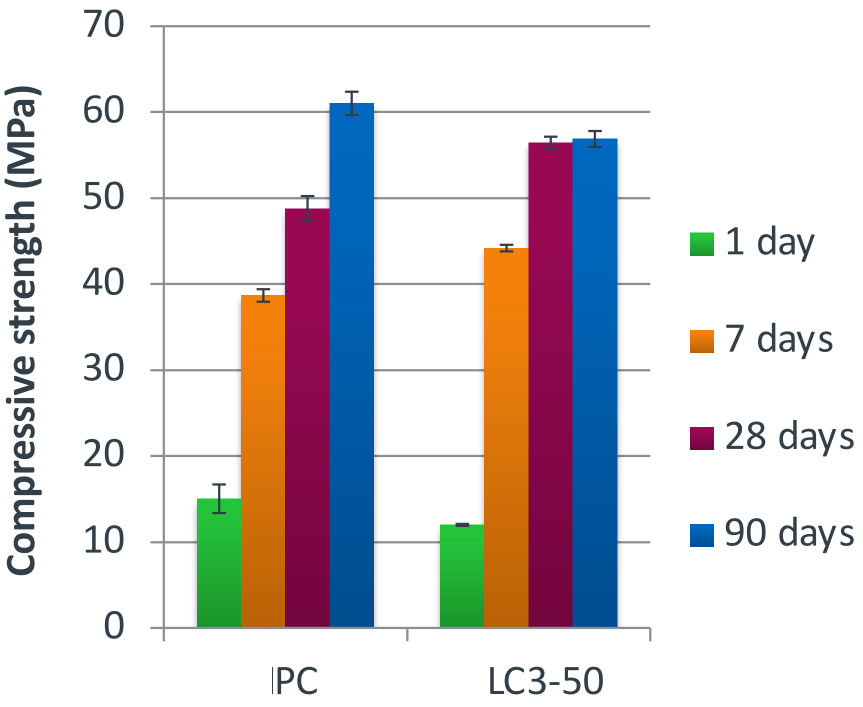
- Blended with SCMs will be best solution for sustainable cements for the foreseeable future.
- **Only material** really potentially available in viable quantities **is clay**.
- **Synergetic reaction** of calcined clay and limestone allows high levels of substitution
- EPFL led the LC^3 Project supported by **Swiss Agency for Development and Cooperation (SDC)**, 2013-2022.
- **Climateworks Foundation** supporting the LC^3 Project since 2022.

How does LC³ reduce emissions?





LC^3 has comparable strength to OPC



LC3-50 = 50% clinker.

- 50% less clinker
- 40% less CO_2
- Similar strength
- Better chloride resistance
- Resistant to alkali silica reaction

HIGH PERFORMANCE

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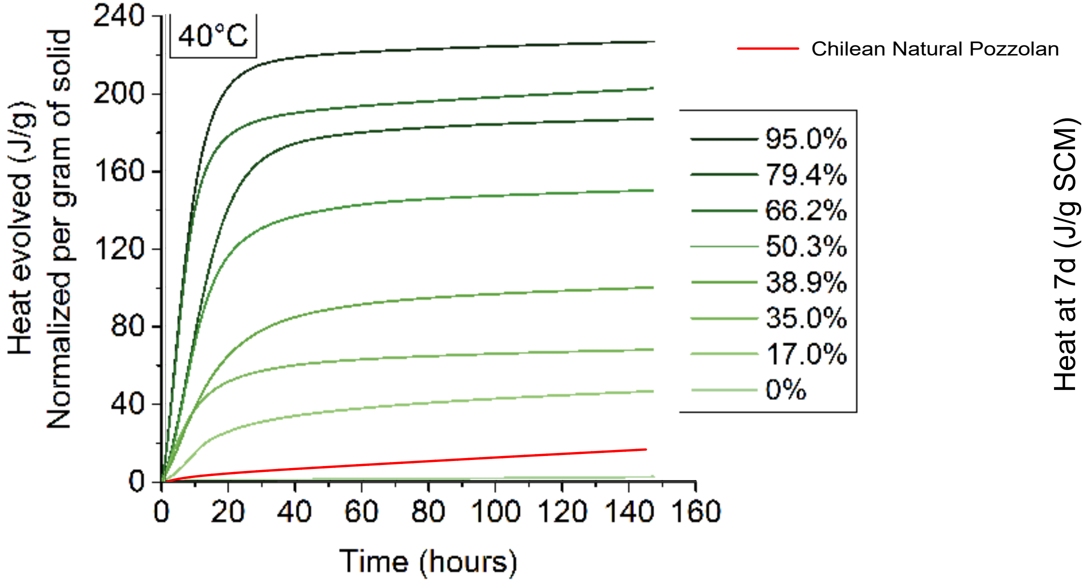
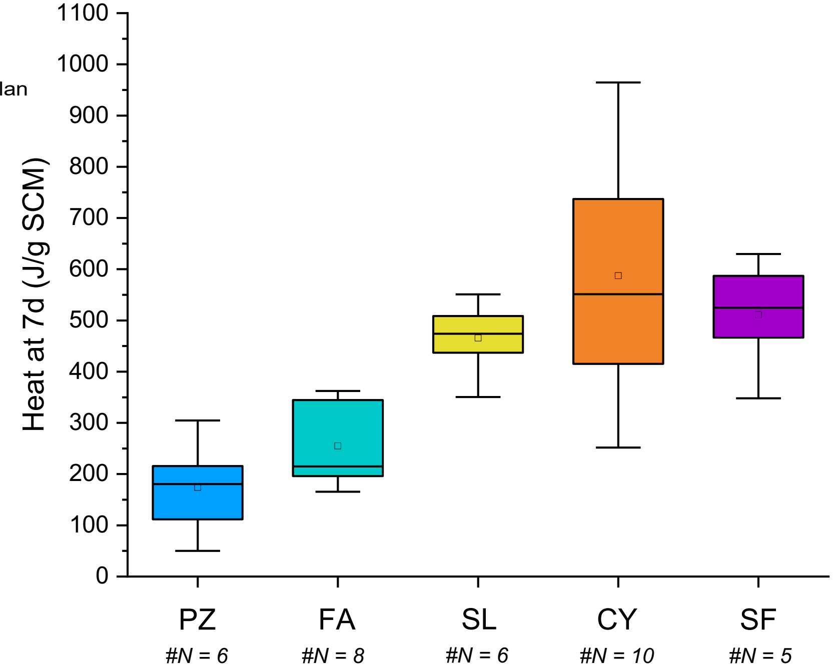
Reactivity of SCMs is important

natural pozzolan (R^3 test)



ASTM C1897

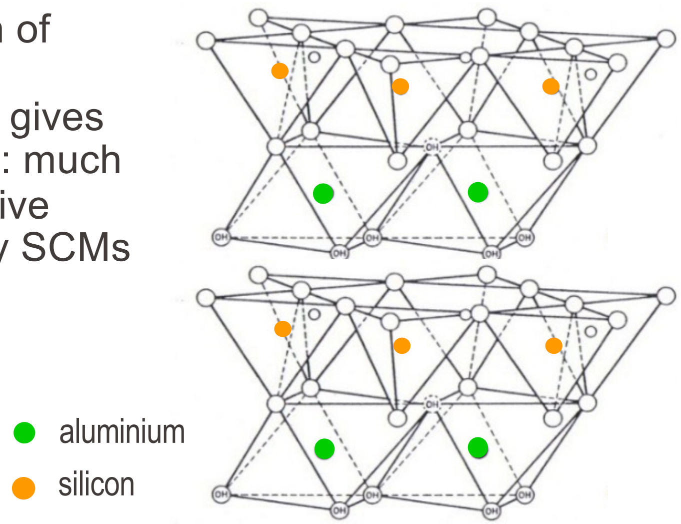


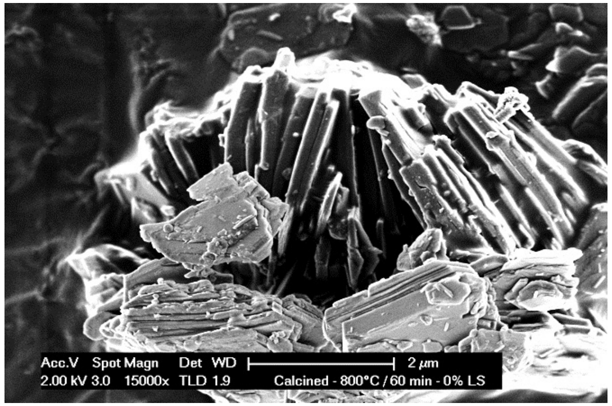
Kaolinitic clay with the lowest kaolinite content is more reactive than most pozzolans commonly used in the industry!!

F. Zunino, RILEM TC-267 TRM

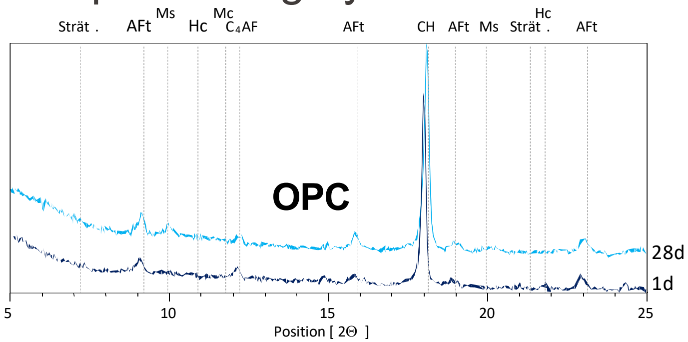
Why can we get such high replacement levels?

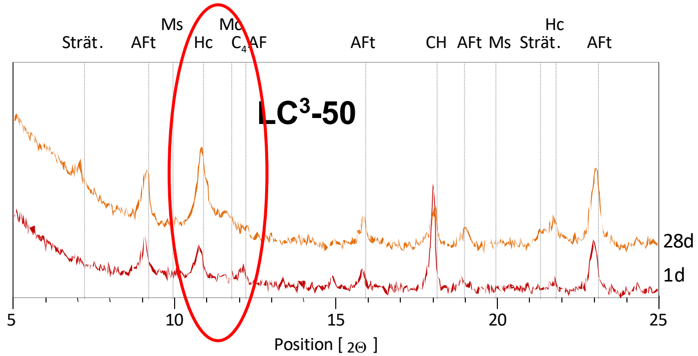
- Calcination of kaolinite at **700-850°C** gives metakaolin: much more reactive than glassy SCMs



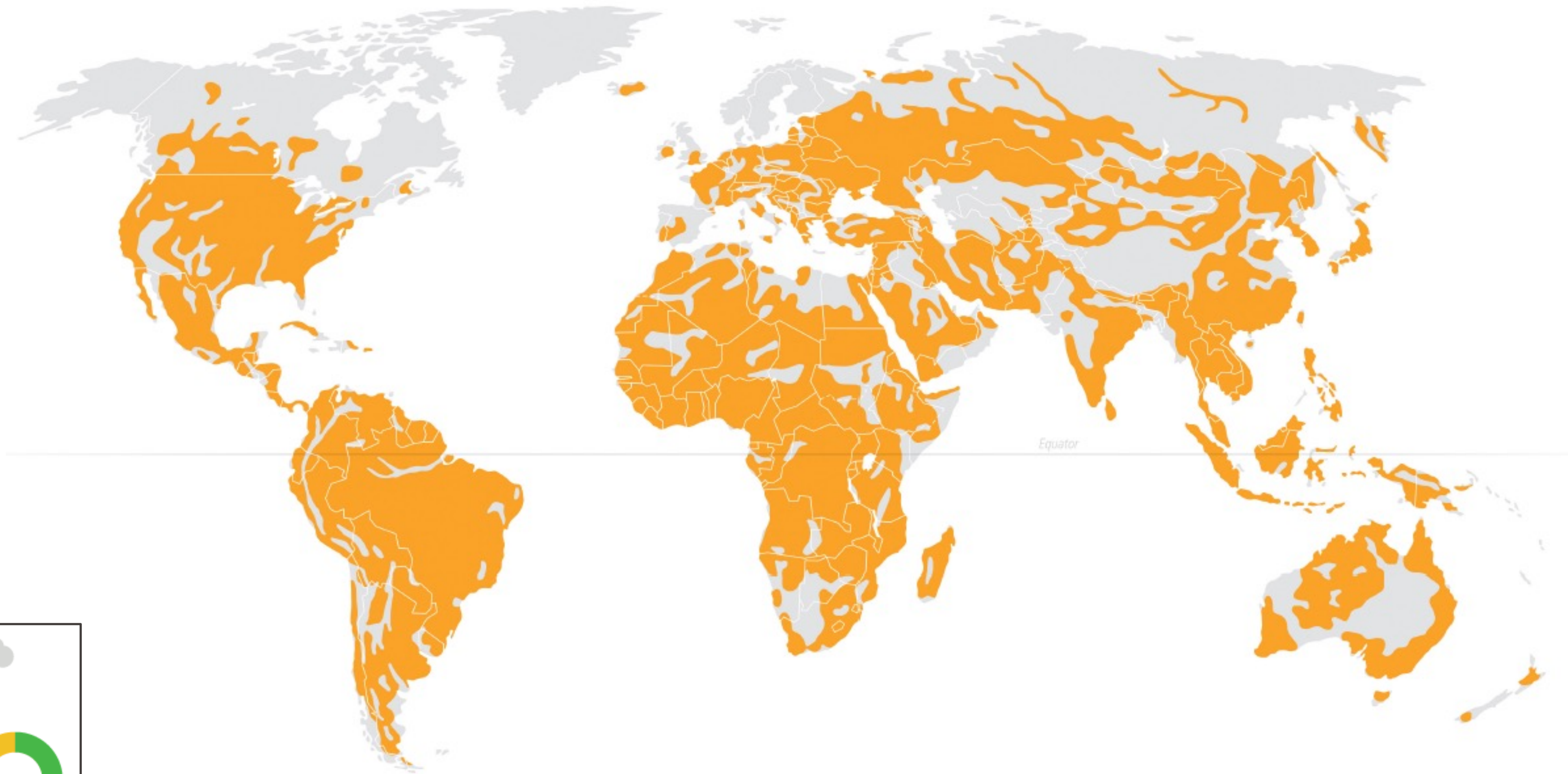


» **Synergetic reaction** of Alumina in metakaolin with limestone to give space filling hydrates





World distribution of kaolinitic clays



Source: Ito and Wagai, Scientific data 2017

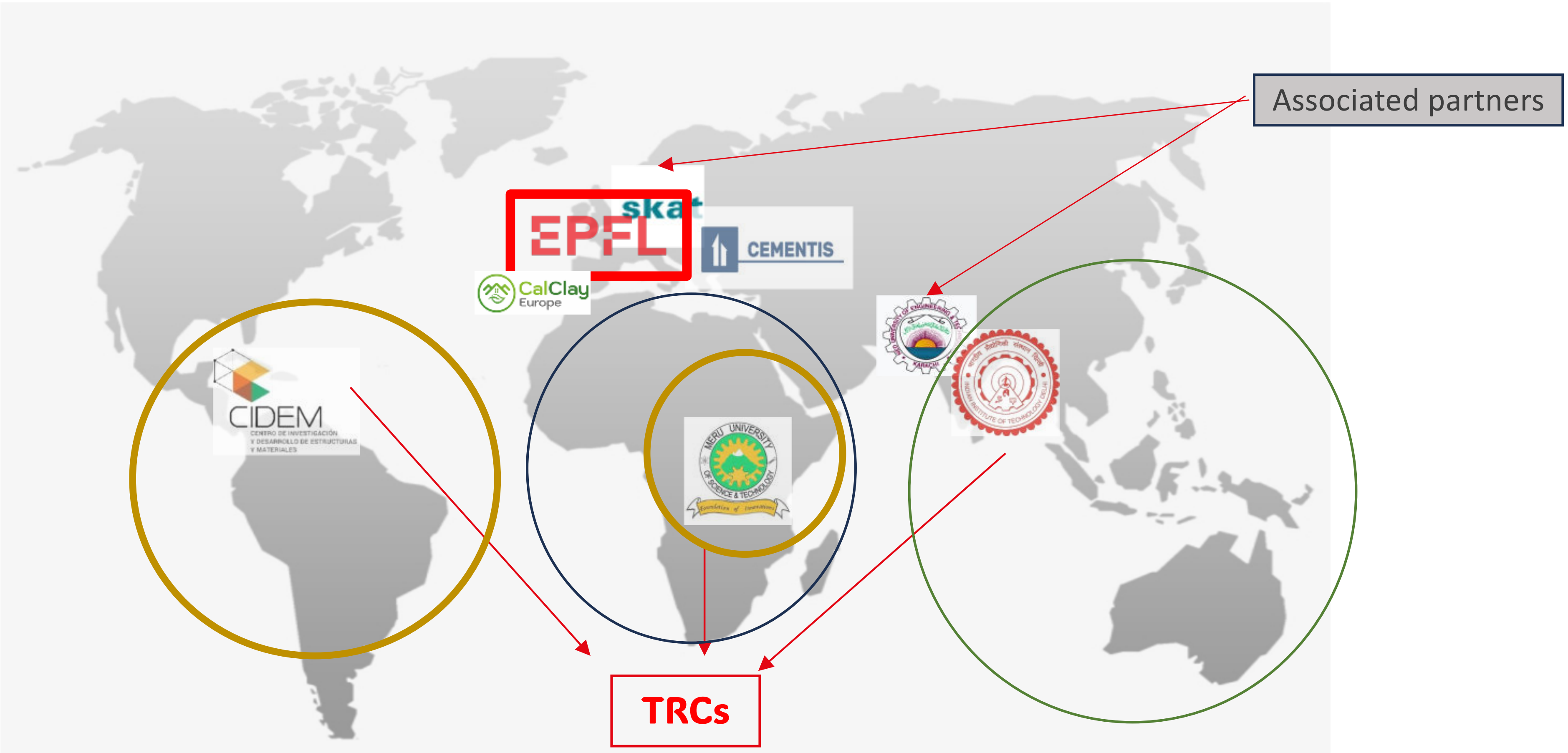
LC^3 *“technology”*

LC^3-x: x=clinker content
LC^3-50

NOT a company

All IP in public domain

Landscape of Partners



Where is LC3 now?

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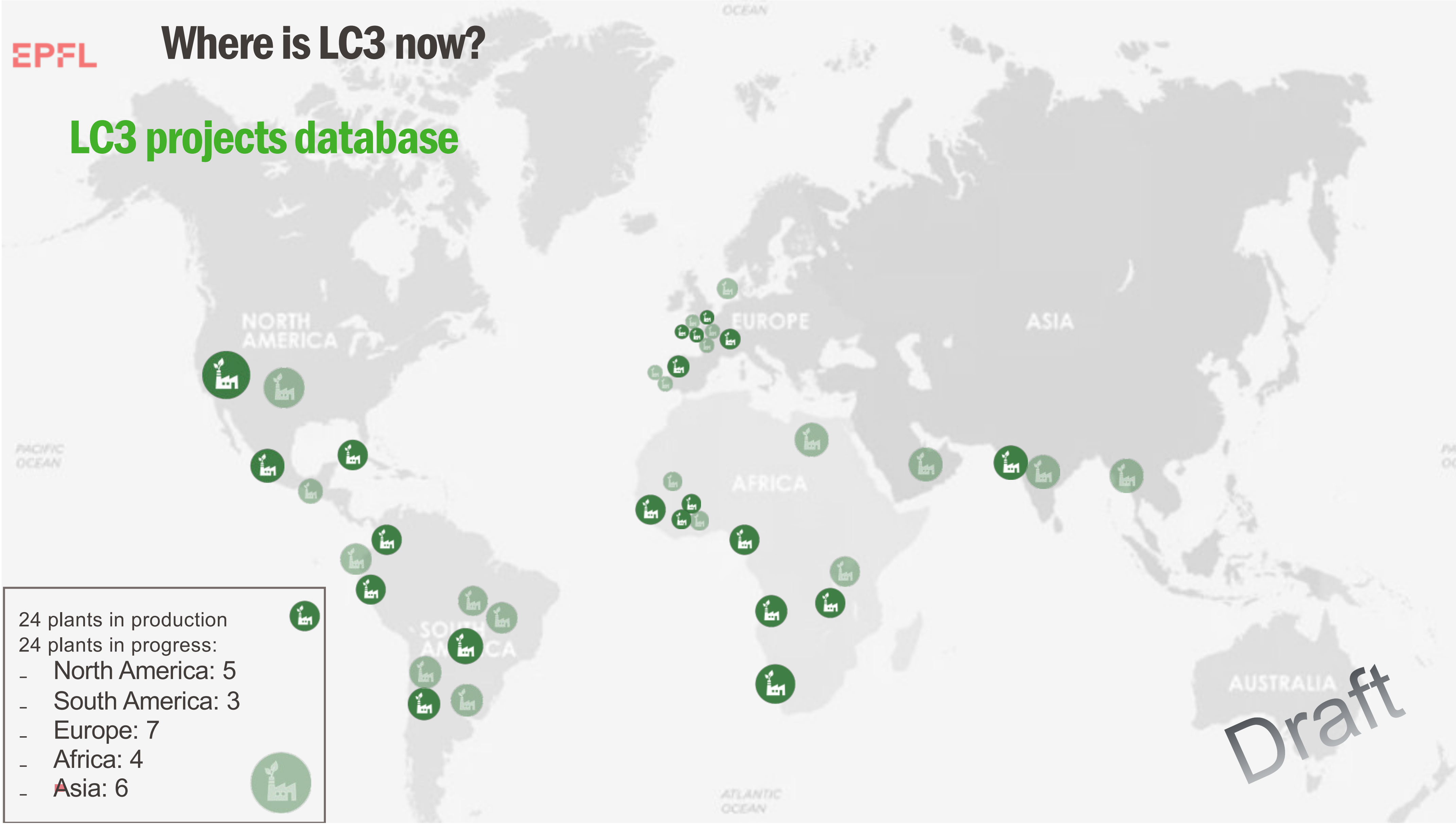
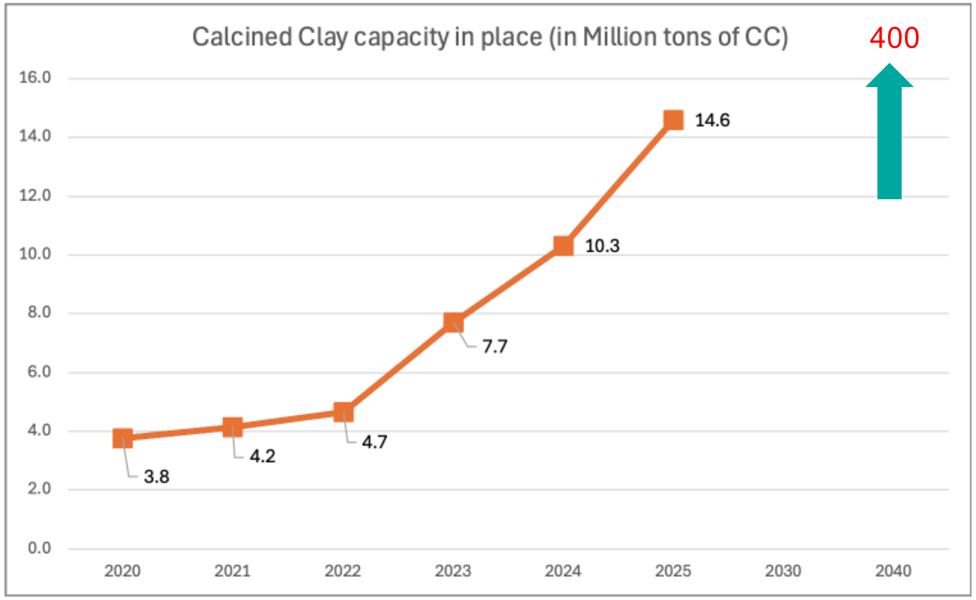
LC3 projects database



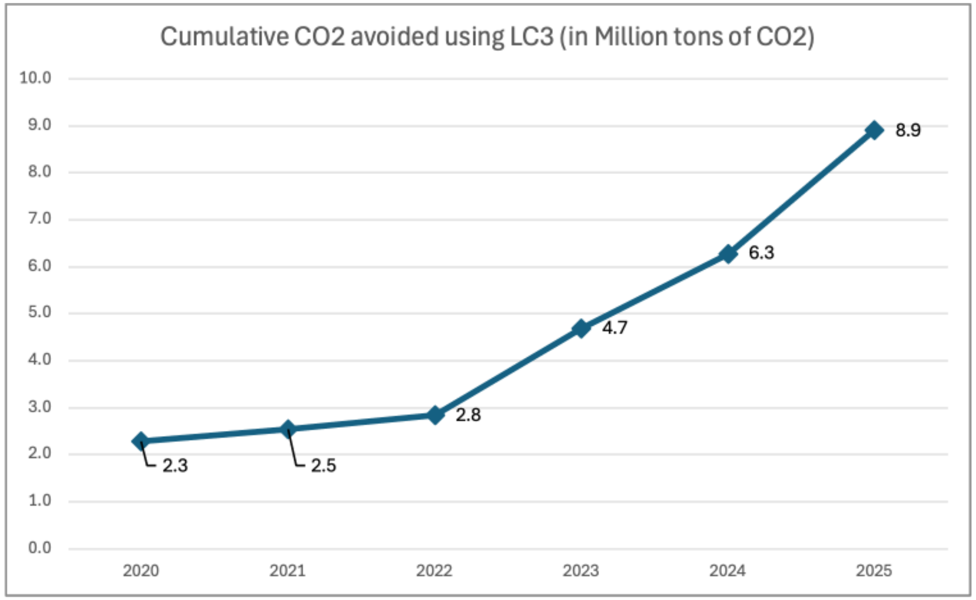
24 plants in production
24 plants in progress:
- North America: 5
- South America: 3
- Europe: 7
- Africa: 4
- Asia: 6

Draft

Capacity development and cumulative Co2 savings



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.



Constructions with LC3 materials

2014 → 2024

Some examples

Limestone
Calcined
Clay
Cement
LC3

LOW CARBON
LOW CAPITAL
HIGH PERFORMANCE
SCALABLE

Comparison of LC3 concrete with concretes prescribed in Dubai

A report on the Dubai Building Code for sustainable concrete - 2021 edition

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Strength class	C28/35		C40/50		C72/90	
Materials (kg/m³)	Dubai		Dubai		Dubai	
Total binder	**380**		**420**		**510**	
GGBS ratio	36%		36%		26%	
SF ratio					8%	
w/b ratio	**0.42**		**0.36**		**0.29**	
SP (%)	0.50		0.50		0.75	
Slump test (mm)	10		10		10	

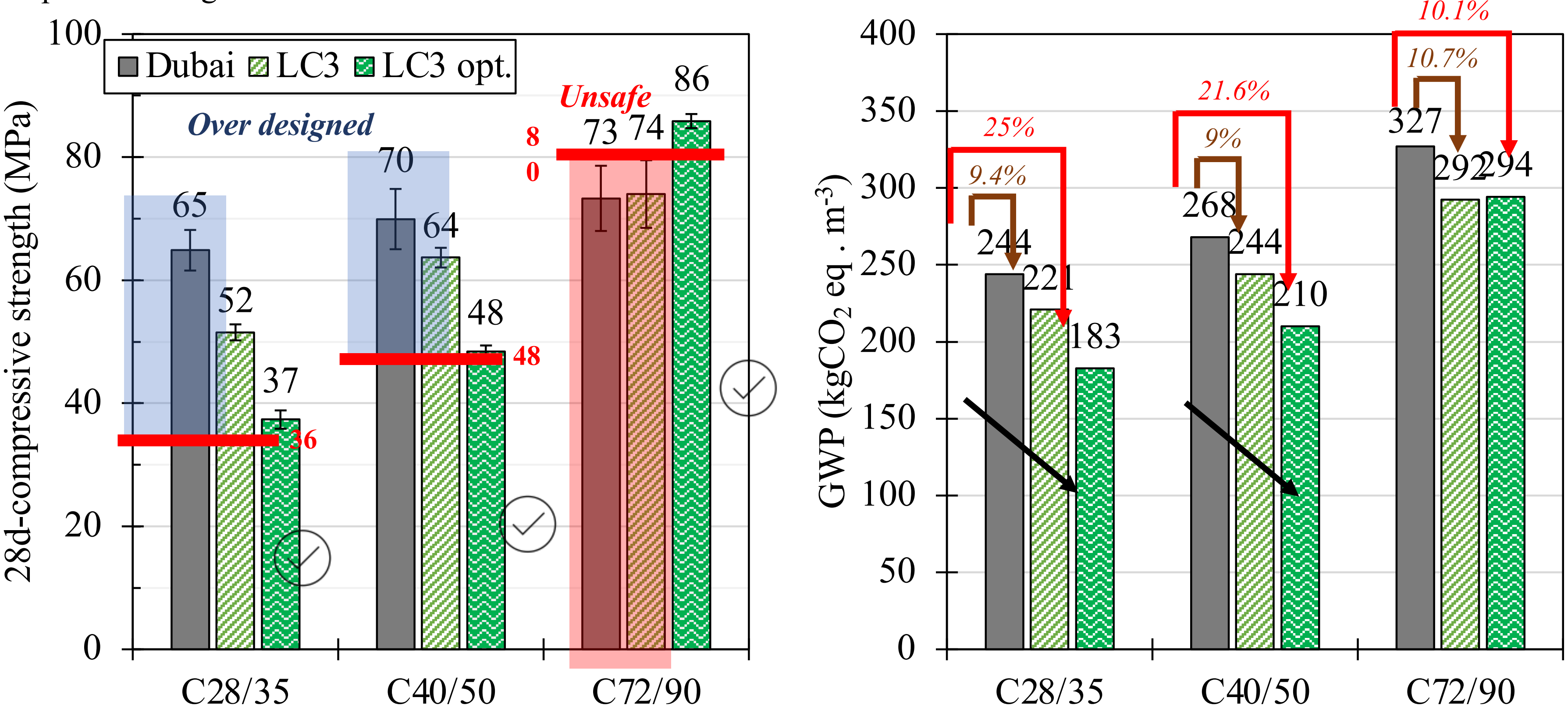
Mix designs

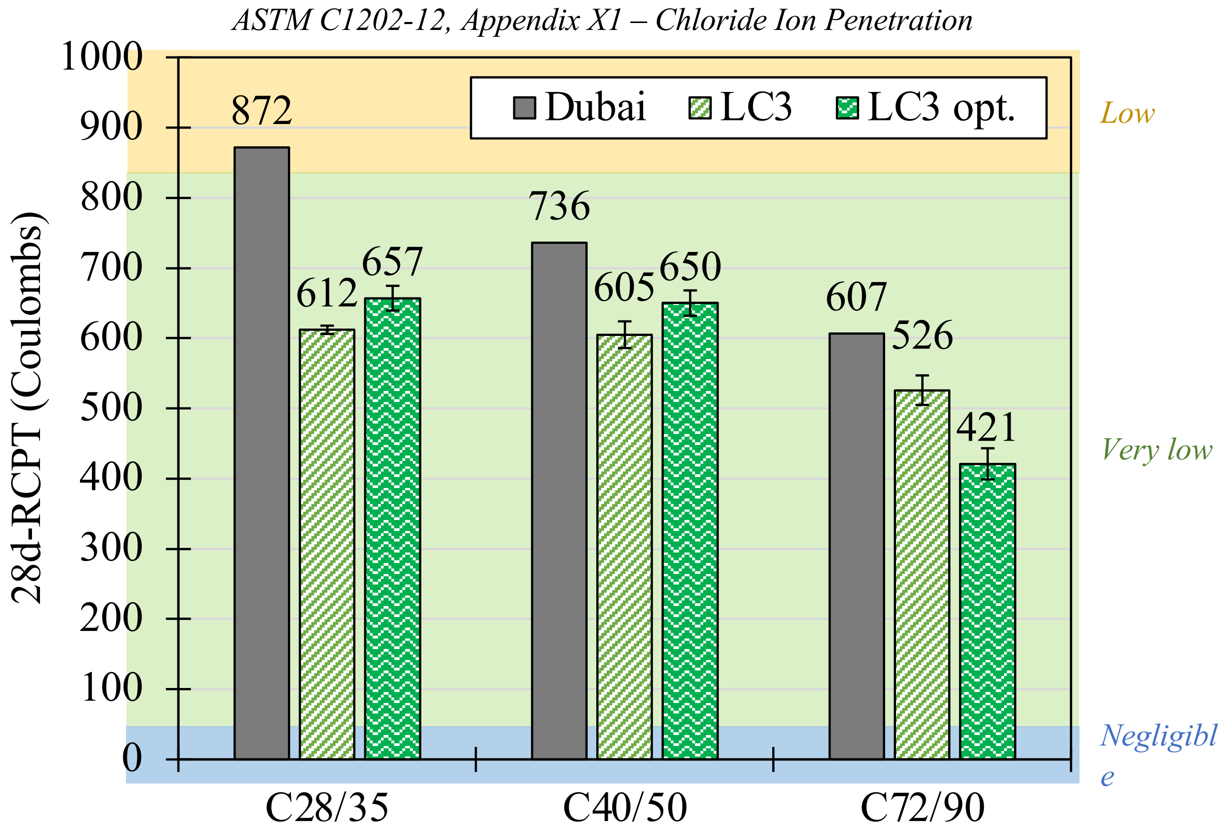
Strength class	C28/35			C40/50			C72/90		
Materials (kg/m³)	Dubai	LC^3	LC^3 opt.	Dubai	LC^3	LC^3 opt.	Dubai	LC^3	LC^3 opt.
Total binder	**380**	**380**	**325**	**420**	**420**	**375**	**510**	**510**	**510**
GGBS ratio	36%			36%			26%		
SF ratio							8%		
w/b ratio	**0.42**	**0.42**	**0.61**	**0.36**	**0.36**	**0.48**	**0.29**	**0.29**	**0.26**
SP (%)	0.50	1.56	0.20	0.50	1.97	0.50	0.75	1.97	2.50
Slump test (mm)	10	-	**100**	10	-	**75**	10	-	**10**

C28/35: 55kg (*15%*)

C40/50: 45kg (*11%*)

Compressive strength and GWP

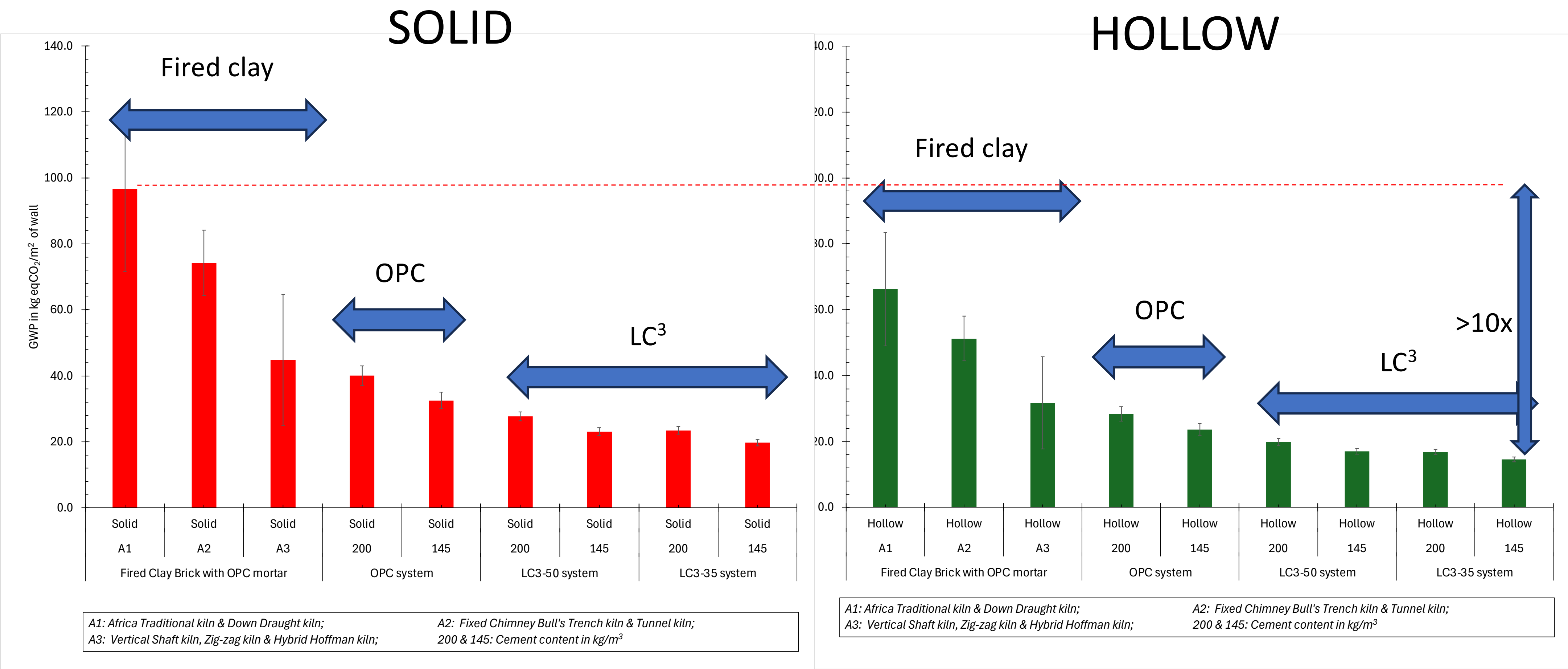



ASTM C1202-12, Appendix X1 – Chloride Ion Penetration
28d-RCPT (Coulombs)
1000
900
800
700
600
500
400
300
200
100
0
Dubai
LC3
LC3 opt.
872
612
657
736
605
650
607
526
421
C28/35
C40/50
C72/90
Low
Very low
Negligibl
e

Concrete blocks

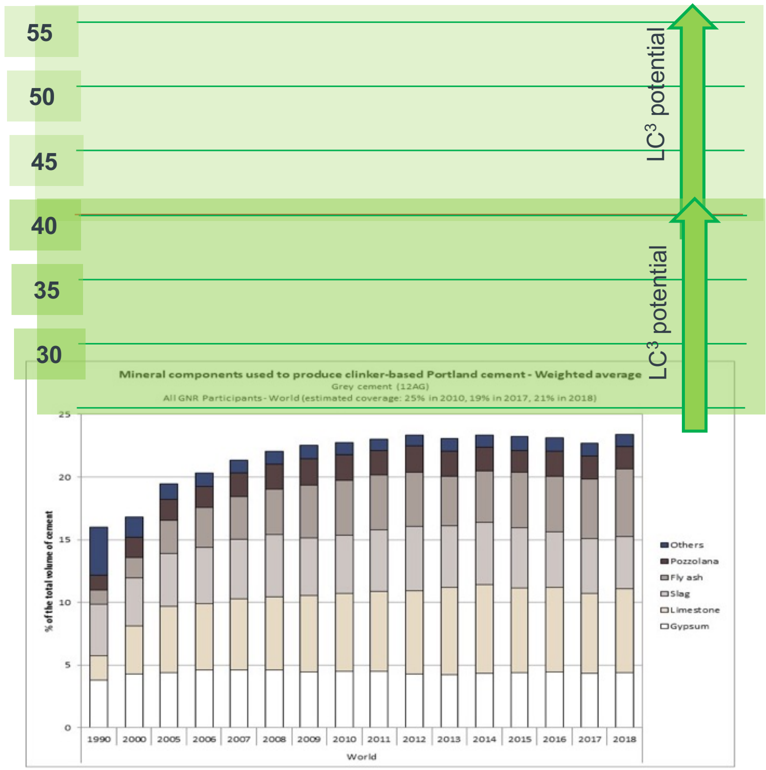
Limestone Calcined Clay Cement

LOW CARBON | LOW CAPITAL | HIGH PERFORMANCE | SCALABLE

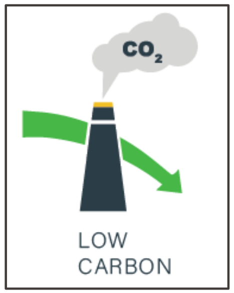


World Potential?

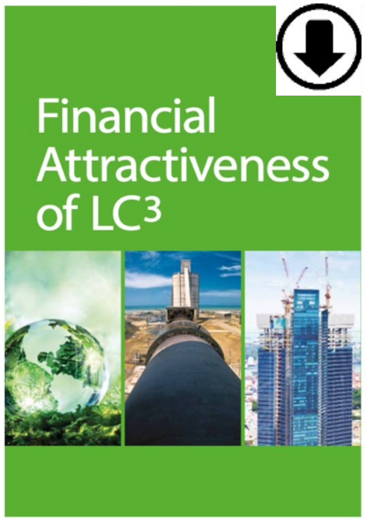
Calcined Clay only SCM which can expand substitution



- ✓ 800 million tonnes CO_2/yr
- ✓ 400 million tonnes CO_2/yr

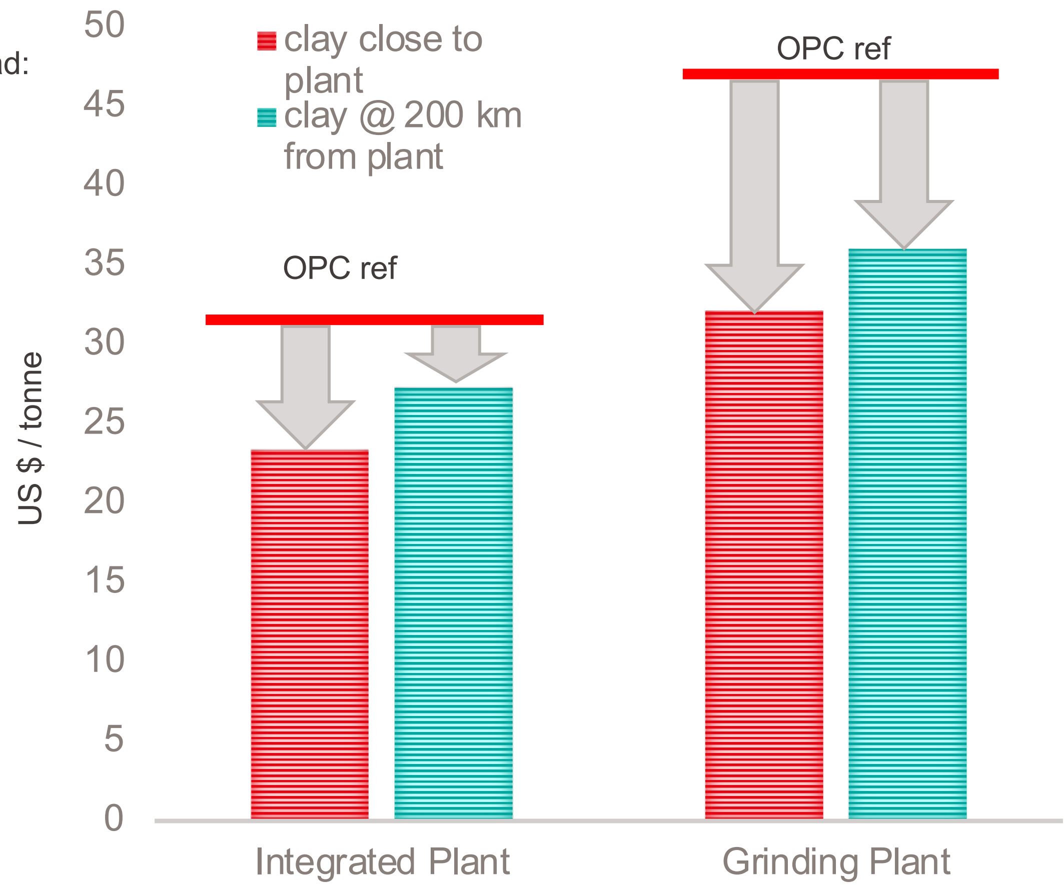


Financial Feasibility



Report available to download:
www.lc3.ch

Study by LC3 Project partner CEMENTIS



Substantial reductions in emissions ~80% could be achieved by working through the whole value chain

Few producers
Quick wins implemented

Reduce CO_2 from clinker production

- Efficient plants
- Waste fuels
- Alternate raw materials

Few producers
Large remaining potential

Reduce clinker in cement

- SCMs

Many producers
Implementation very difficult

Reduce cement in concrete

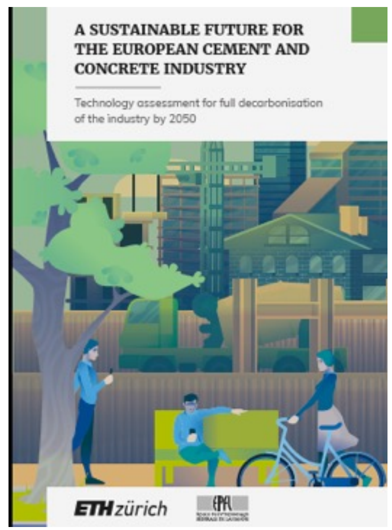
- Aggregate grading
- Good admixtures
- Use filler

Chain of deciders
Implementation very difficult

Reduce concrete in building

Big changes in mindset needed

More efficient (re)use of buildings



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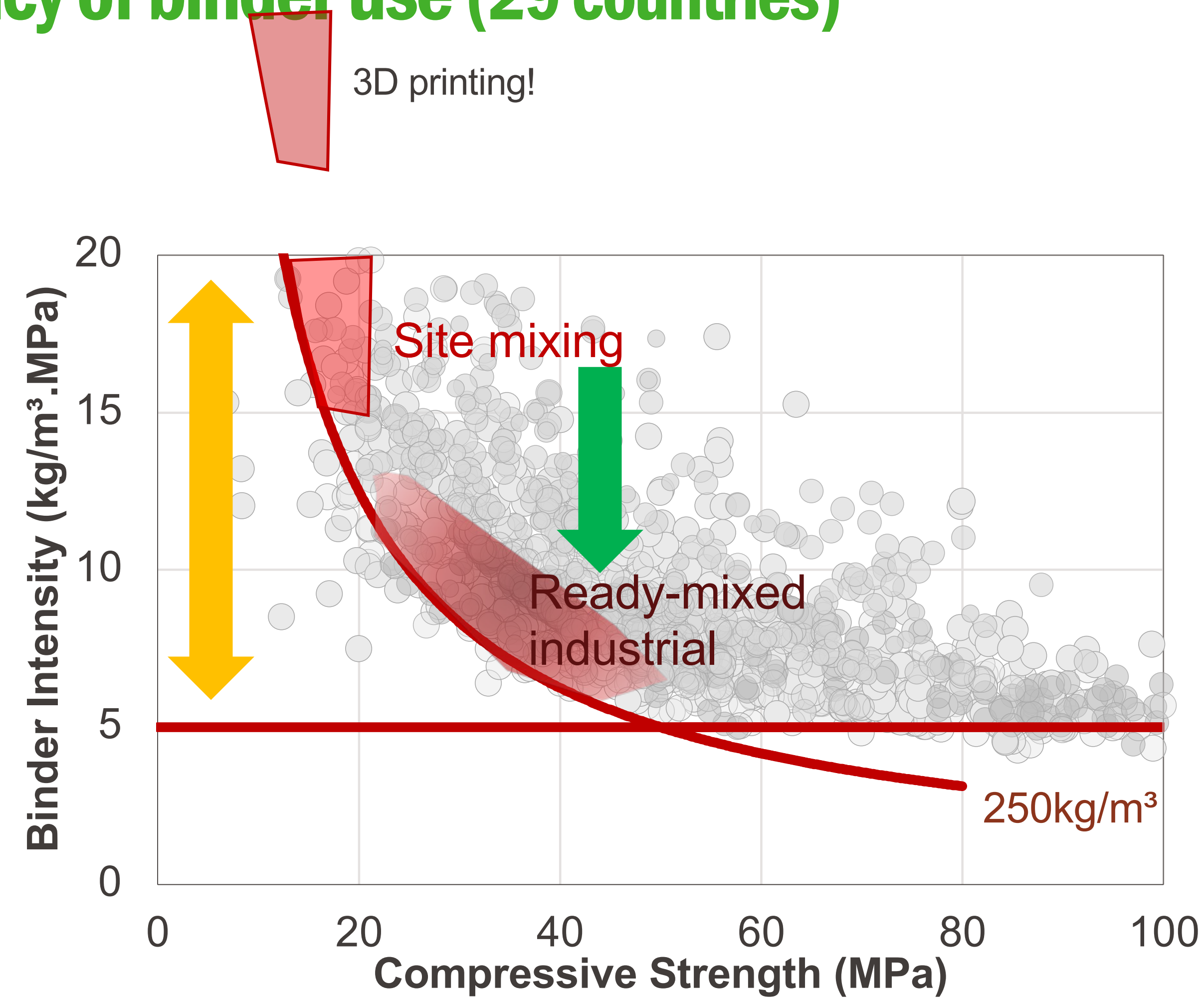
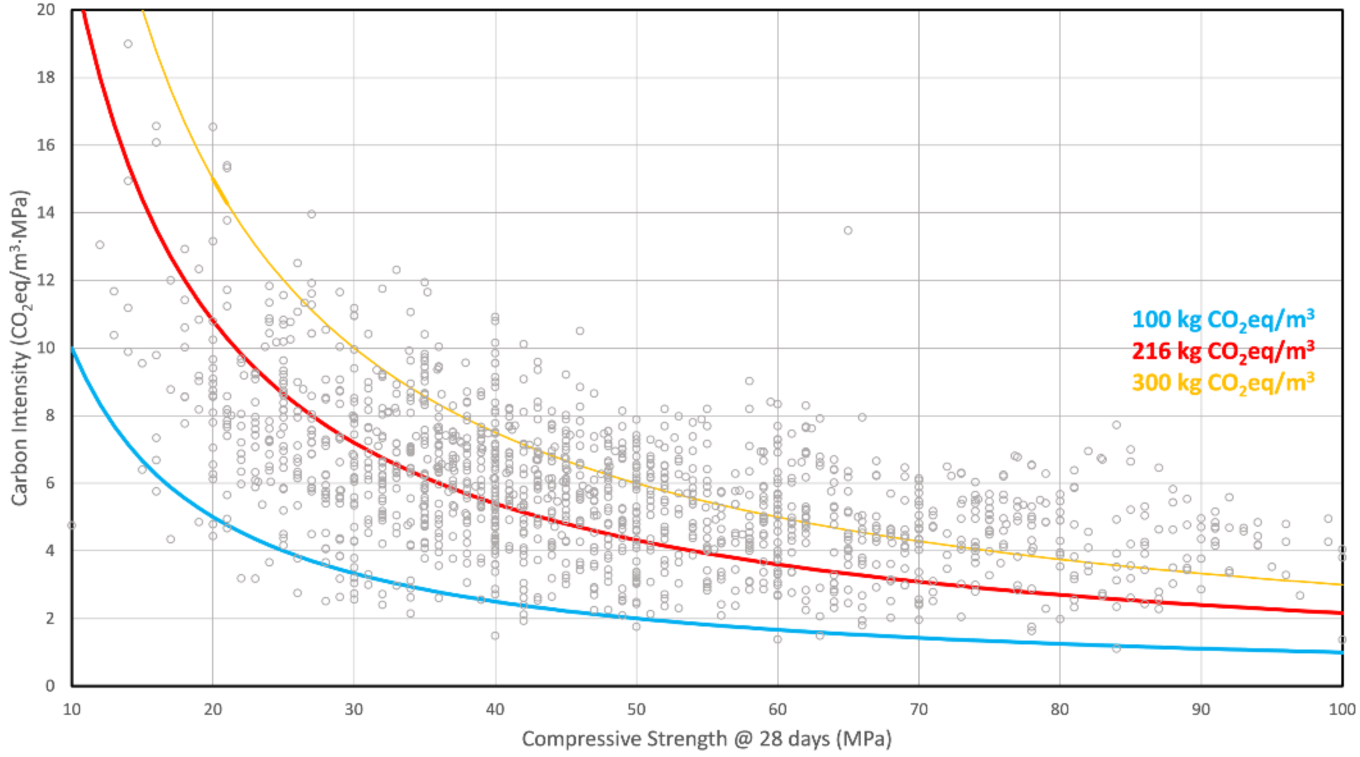
Efficiency of binder use (29 countries)



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

We can have concrete at 100 kg CO2 eq/m3



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

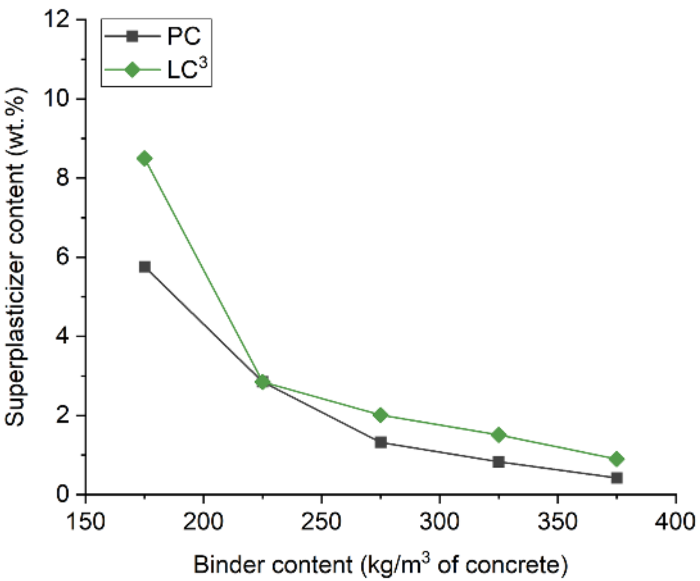
- What are the barriers to implementation?

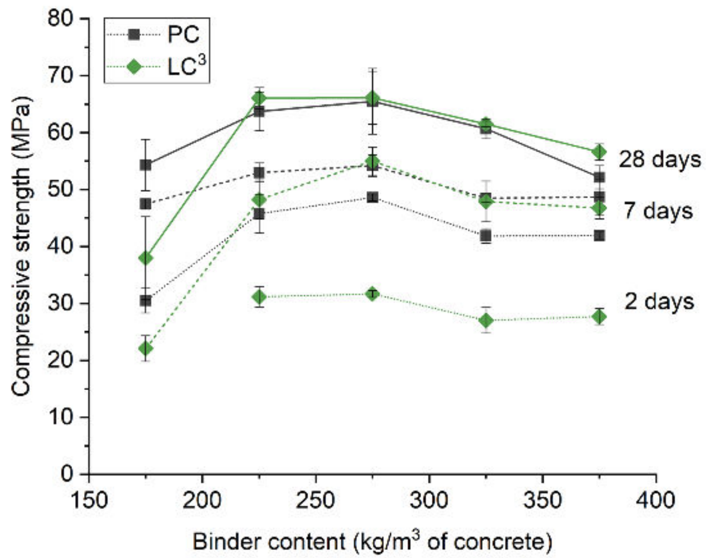
Cement level

- 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!

David Ruggiero

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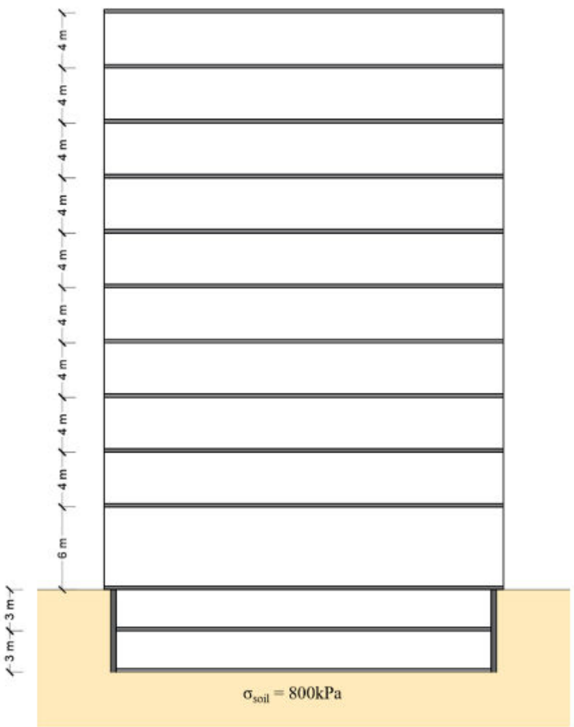
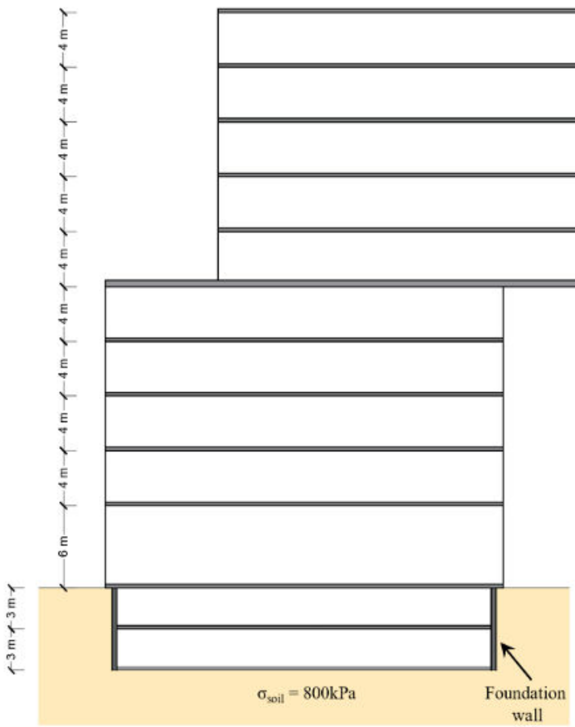
Carbon cost of irregularity



vs.



~50% more embodied carbon on average

Source: David Ruggiero

Output of Panda software from Cyrille Dunant, University Cambridge

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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

Concluding remarks

- ✓ Substantial reductions in CO_2 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 CO_2 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

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Thank You

Karen Scrivener

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polytechnique
fédérale
de Lausanne