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Environmentally friendlier options for future cement based materials

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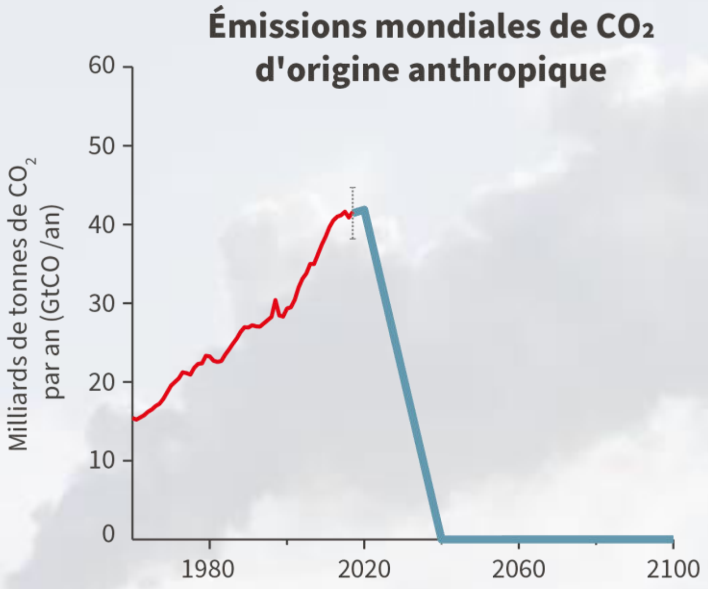
Sustainable construction is key to achieving net zero

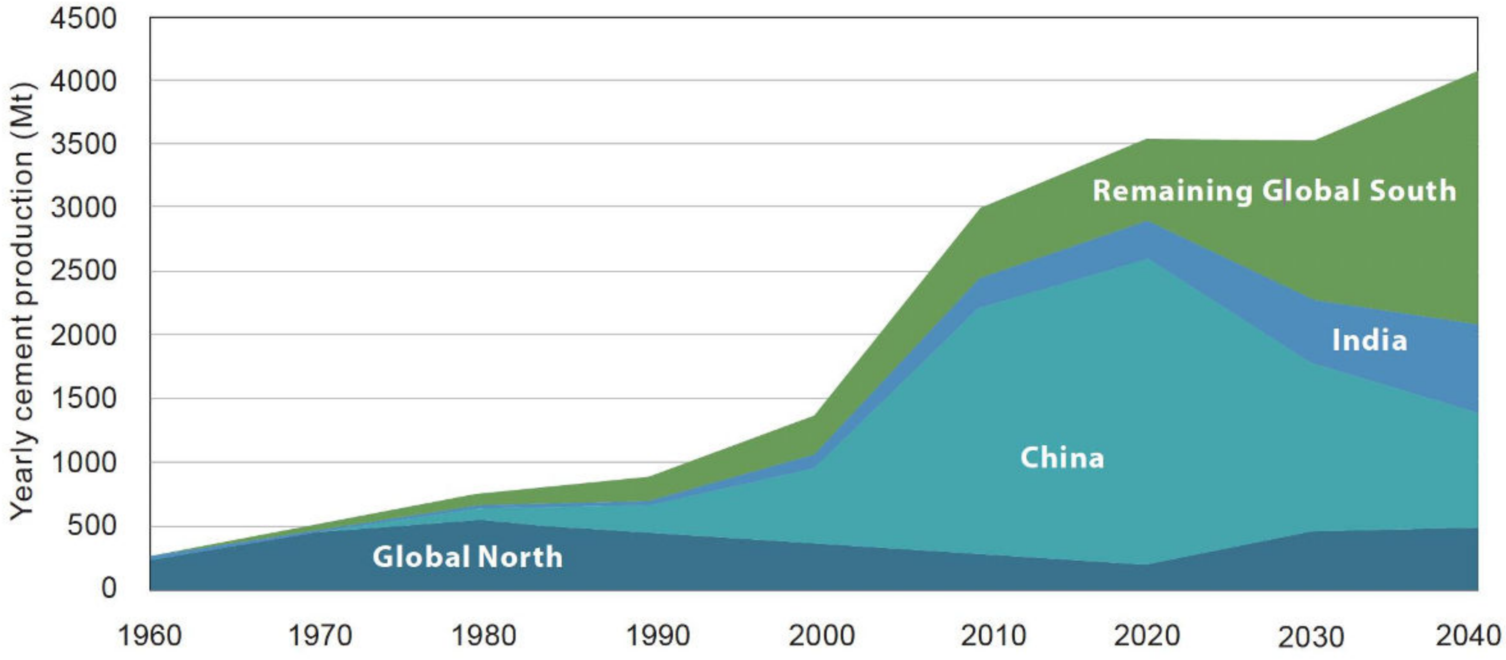
A radical transition is imperative:

- Cut CO_2 emission in half in the next 10 years
- Reach net zero in 2040



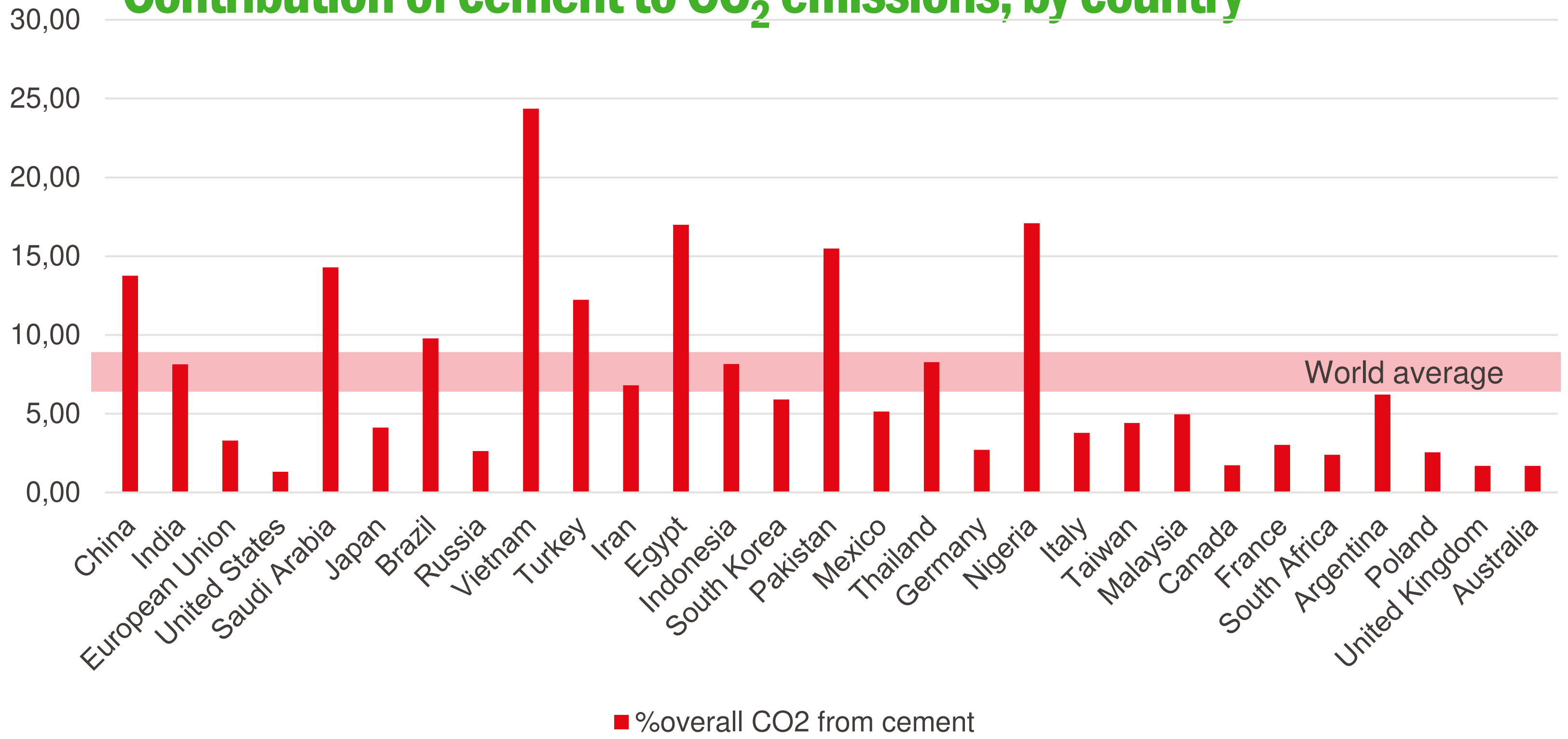
Source: *IPCC. 2019. 1.5°C report*

Demand in global south



We need solutions for people in developing countries

Contribution of cement to CO_2 emissions, by country



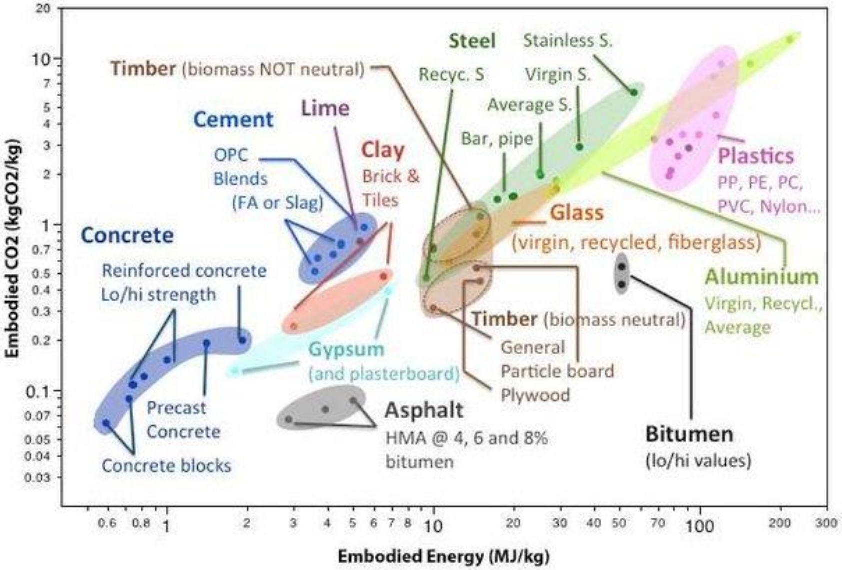
Although the USA is the third largest consumer of cement, it accounts for < 1.5% of the country's emissions

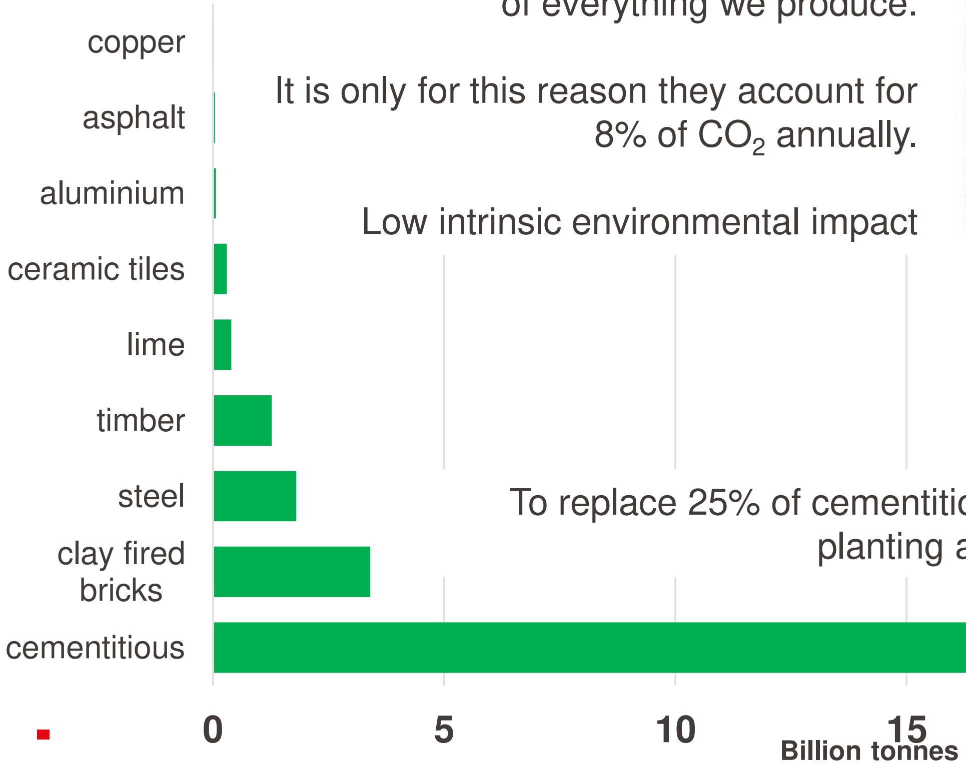
Large contribution worldwide due to enormous volumes

Cementitious materials make up >50% of everything we produce.

It is only for this reason they account for 8% of CO_2 annually.

Low intrinsic environmental impact





To replace 25% of cementitious with timber would require planting a forest 1,5 x the size of India

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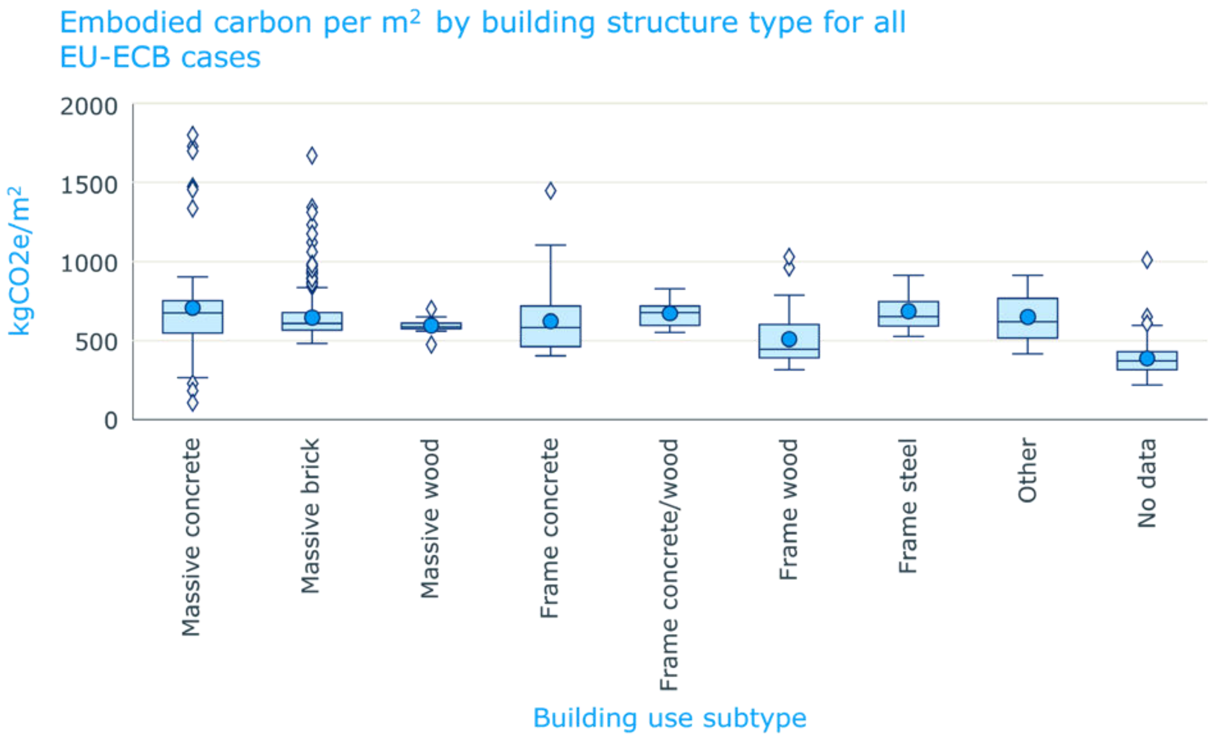
Would it help to replace concrete by other materials?



- 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.

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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

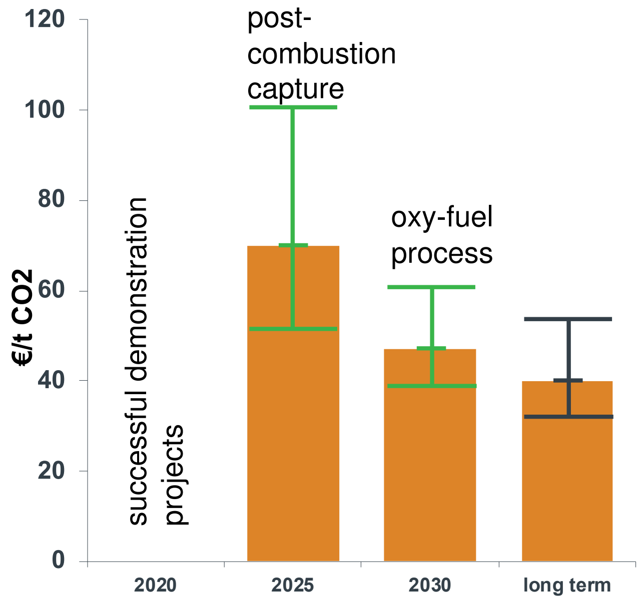
RECYCLE!

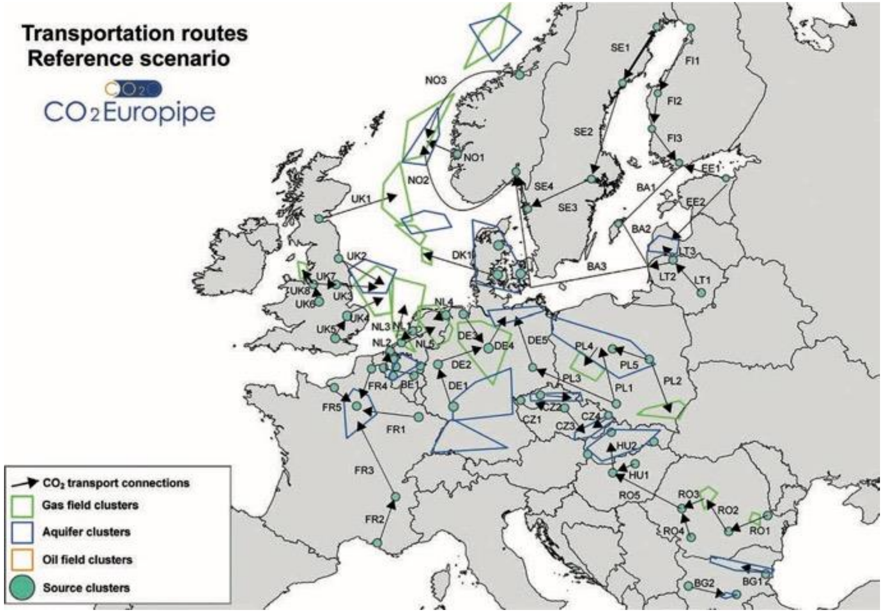
Substantial reductions in emissions > 80% can be achieved by working through the whole value chain

If only cement level is considered not more than about 50% possible without carbon capture and storage

Carbon Capture and Storage

Capture costs





At the very least it will be expensive
Reducing now will be a very sound investment

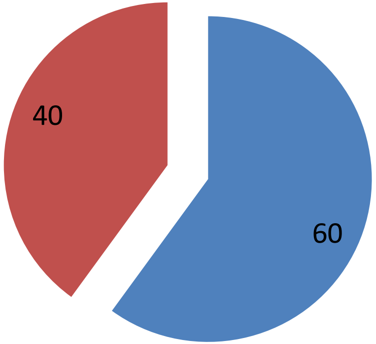
Scale of production >>> any “use” scenario
Need to build network to transport to storage sites

Origins of CO_2 emissions in clinker production: CO_2 from the clinker remains around 90% through to the Concrete

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



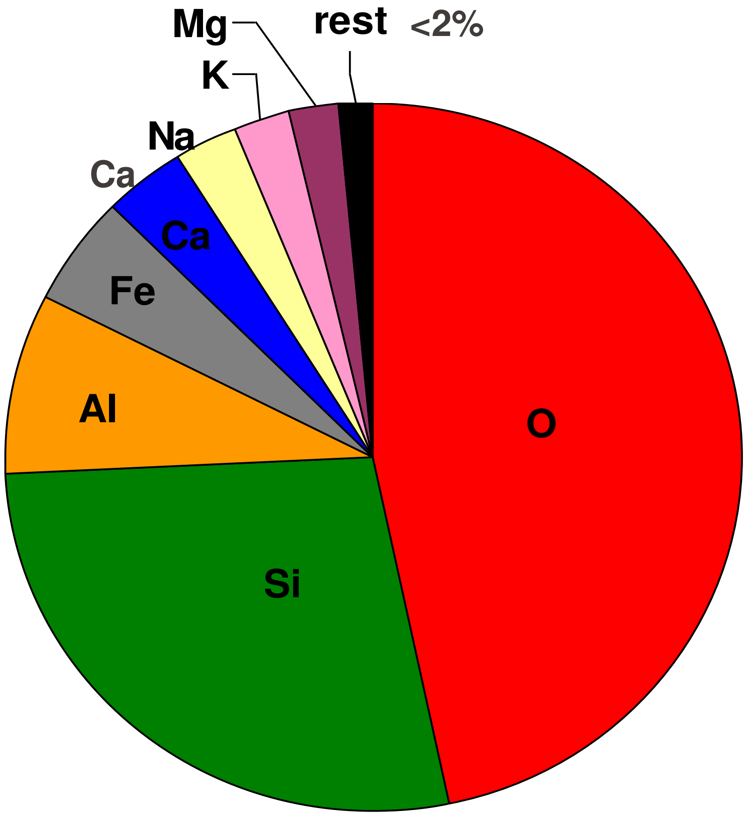
1 tonne of clinker leads to the emission of 750 – 900 kg CO_2 Average 850kg/t

$$CaCO_3 \rightarrow CaO + CO_2$$

Limestone 80% of raw material

Can we make cement with a different chemistry?

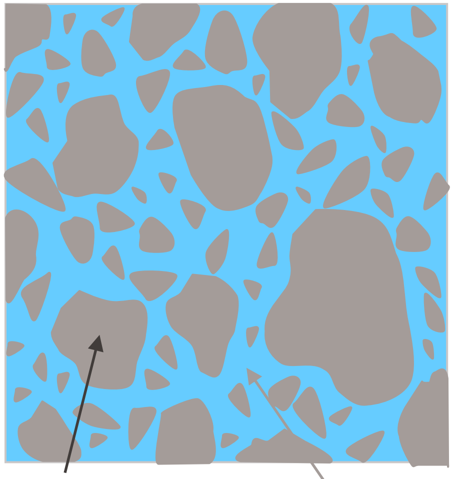
What is available on earth?



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

How does cement work?

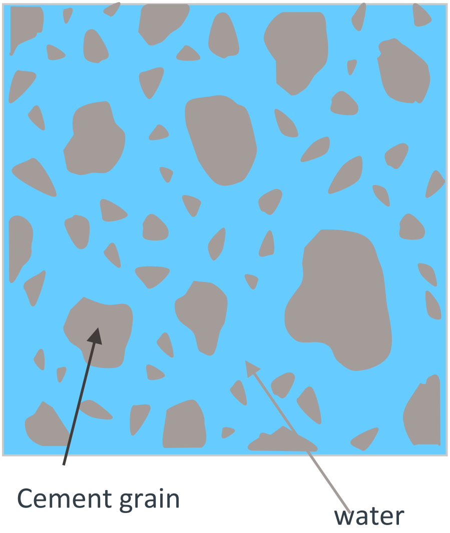
How cement works:



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

How cement works:



The cement grains
dissolve in the water

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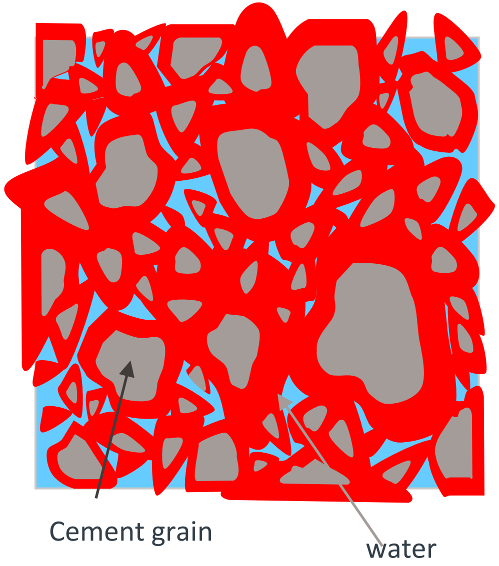
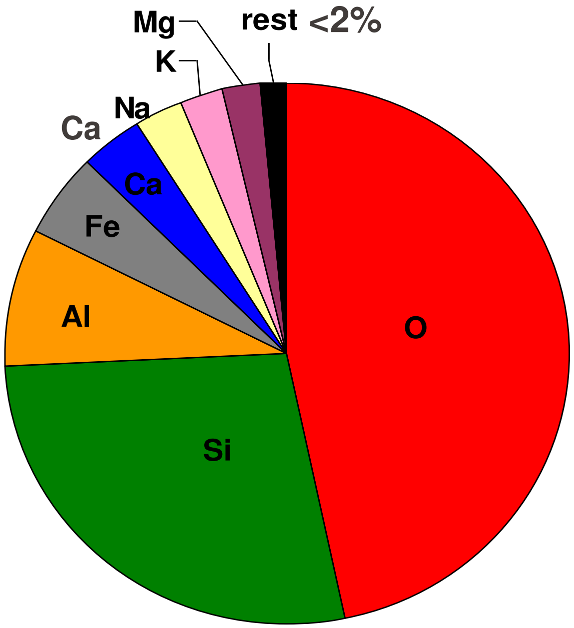
How cement works:



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

What is available on earth?

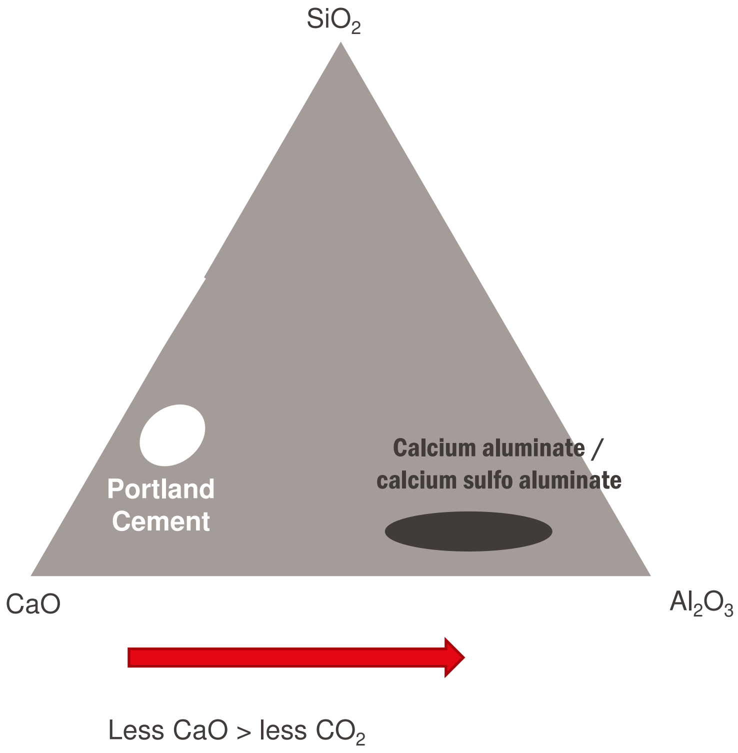


Na_2O
K_2O
} Too soluble

Fe_2O_3
MgO
} Too insoluble in alkaline solutions

CaO
SiO_2
Al_2O_3
} The most useful

Hydraulic minerals in system $CaO-SiO_2-Al_2O_3$



BUT, what sources of minerals are there which contain Al_2O_3 >> 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
and falling

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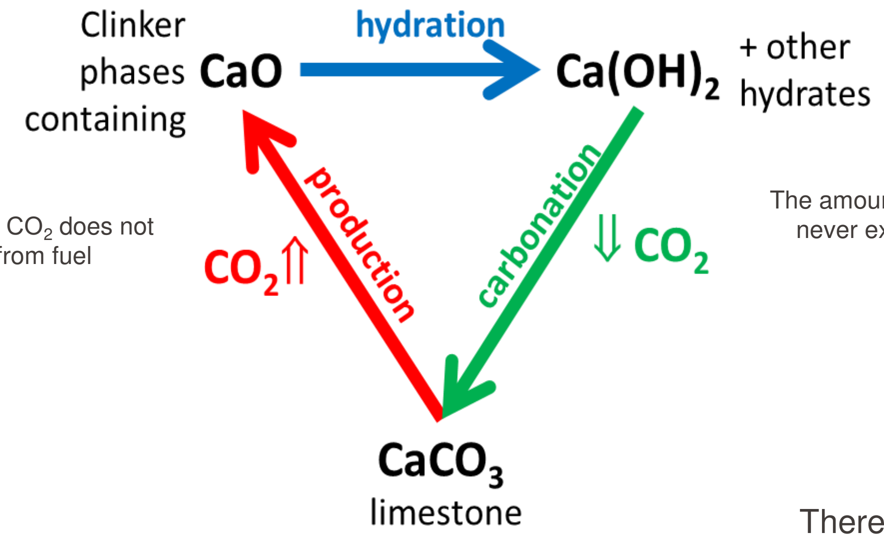
What does not make sense

- Many roadmaps indicate a significant amount of future CO_2 reduction will come from *"breakthroughs"*
- When we consider cement is a solid material that has to come from the earth, we can see that the idea of future radical breakthroughs borders on magical thinking or alchemy
- People cannot live in nano or virtual houses
- First let's look at a few things, much touted, with no prospect to lower atmospheric CO_2

Biochar

- Use as soil conditioner?
- Use as fuel?
- Use in concrete?

The cement carbon cycle



This is only the "chemical" CO_2 does not include that coming from fuel

The amount of CO_2 reabsorbed here can never exceed the amount on the left

Almost all calcium in earth's crust is in the form of calcium carbonate

There is some in sea water but very dilute so would have to handle huge volumes of water to get significant amounts out

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The most common fallacy:

- So of course calcium oxide, hydroxide etc can (and do) react with atmospheric CO_2, but these would have to come from ***uncarbonated*** sources of CO_2 to have any net benefit

- Microorganisms (algae, bacteria, etc) ***can*** form calcium carbonate from atmospheric CO_2, but they need a source of calcium.
  Again only if this was originally uncarbonated does it have any net benefit

- Any ***uncarbonated*** sources of calcium can already be simply exploited to produce conventional clinker.

Portland based cements will continue to dominate

Blended cements are the most realistic option to reduce CO_2 and extend resources

Most promising approach – reducing the clinker factor

↓ CO_2

Process optimisation

↓ clinker factor

Clinker

+

Gypsum

Cement

+

SCMs – Supplementary Cementitious Materials

Limestone

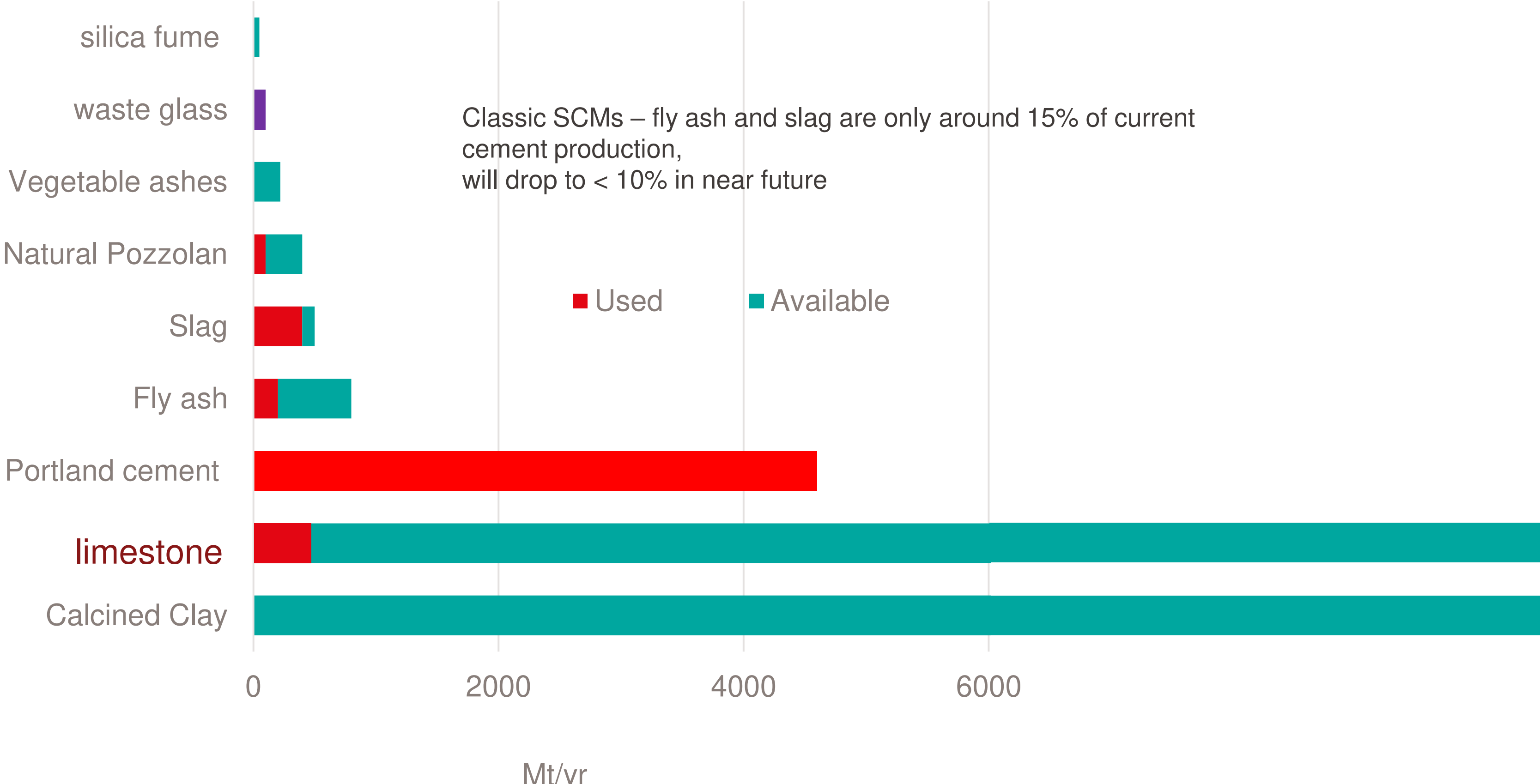
Fly ash

Slag

Calcined clays

Often by-products or wastes from other industries

Availability of SCMs



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There is no magic solution

- Blended with SCMs will be best solution for sustainable cements for foreseeable future
- **Only material really potentially available in viable quantities is calcined clay.**
- **Synergetic reaction** of calcined clay and limestone allows high levels of substitution:
  EPFL led LC^3 project supported by SDC. **Started 2013**

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Agency for Development and Cooperation SDC

Limestone Calcined Clay Cement LC^3

The LC3 project team

2 not for profit Technical Resource Centres (TRCs):

ecosolutions

Limestone Calcined Clay Cement LC3 Technology Resource Centre

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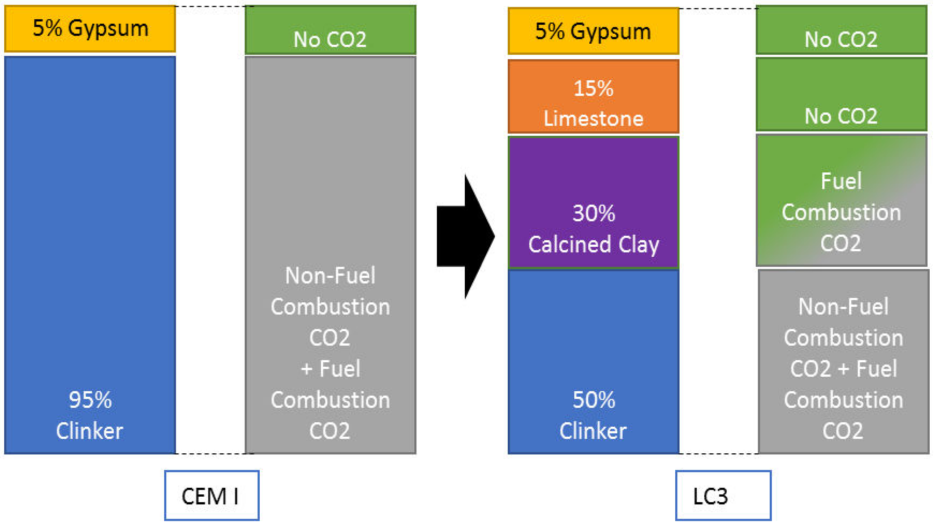
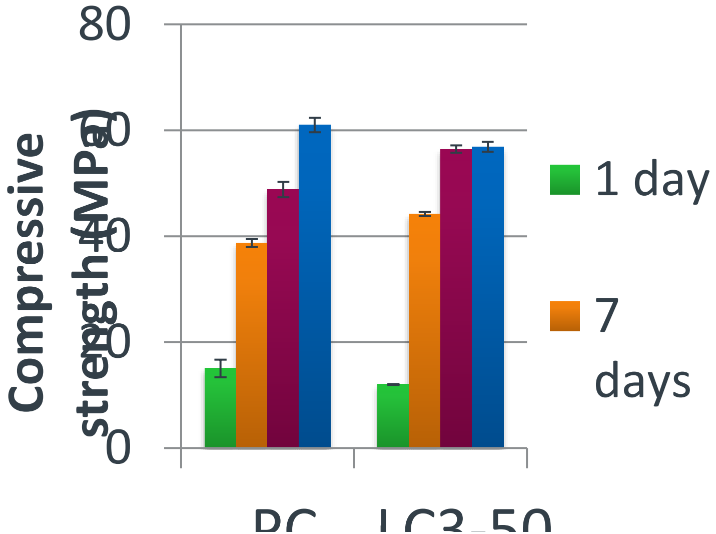
What is LC³



LC³ is a family of cements, the figure refers to the **clinker** content



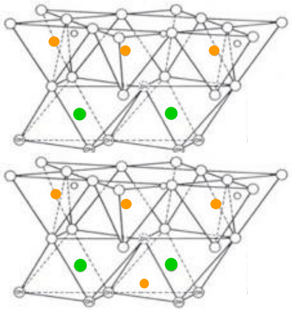
- 50% less clinker
- 40% less CO_2
- Similar strength
- Better chloride resistance
- Resistant to alkali silica reaction

What kinds of clay are suitable?

Need about 40% kaolin:
These materials widespread
does not compete
with ceramic applications

Three basic clay structures

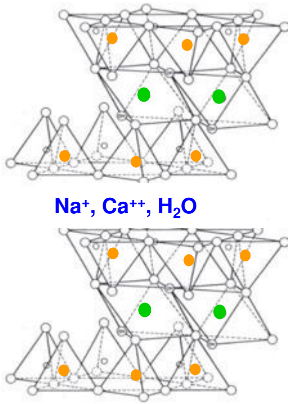
Kaolinite (1:1)



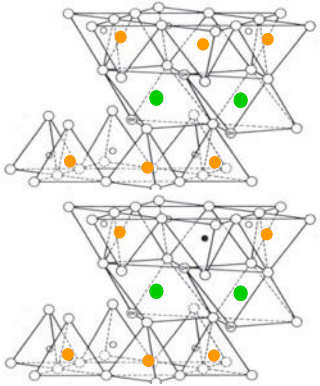
● aluminium

● silicon

Montmorillonite (2:1)
(Smectites)



Illite (Micas)
(2:1)

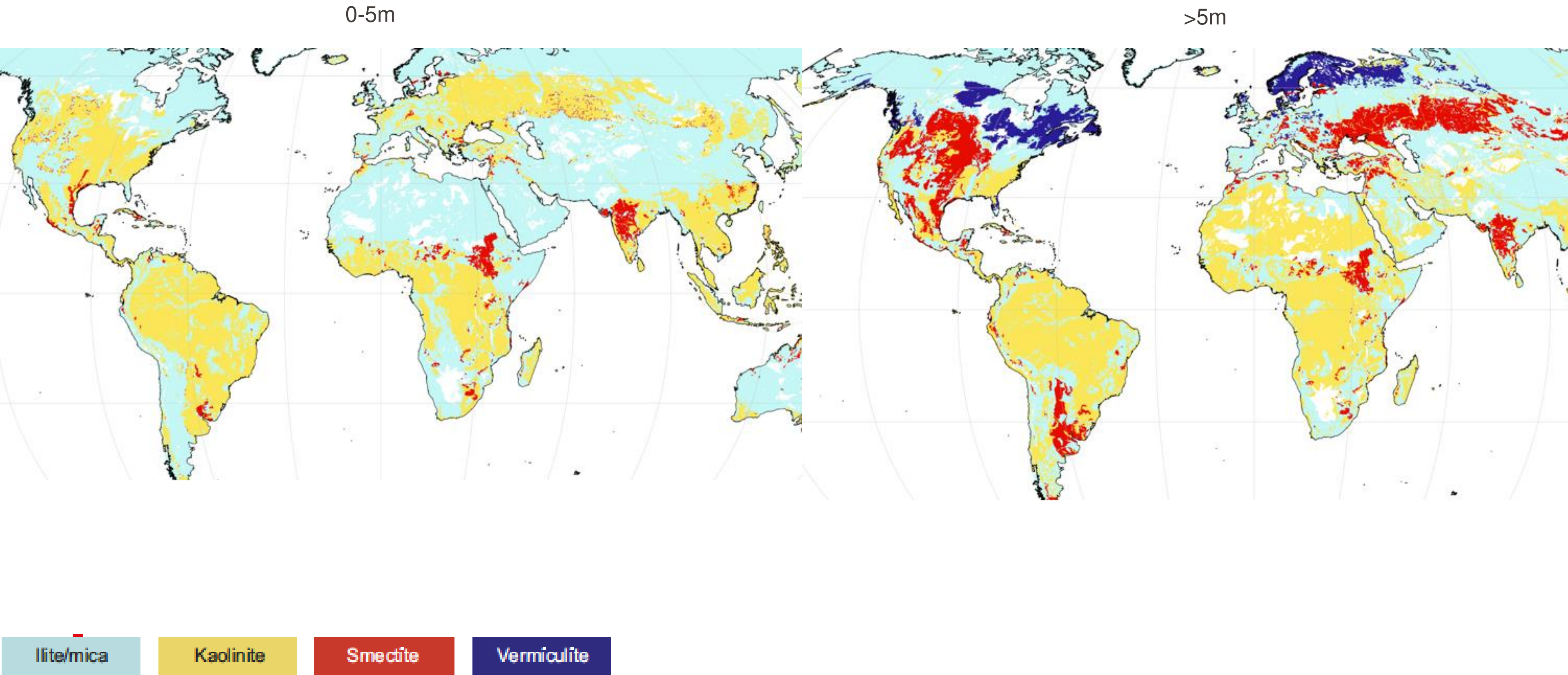


“Metakaolin”, sold as high purity product for paper, ceramic, refractory industries
Requirements for purity, colour, etc, mean expensive 3-4x price cement

Clays containing metakaolin available as wastes
– over or under burden NOT agricultural soil
Much much less expensive often available close to cement plants

Distribution of Kaolinitic clays

Ito and Wagai, Scientific data 2017



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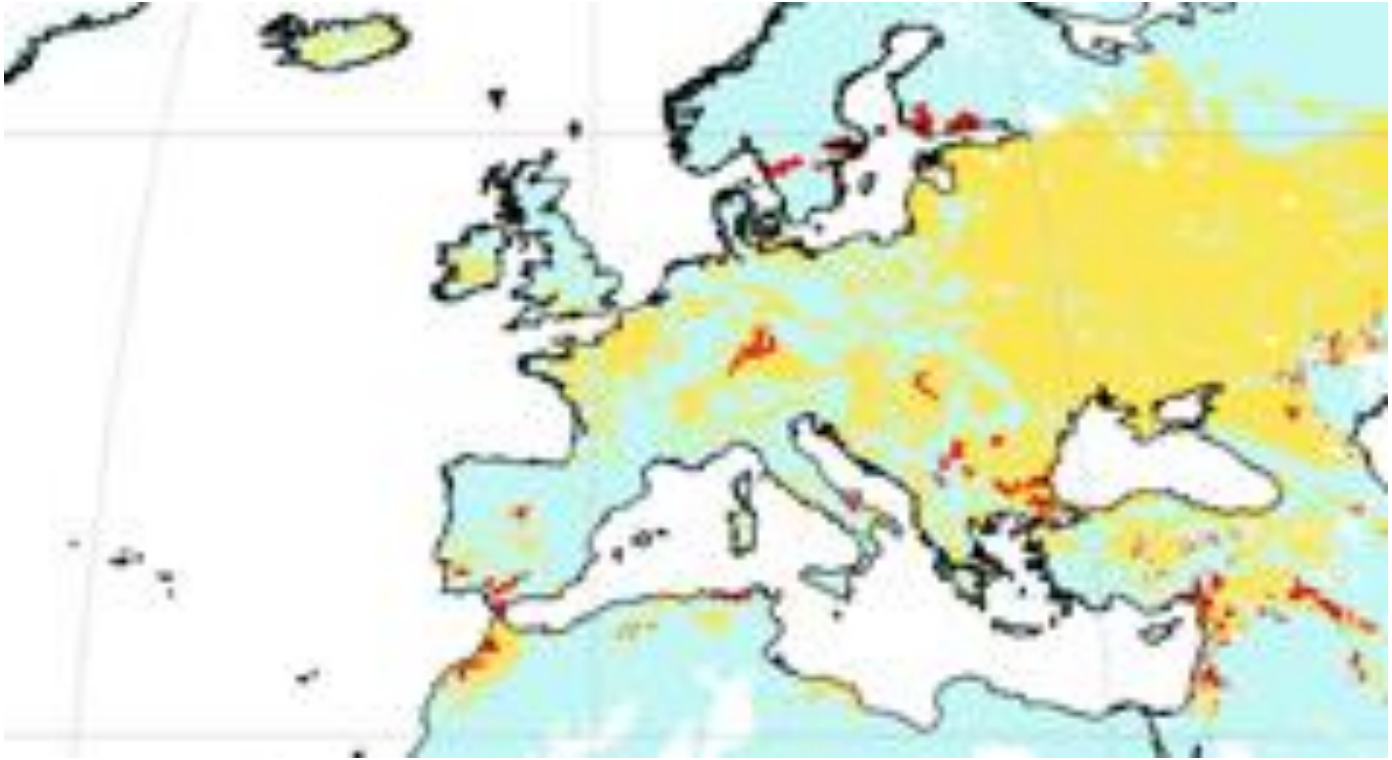

Ilite/mica | Kaolinite | Smectite | Vermiculite

Calcination of clay

Can be achieved with existing technology:

Rotary kilns (even clinker kilns)

Flash Calciners

CO_2 emission as low as **90** kg /tonne

Possible to electrify

Demonstration structure, India

Around 14 tonnes of CO_2 saved
Compared to existing solutions

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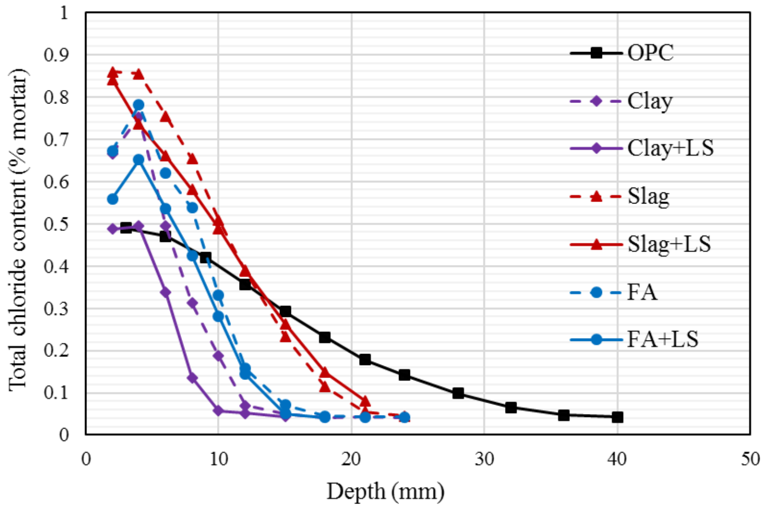
New Calcination plant Ivory Coast

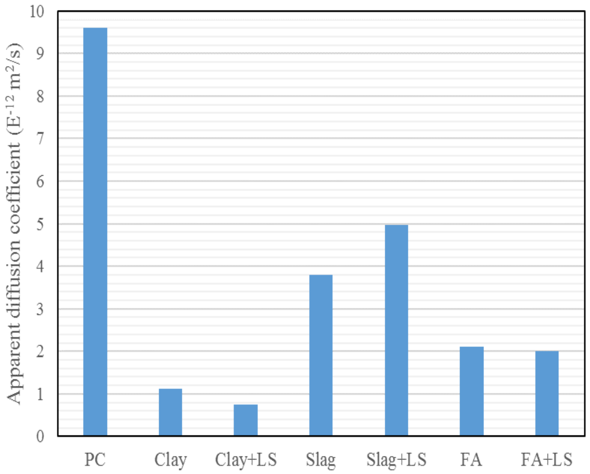
Colour control at Ivory Coast plant

Key Advantages

- Chloride resistance
- Suppression of alkali silica reaction

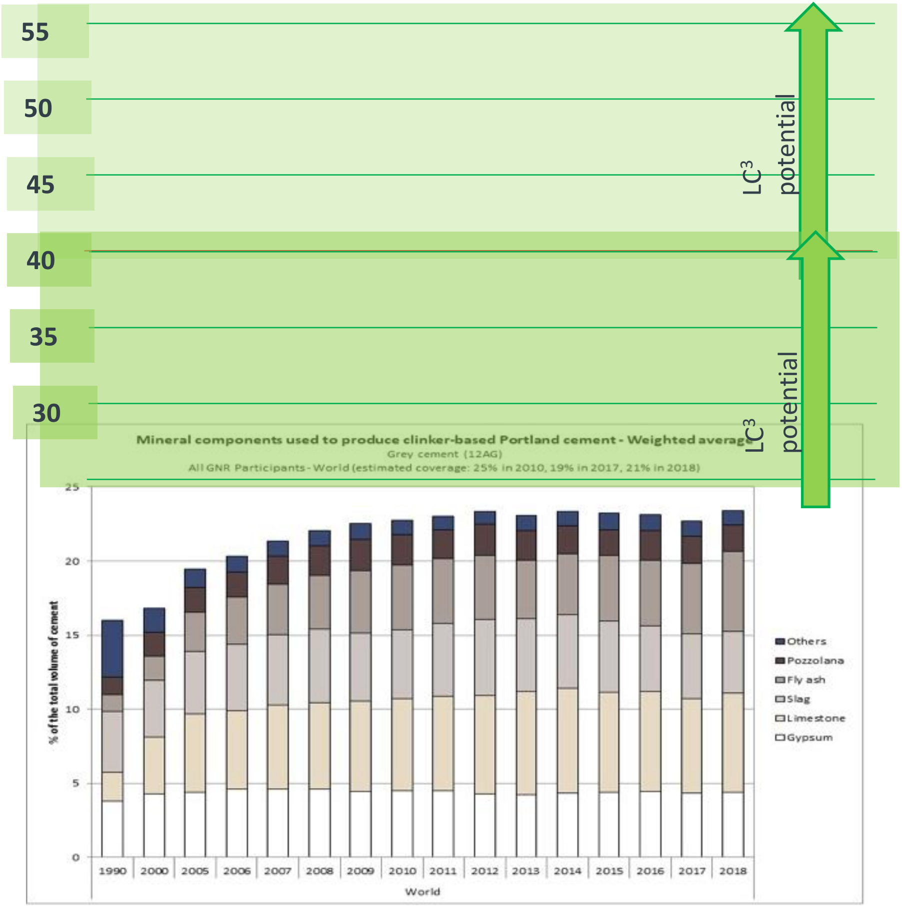
Chloride ponding ASTM





Apparent diffusion coeffs.

Calcined Clay only SCM which can expand substitution



> 800 million Tonnes CO_2/yr

> 400 million Tonnes CO_2/yr

Financial Feasibility

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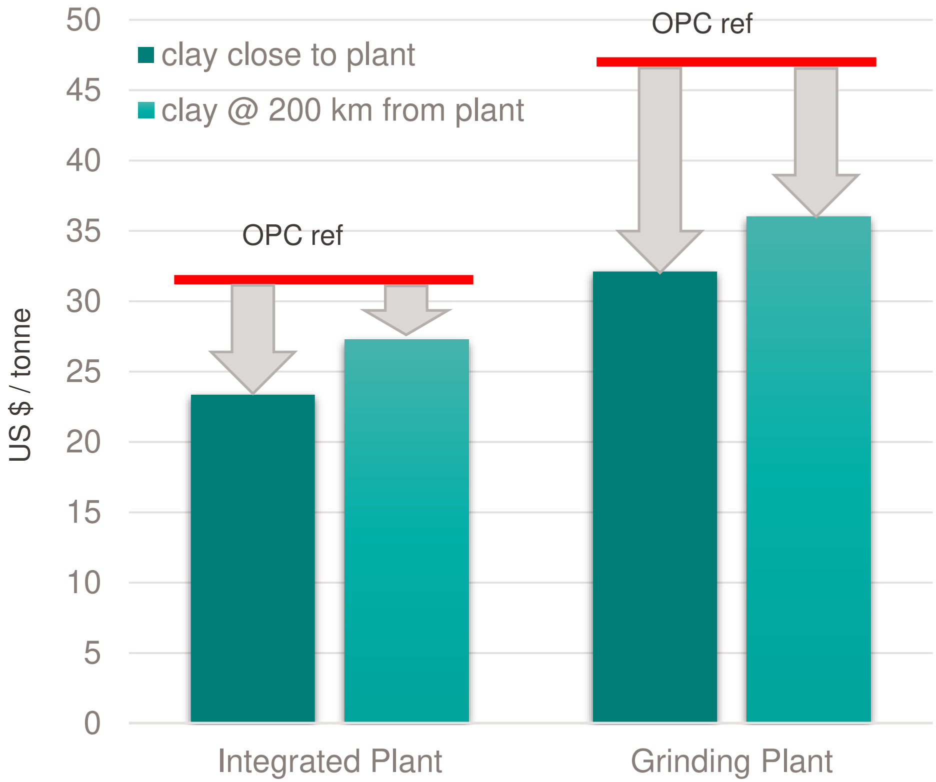
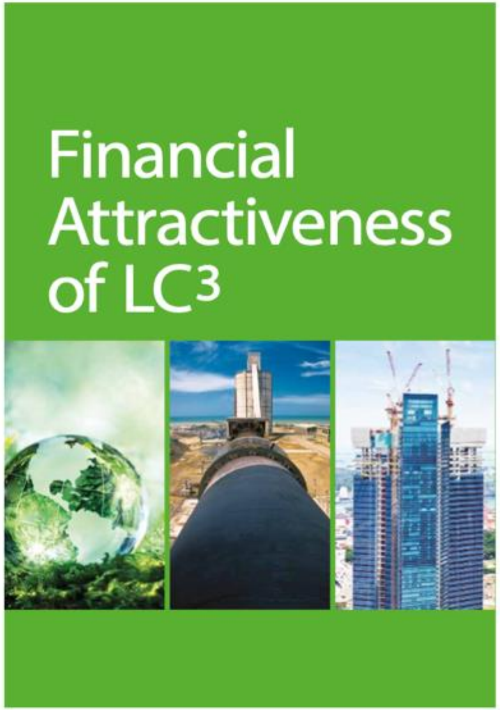
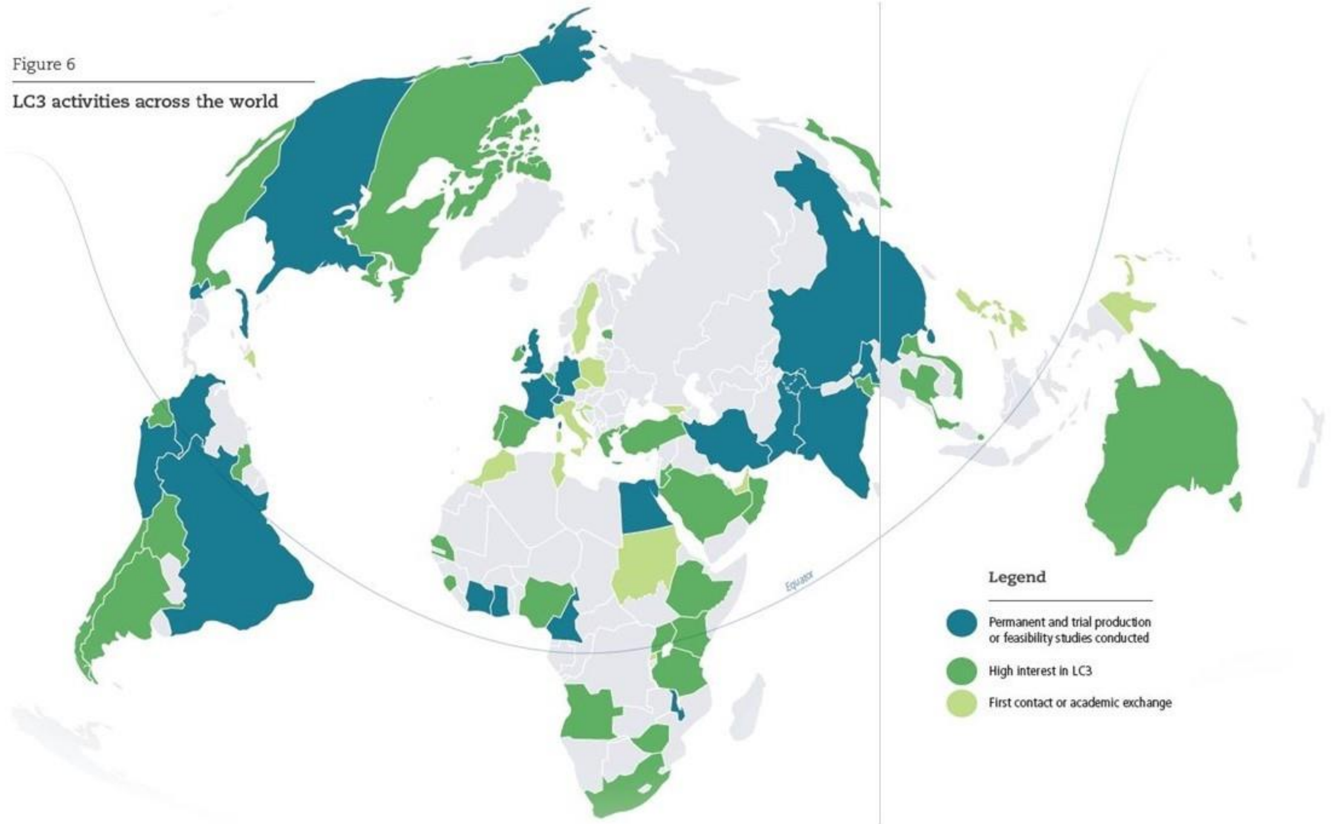
Lower cost: Cementis study

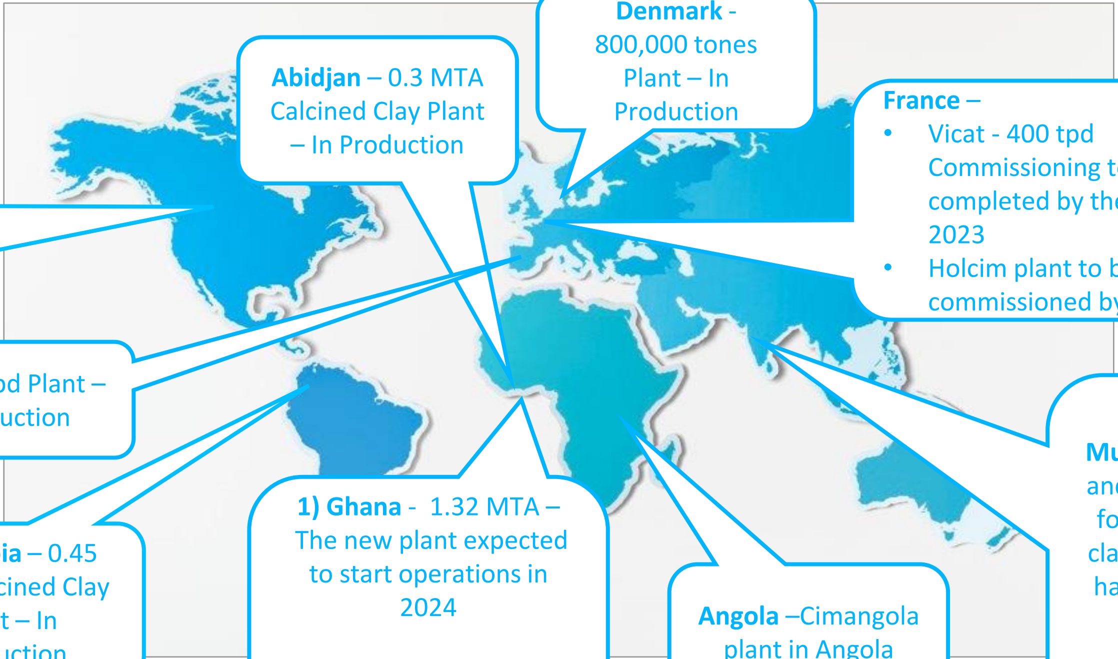




Report available:
https://lc3.ch/wp-content/uploads/2020/10/2019-LC3FinancialAttractiveness-WEB.pdf

LC3 activities across the world





Nebraska USA – Calcined Clay Plant – In Production Ash Grove

Abidjan – 0.3 MTA Calcined Clay Plant – In Production

Denmark - 800,000 tones Plant – In Production

France –
- Vicat - 400 tpd Commissioning to be completed by the end of 2023
- Holcim plant to be commissioned by 2024

Spain - 4tpd Plant – In Production

Colombia – 0.45 MTA Calcined Clay Plant – In Production

1) Ghana - 1.32 MTA – The new plant expected to start operations in 2024

2) Ghana – 1.5 MTA - The plant is scheduled to be commissioned in the 1st Q23.

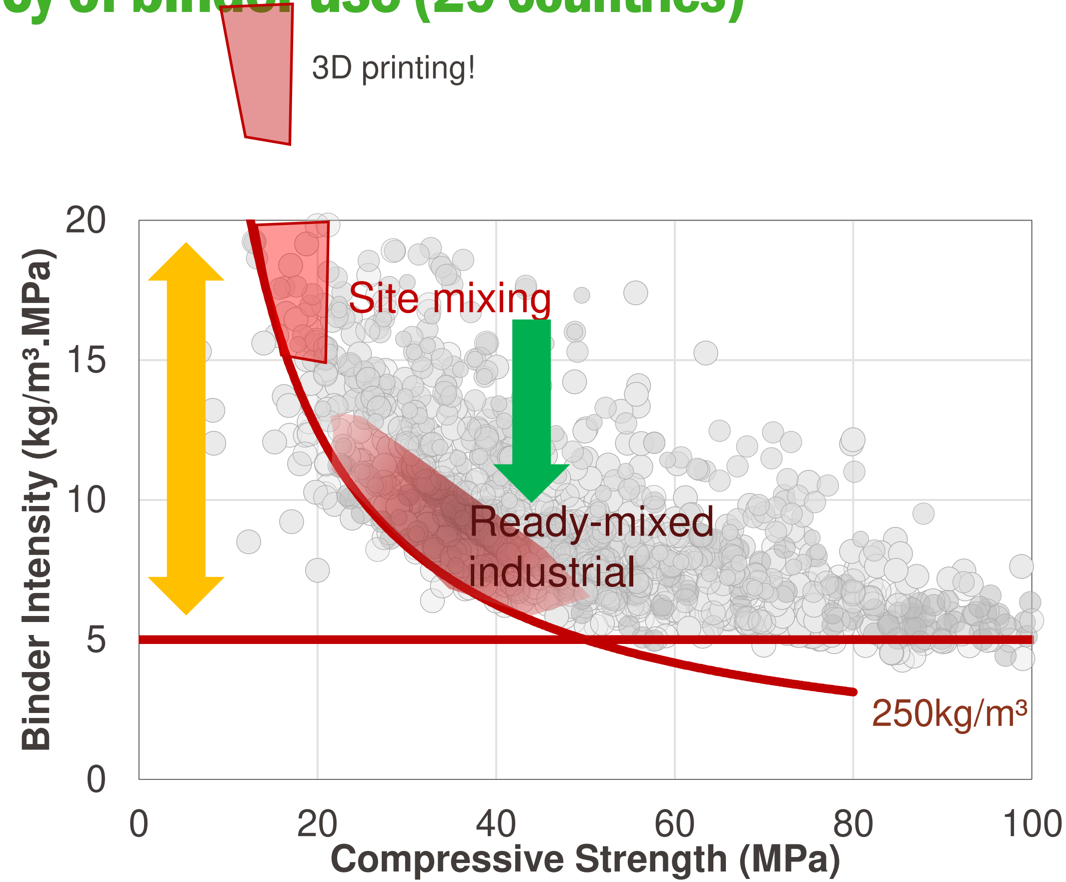
Angola –Cimangola plant in Angola – In Production

Mumbai - In India ACC and Ambuja are at the forefront of calcined clay development and have begun a project with the Indian Institute of Technology Delhi to develop calcined clays.

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

Few producers Quick wins implemented	Few producers Large remaining potential	Many producers Implementation very difficult	Chain of deciders Implementation very difficult	Big changes in mindset needed
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		

Efficiency of binder use (29 countries)



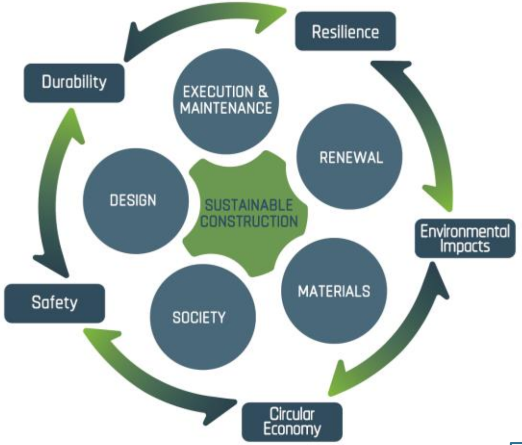
DAMINELI, et al. Measuring the eco-efficiency of cement use. **Cement and Concrete Composites**, 32, p. 555-562, 2010

Recommending a new paradigm for the built environment

Global consensus on sustainability in the built environment

GLOBE

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



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Concluding remarks

- Substantial reductions in CO2 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 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

Karen Scrivener

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