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Cement, Concrete, Innovation LC^3

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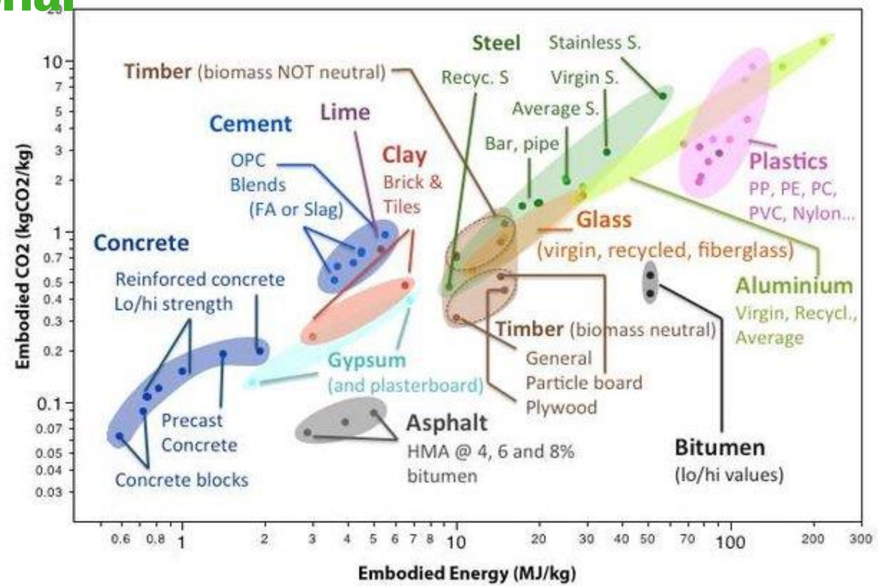
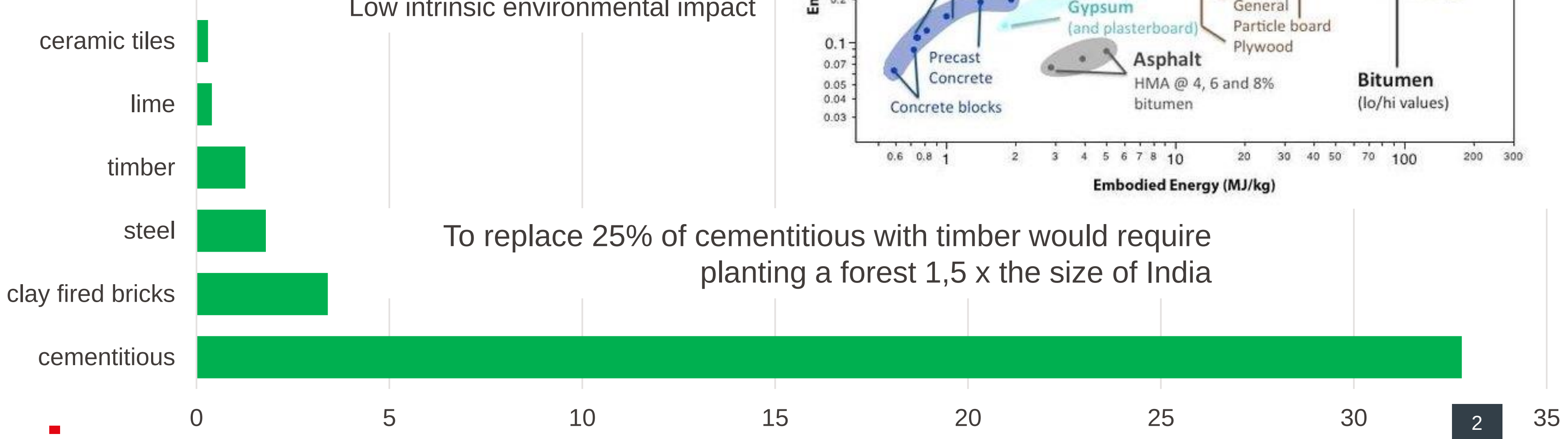
Cement IS NOT a carbon intensive material

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

low environmental impact
low cost
=
hard to innovate

Some innovations which stand out from last 40 years

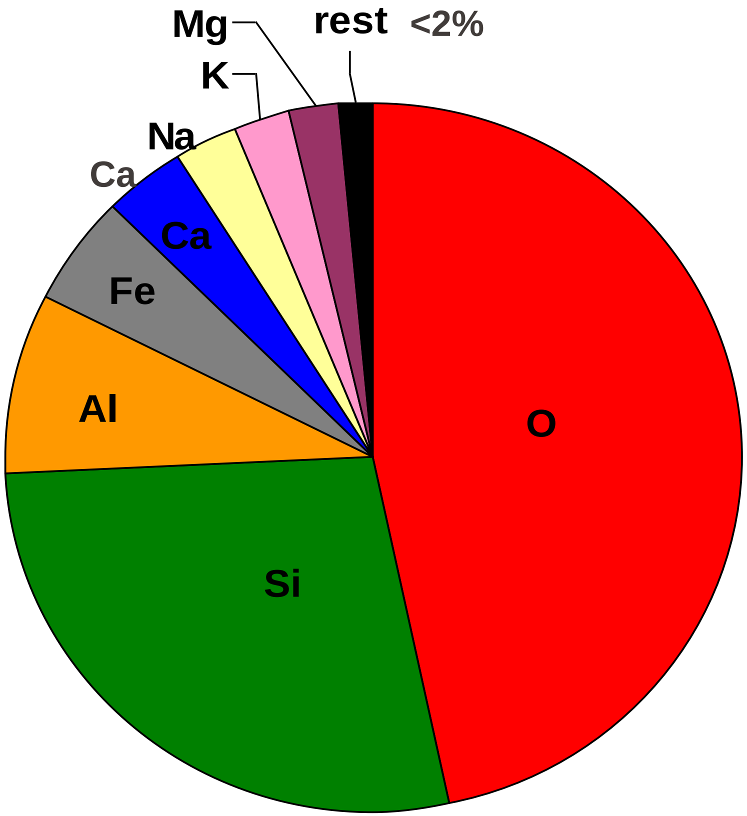
- High strength concrete
- Self placing concrete
- Super plasticizers

- Self cleaning concrete?
- Self healing concrete?

- 90% of concrete is still “Plain Vanilla”

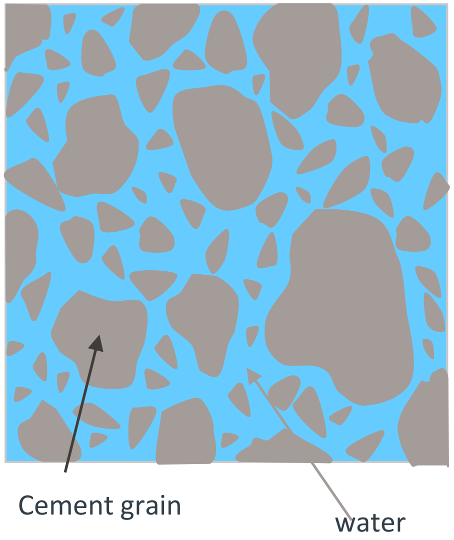
Why do we use “Portland” cement?

What is available on earth?



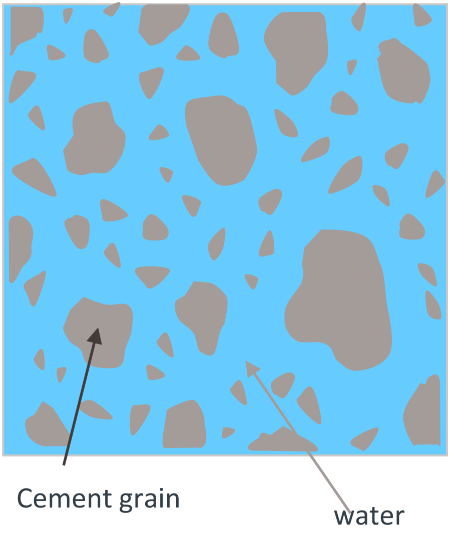
8 elements make up more than **98%** of the earth's crust

How does cement work?

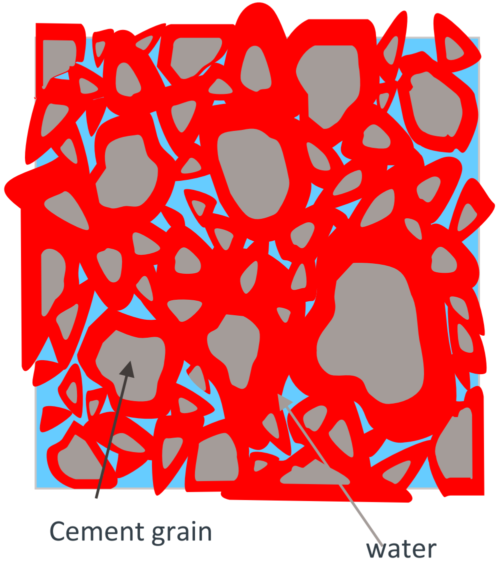


We mix the grey cement powder with water.

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



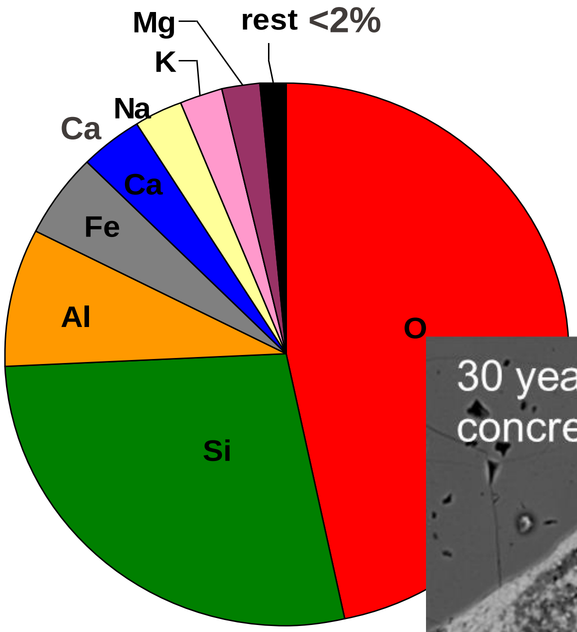
The cement grains
dissolve in the water



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

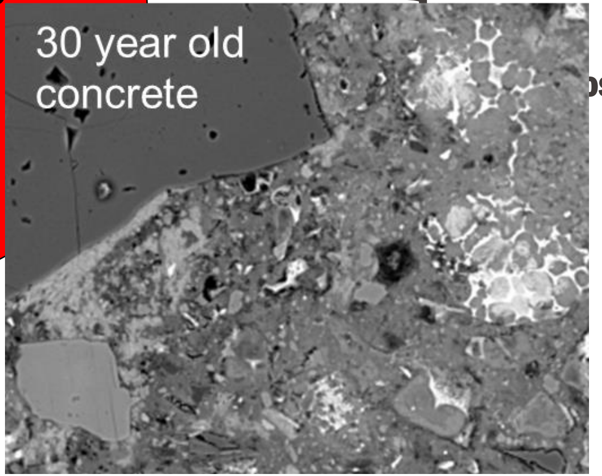
What is available on earth?

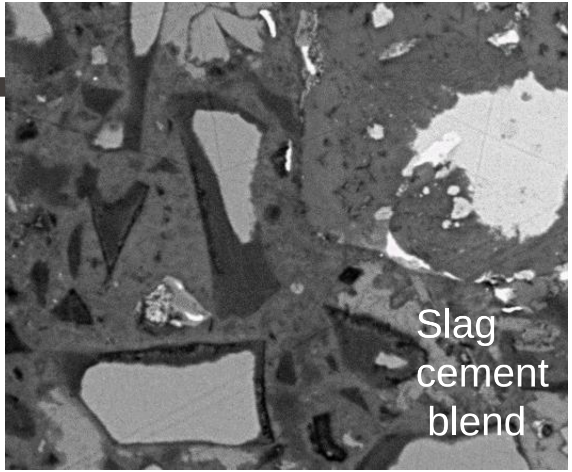


Na_2O
K_2O
Too soluble

Fe_2O_3
MgO
Too insoluble in alkaline solutions

ost usefu





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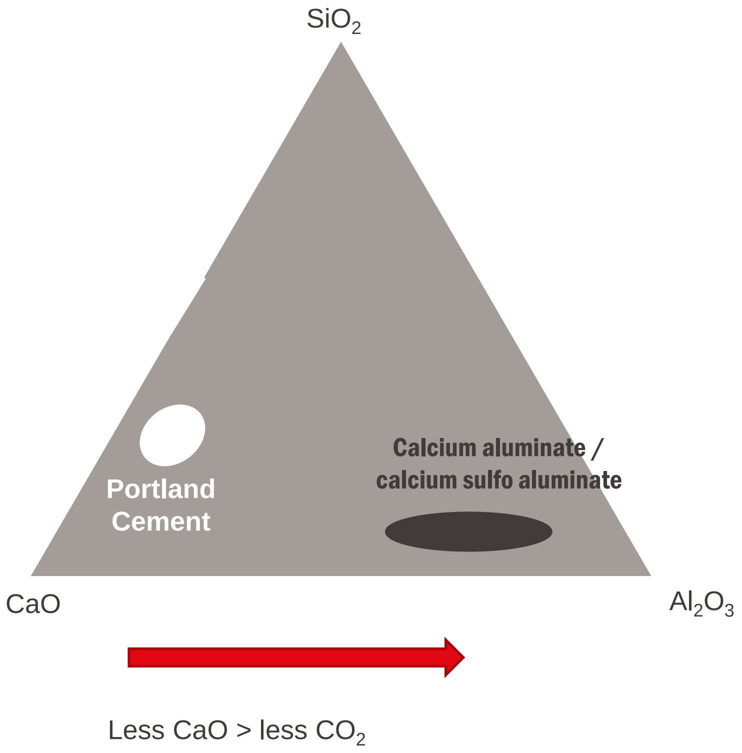
Hydraulic minerals in system $CaO-SiO_2-Al_2O_3$



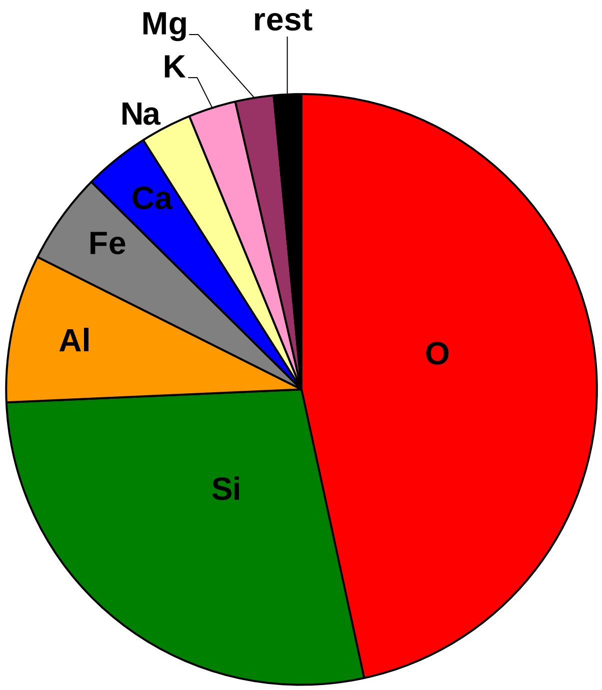
BUT, what sources of minerals are there which contain $Al_2O_3 >> SiO_2$?

Bauxite – localised, 90% or reserves in 10 countries under increasing demand for Aluminium production, EXPENSIVE

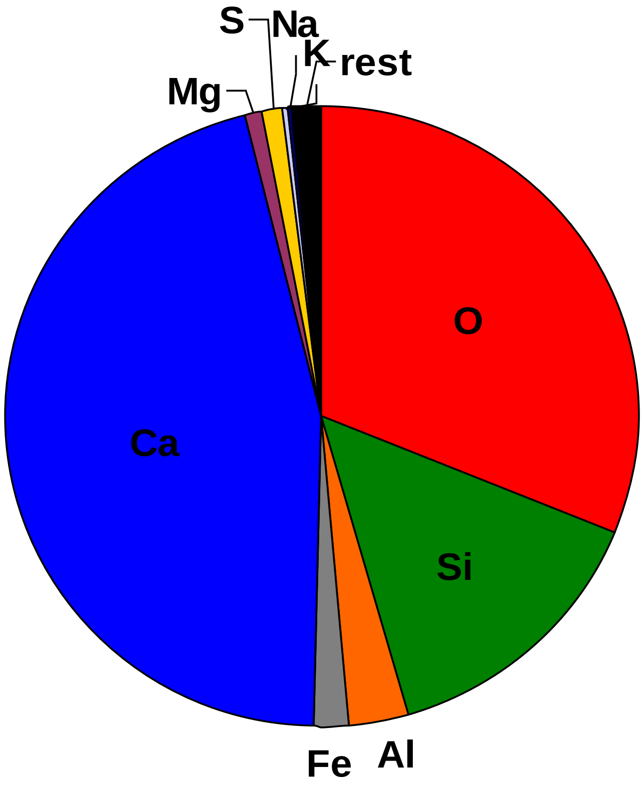
Even if all current bauxite production diverted would still only replace 10-15% of current demand.

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

Composition of earth's crust



Composition of ciment

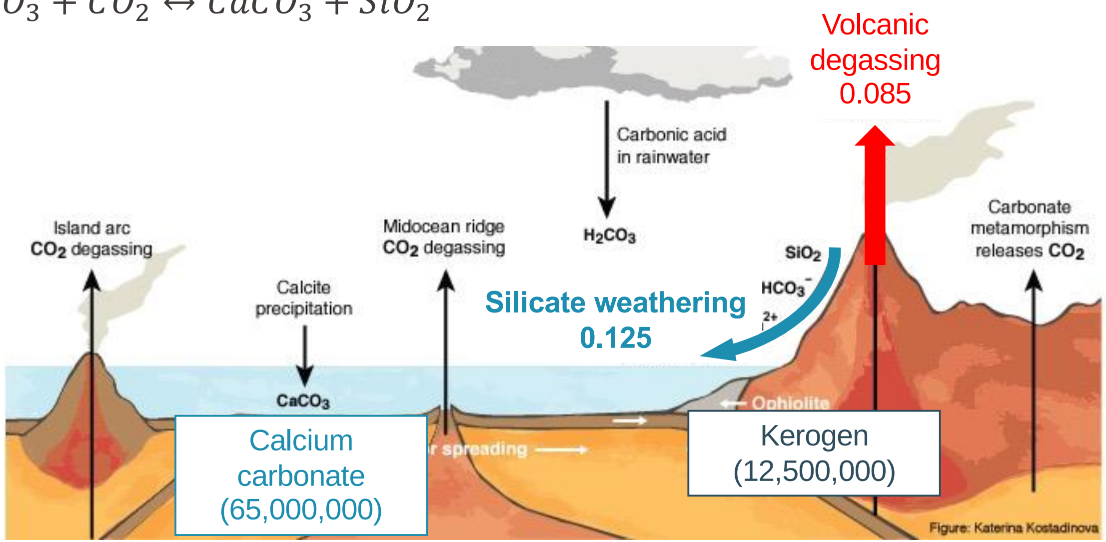


80% limestone

20% clay

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

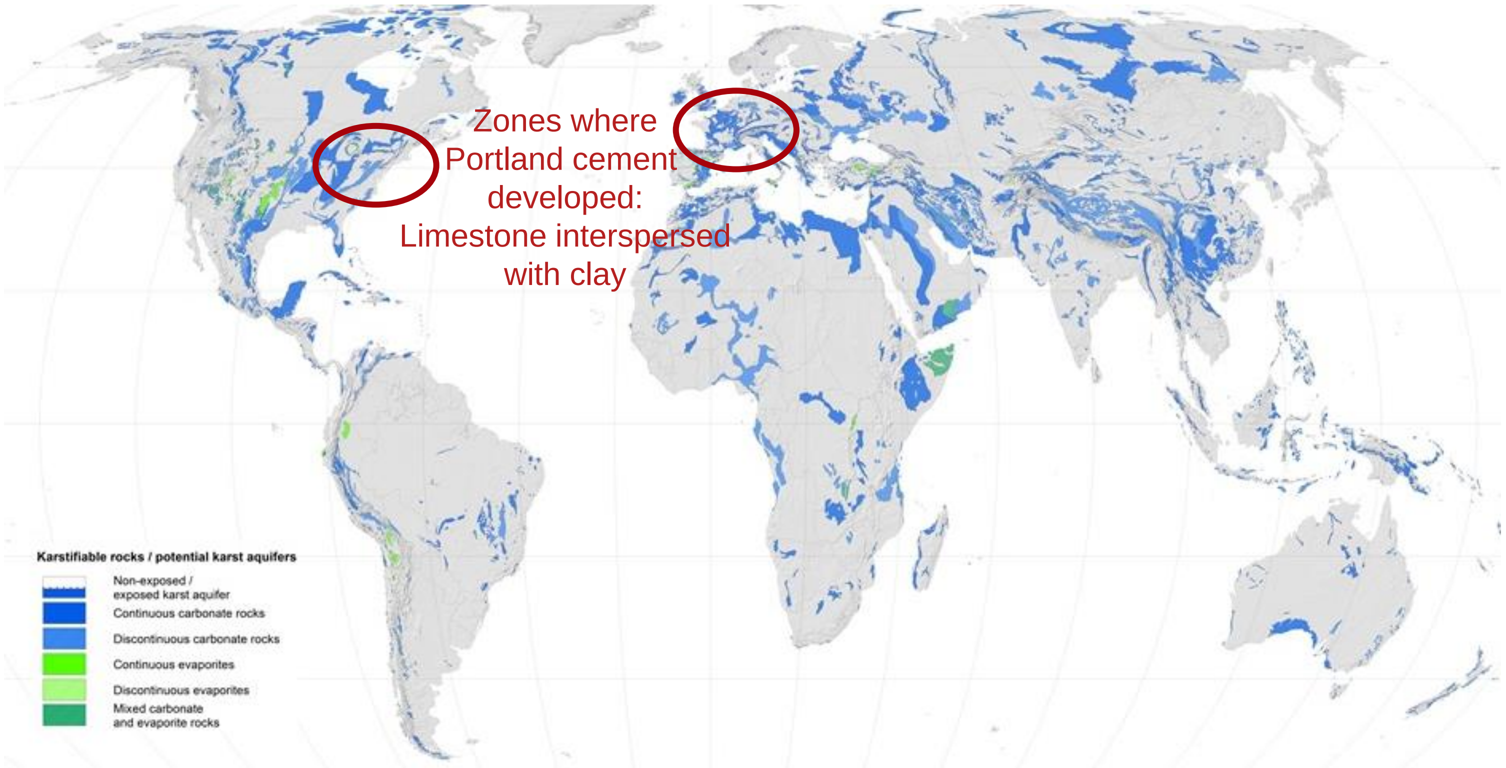
The advantages of limestone

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

BUT

- High emissions of CO_2, 60% of embodied cement emissions
  - $CaCO_3 \leftrightarrow CaO + CO_3$

Distribution of limestone



Limestone is sparse in many developing regions

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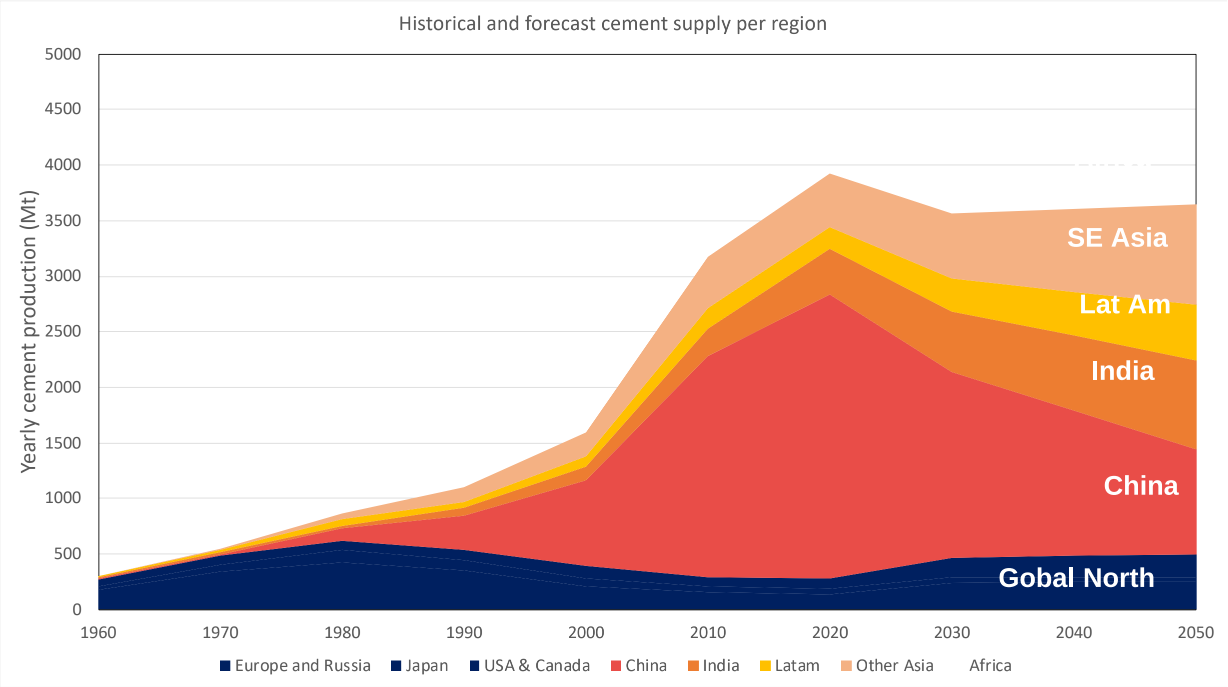
Changing pattern of cement use



We need solutions for people in developing countries

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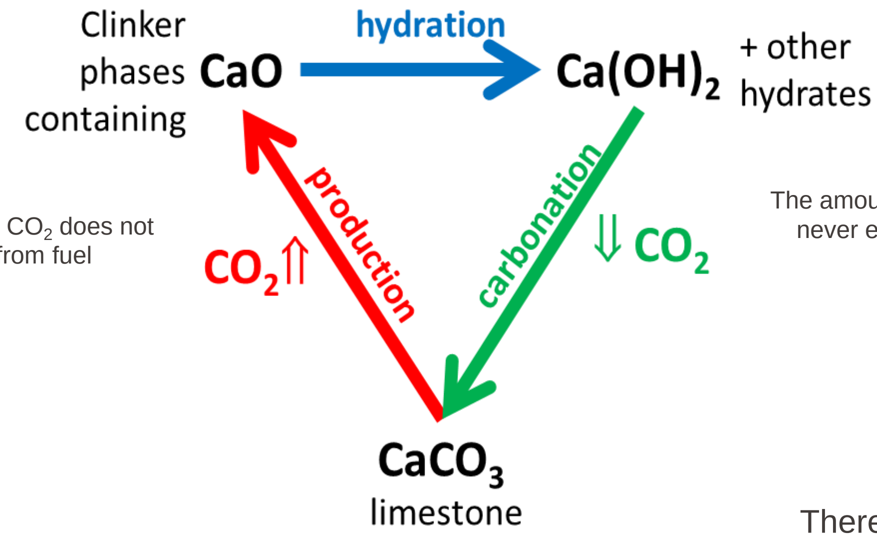
What does not make sense

- 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 little prospect to lower atmospheric CO_2

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**
  - Total global generation rate of carbonatable materials is estimated to be **3.9 Gt / year**
  - material with the highest generation rate is end-of-life cement paste (CDW) **1.39 Gt / year**
  - Coal fly ash (0.68 Gt $year^{-1}$) and
  - blast furnace slag (0.38 Gt $year^{-1}$)
  - carbonation of all the materials considered could directly absorb 0.63 Gt CO_2 about 20% of cement emissions
  - Gross Upper limit, since it requires:
    i. 100% recovery of end-of-life concrete and mortar,
    carbonation of
    i. Hazardous or
    ii. already used materials (e.g. blast furnace slag and coal fly ash as clinker substitutes),

- *Driver et al. submitted

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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
  the high dilution of Calcium in sea water would require
  processing colossal volumes of water (expense)
  compare to desalination plants

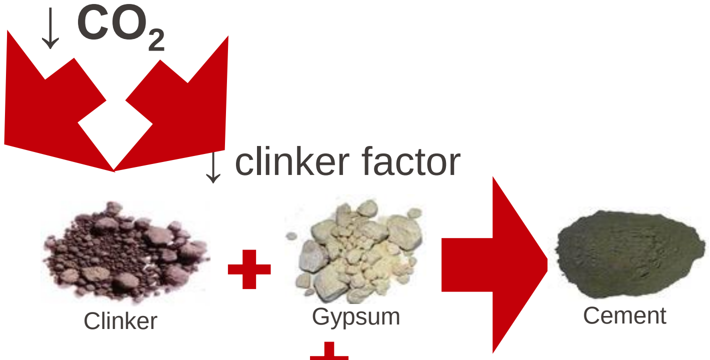
- Any *uncarbonated* sources of calcium can already be simply exploited to produce conventional clinker.

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

Process optimisation



↓ clinker factor

SCMs – Supplementary Cementitious Materials


Limestone

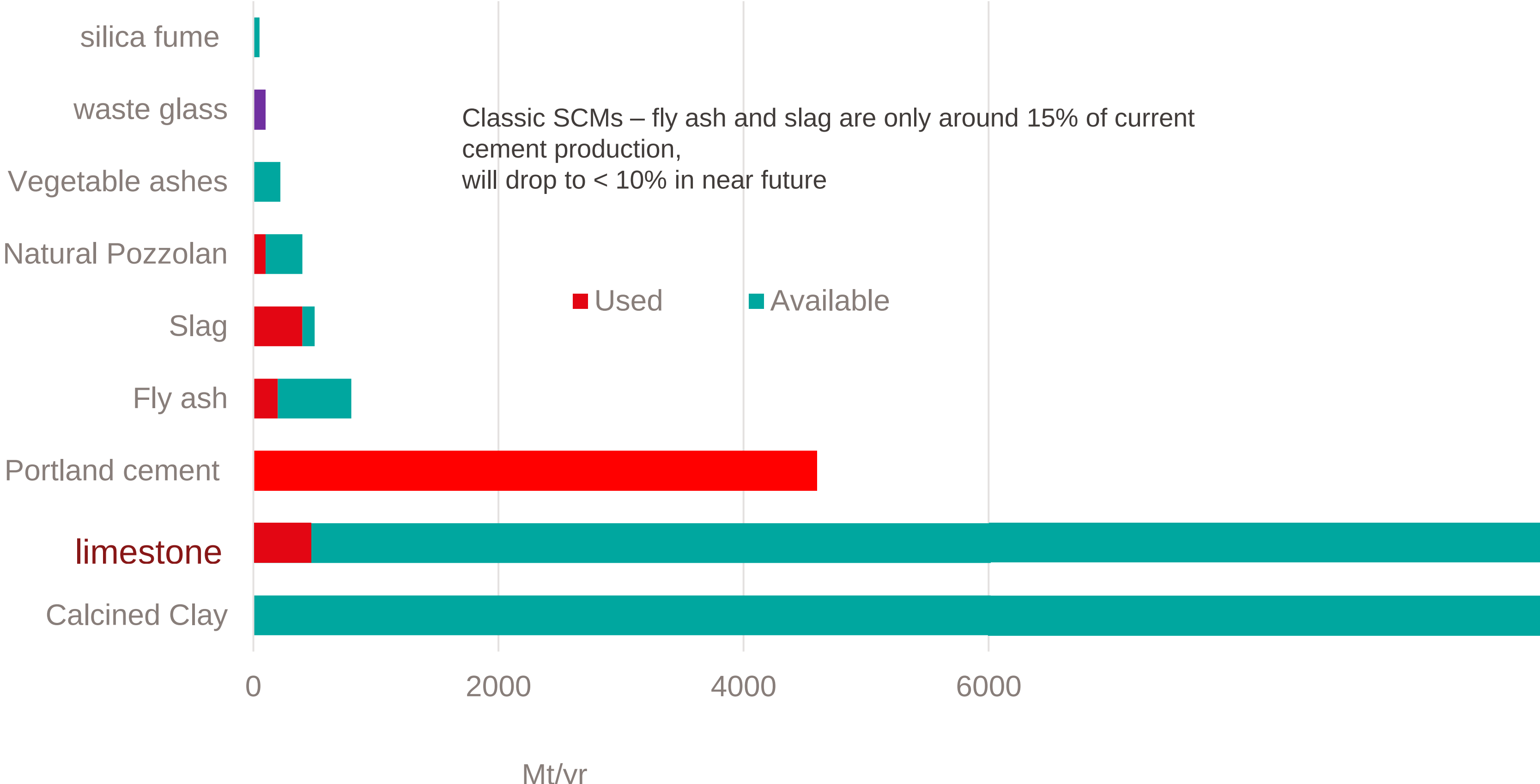

Fly ash


Slag


Calcined clays

Often by-products or wastes from other industries

Availability of SCMs



Classic SCMs – fly ash and slag are only around 15% of current cement production,
will drop to < 10% in near future

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There is no magic solution

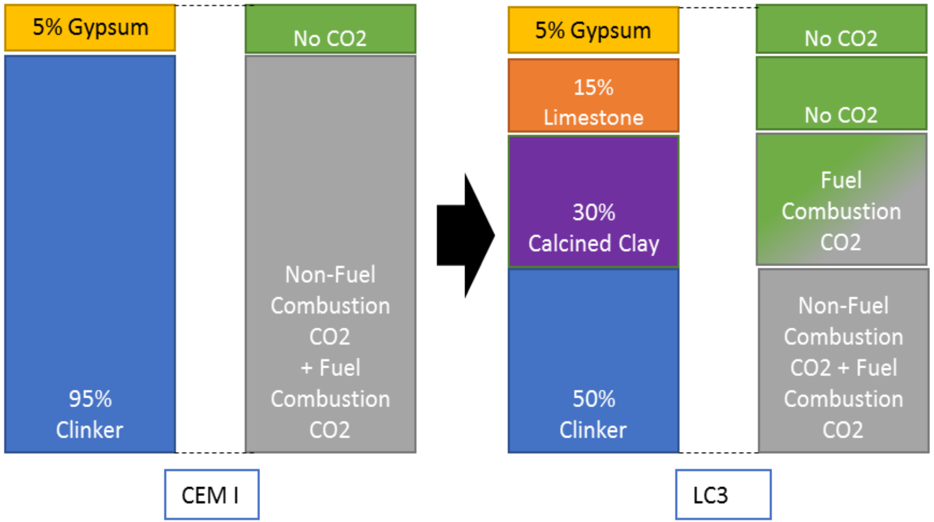
- **Blended with SCMs will be best solution for sustainable cements for foreseeable future**
- **Only material really potentially available in viable quantities is calcined clay.**
- **Synergetic reaction of calcined clay and limestone allows high levels of substitution:**
  EPFL led LC³ project supported by SDC. Started 2013

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

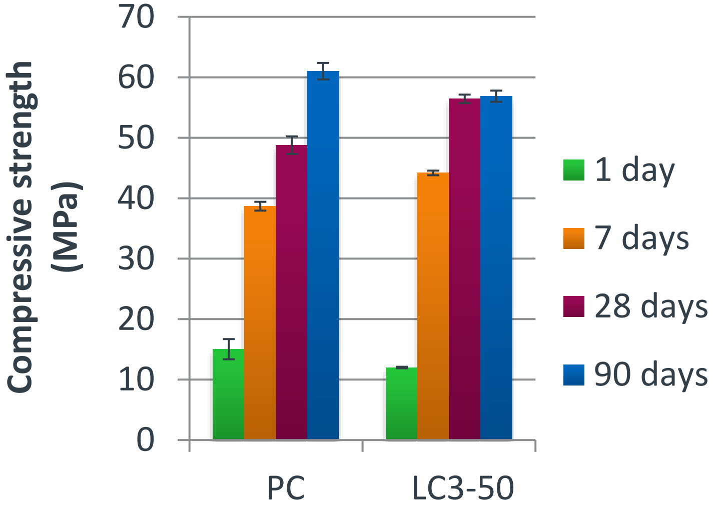
Swiss Agency for Development and Cooperation SDC

Limestone
Calcined
Clay
Cement
LC3

What is LC³



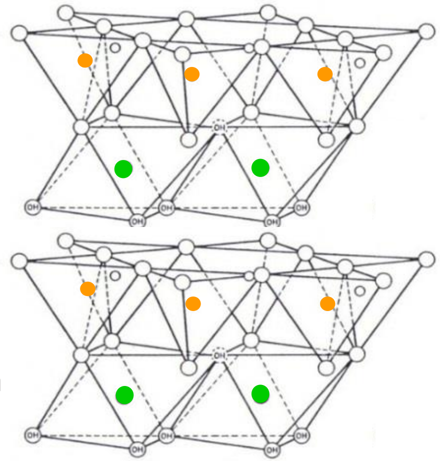
LC³ is a family of cements,
the figure refers to
the **clinker** content

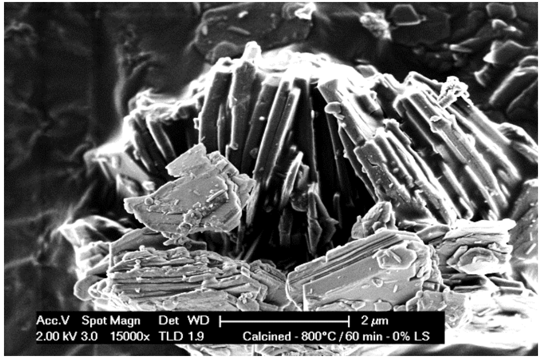


- 50% less clinker
- 40% less CO_2
- Similar strength
- Better chloride resistance
- Resistant to alkali silica reaction

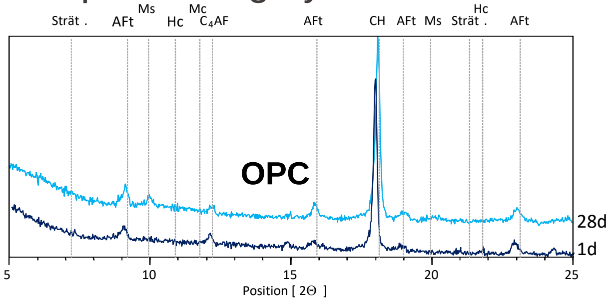
Why can we get such high replacement levels?

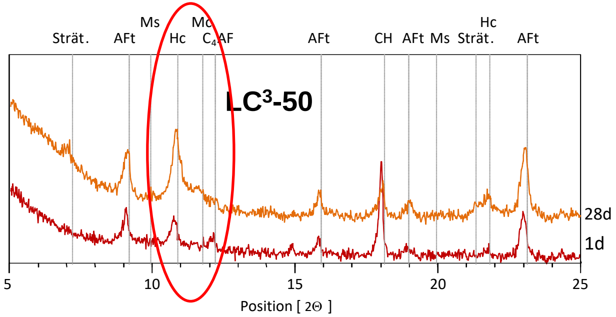
- Calcination of kaolinite at **700-850°C** gives metakaolin: much more reactive than glassy SCMs



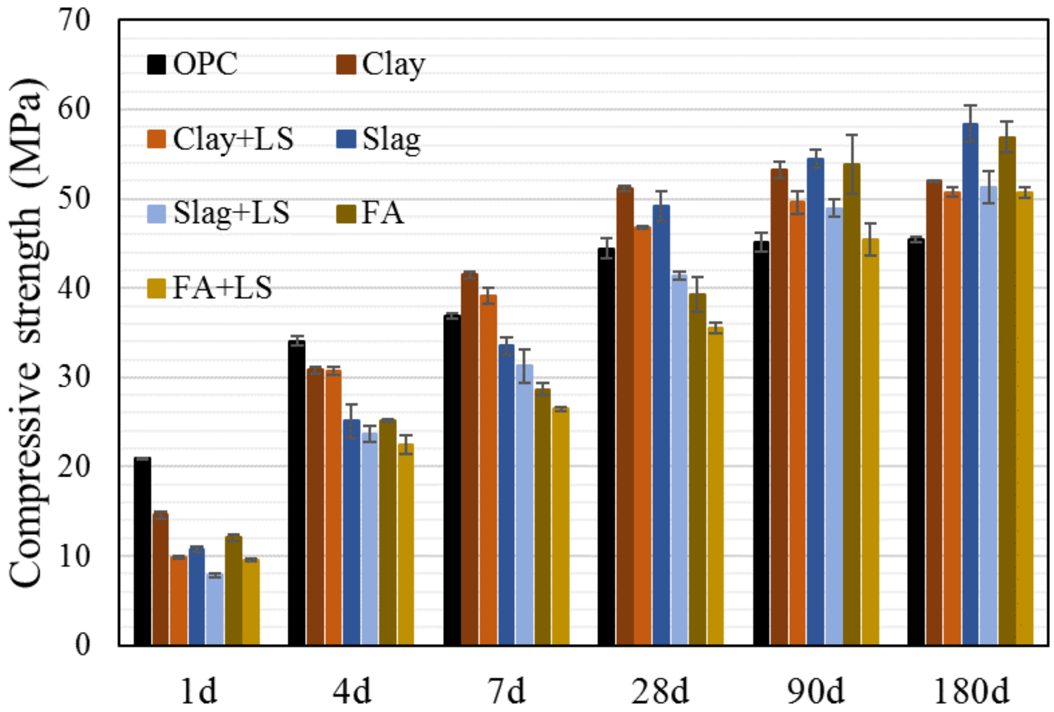


» **Synergetic reaction** of Alumina in metakaolin with limestone to give space filling hydrates



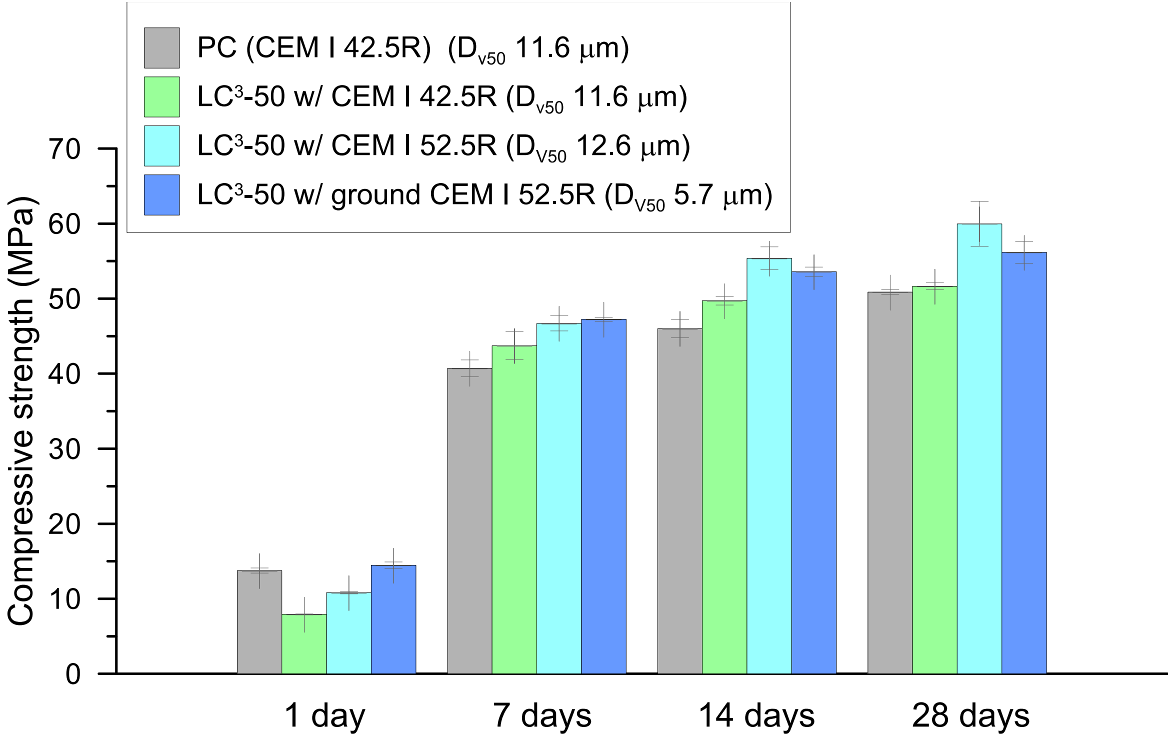


Comparison of calcined kaolinitic clay, slag and fly ash



Binary systems 70% clinker, 30% SCM
Ternary systems, with limestone 50% clinker, 30% SCM, 15% limestone

Possible to get early strength by grinding clinker finer



Comparison with natural pozzolans, example Chile

Roadmap ICH/FICEM 2019

- Pozzolanic cements have been in widespread use since the 1960s
- Standardization built around the cements available in the local market

High strength (80% CK)

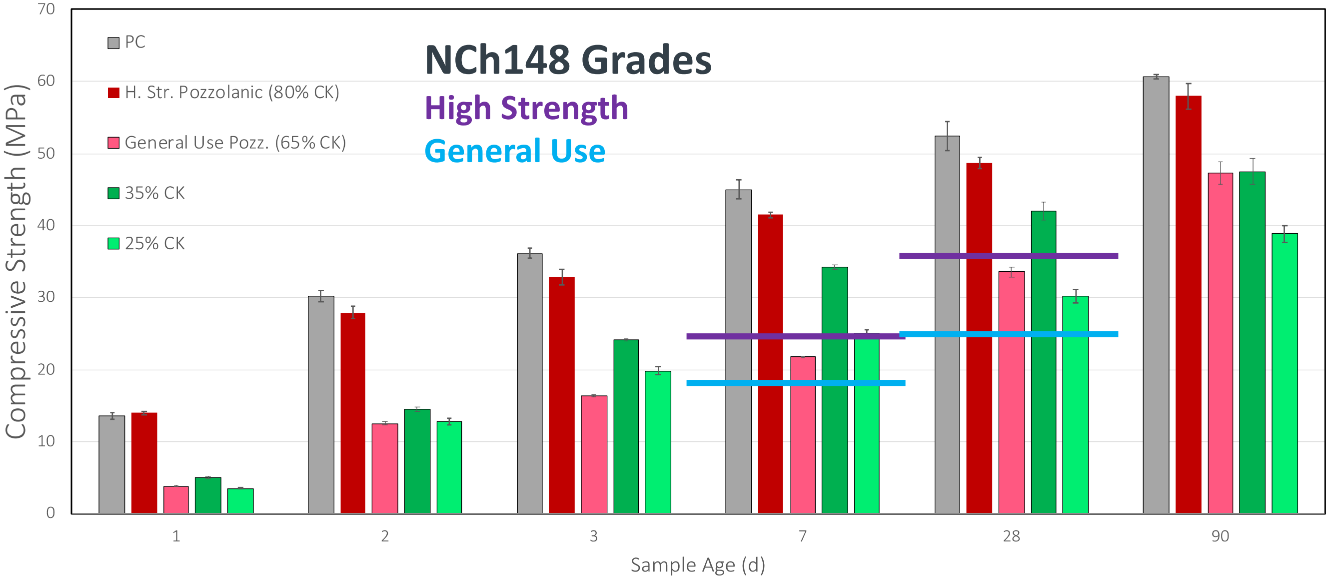
General use (65% CK)

LC³-35 (35% CK)

LC³-25 (25% CK)

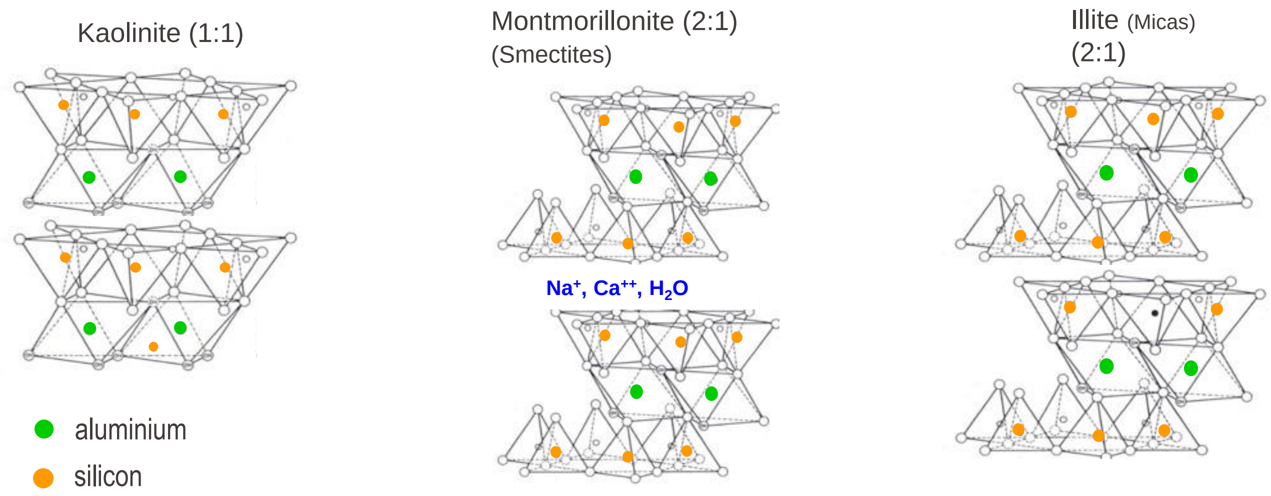
Clinker savings

40-45%



The reactivity of SCMs matters!

Three basic clay structures



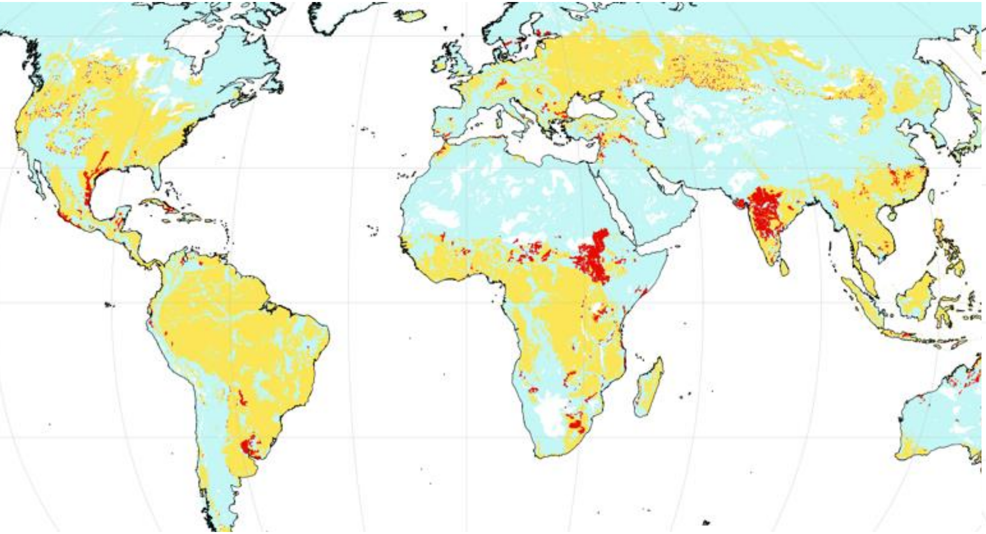
“Metakaolin”, sold as high purity product for paper, ceramic, refractory industries
Requirements for purity, colour, etc, mean expensive 3-4x price cement

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

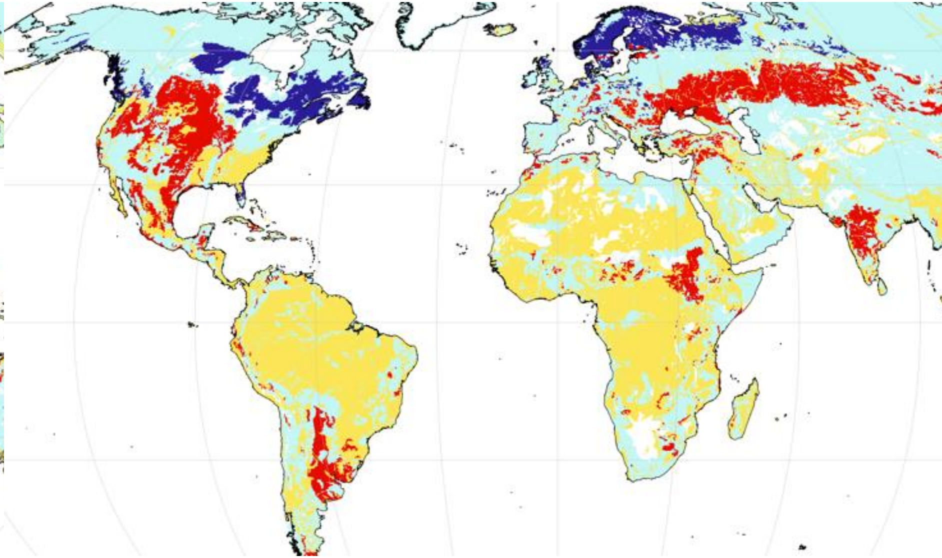
Distribution of Kaolinitic clays

Ito and Wagai, Scientific data 2017

0-5m



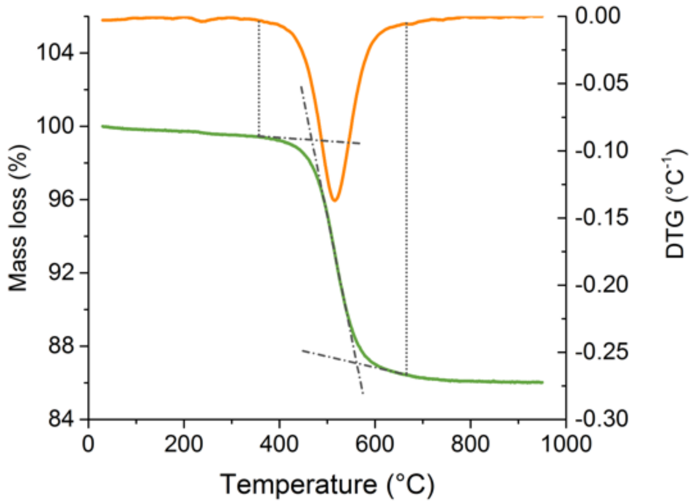
>5m

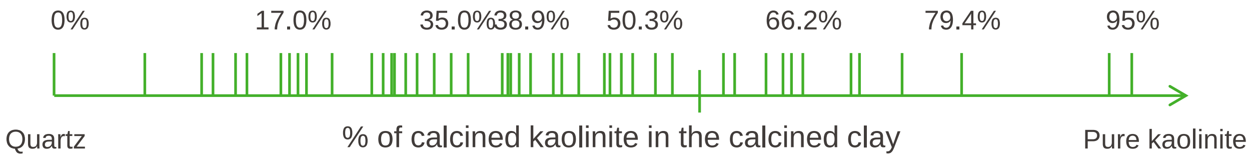


Ilite/mica | Kaolinite | Smectite | Vermiculite

Over 100 clays studied from around the world

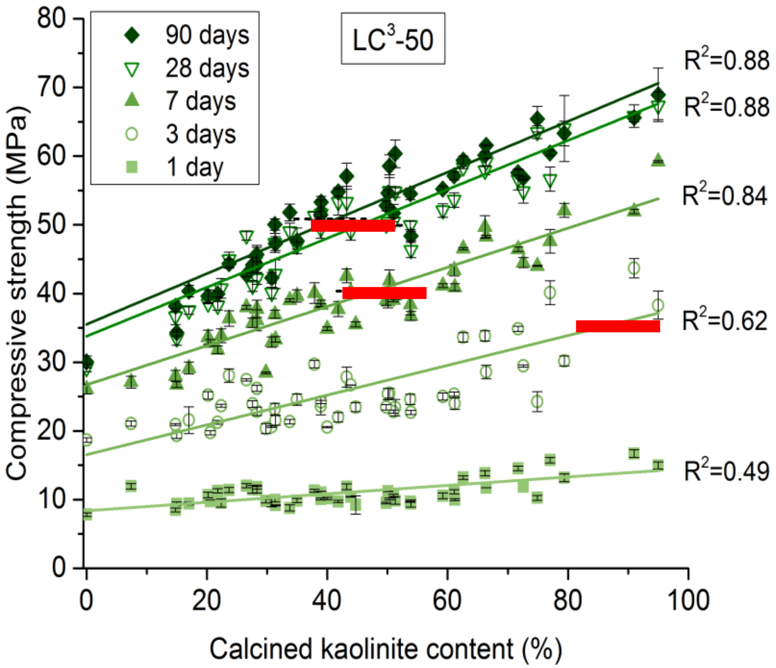
Different calcination conditions
Different compositions, impurities
Different physical properties





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

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

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Demonstration structure, India

Around 14 tonnes of CO_2 saved
Compared to existing solutions

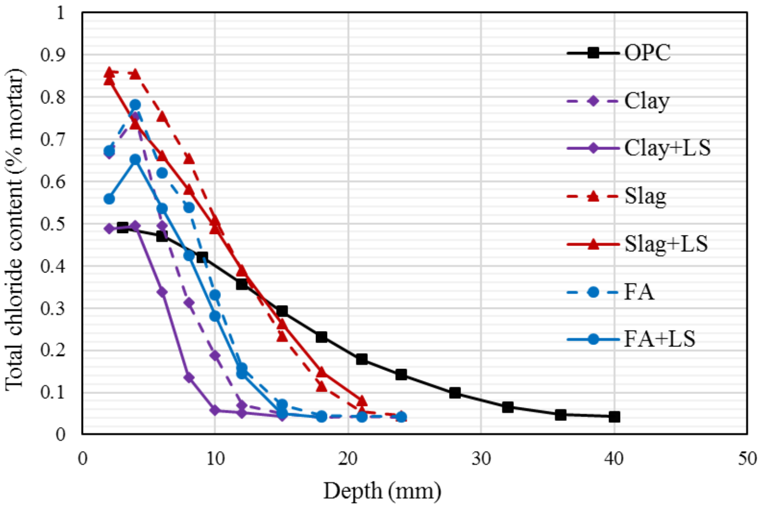
New Calcination plant Ivory Coast

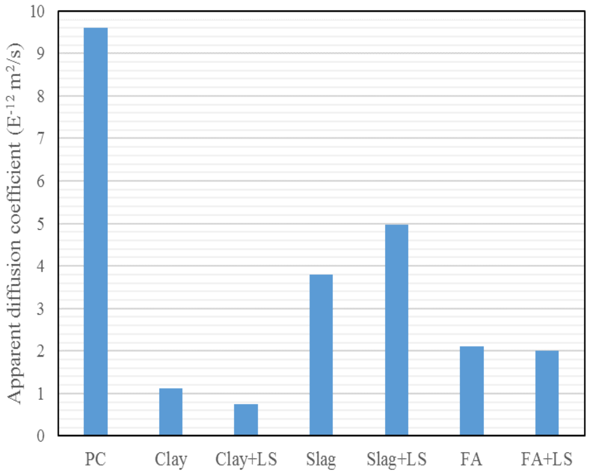
Colour control at Ivory Coast plant

Key Advantages

- Chloride resistance
- Suppression of alkali silica reaction

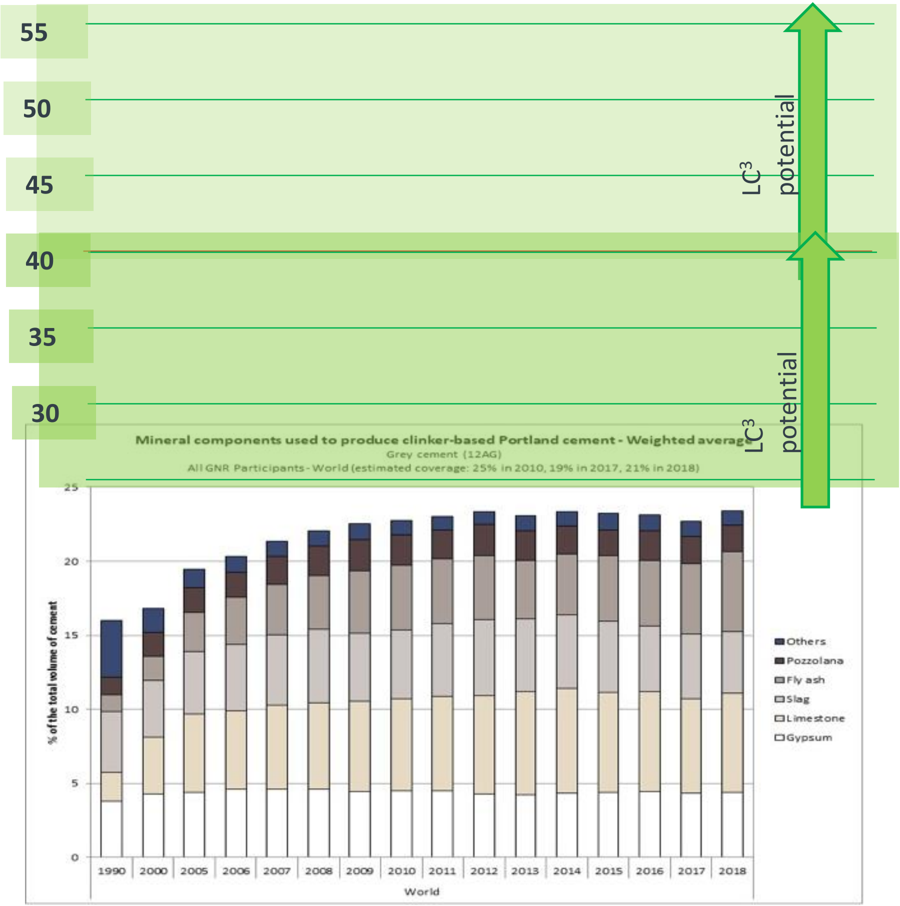
Chloride ponding ASTM





Apparent diffusion coeffs.

Calcined Clay only SCM which can expand substitution

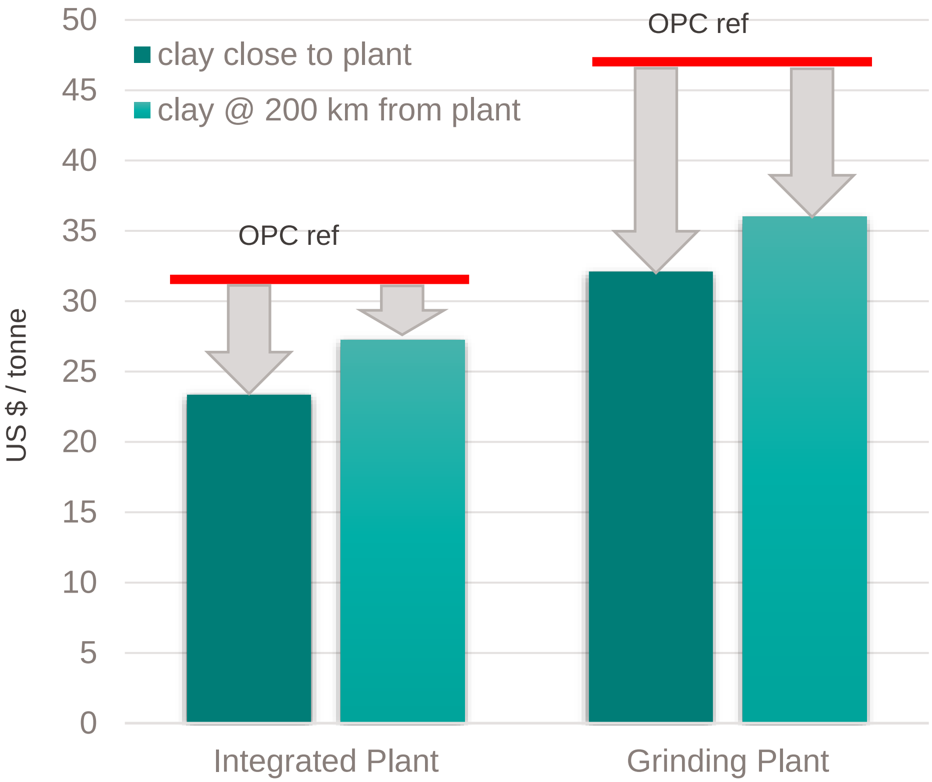


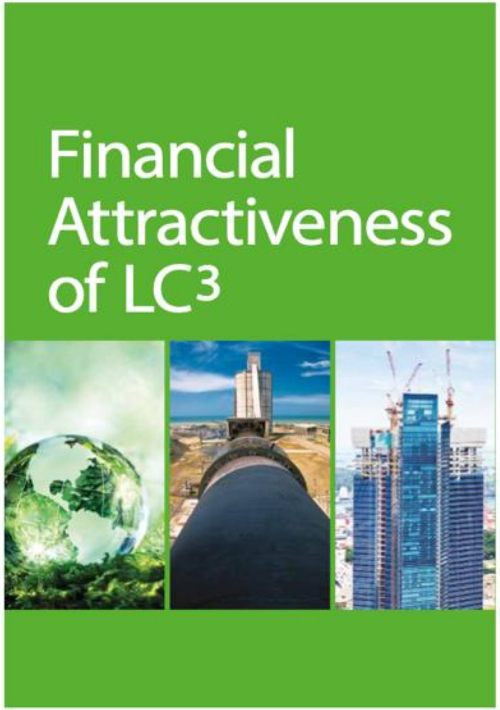
> 800 million Tonnes CO_2/yr

> 400 million Tonnes CO_2/yr

Financial Feasibility

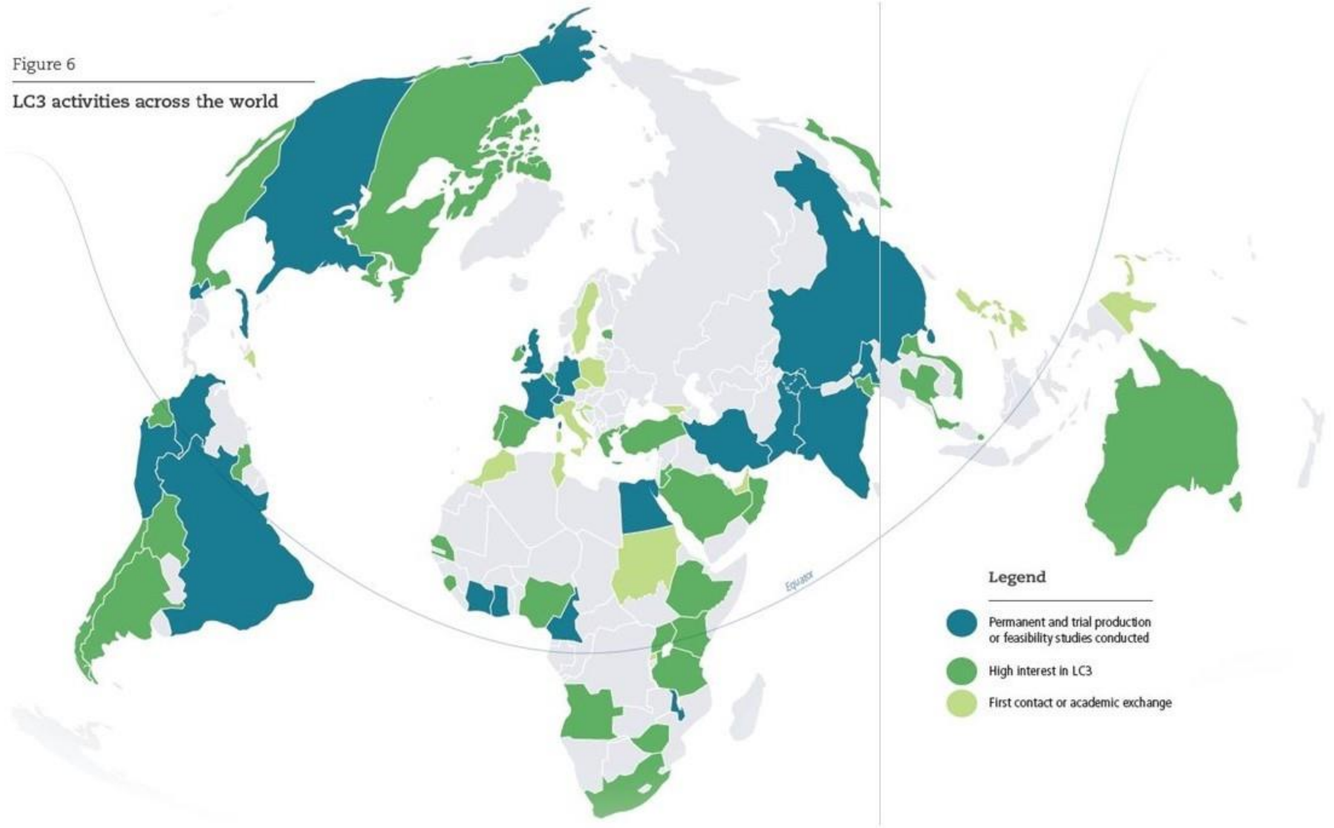
Lower cost: Cementis study





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

LC3 activities across the world



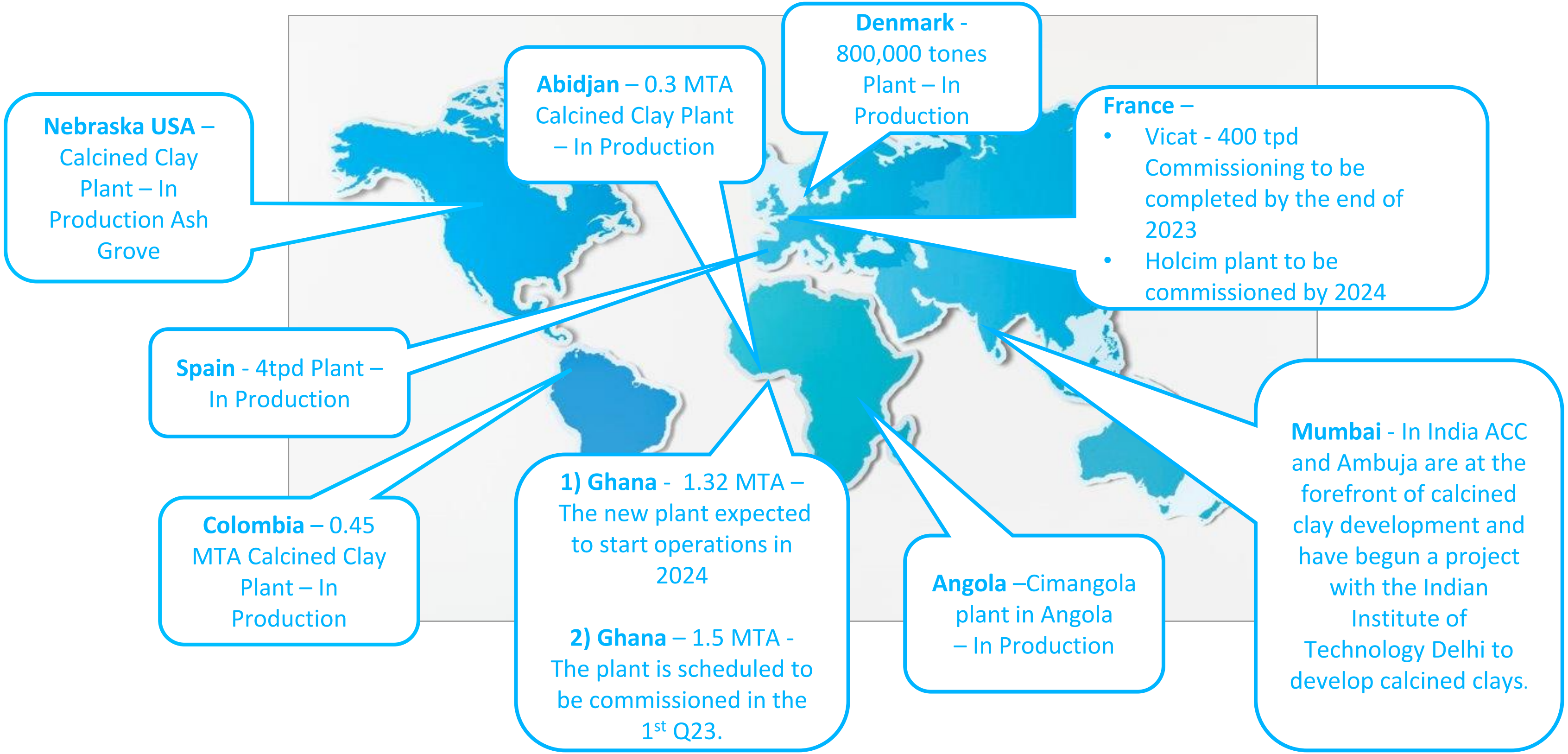
What are the blockages

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

Strategy

- >3000 cement plants in the world
- Majors only own about 30% of these, Outside China

- First strategy focus on Majors and establish academic credentials
  - 1st International Conference of Calcined Clays for Sustainable Concrete 2014



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.

Strategy

- >3000 cement plants in the world
- Majors only own about 30% of these, Outside China

- First strategy focus on Majors and establish academic credentials
- NOW
- Country specific “Information” days,
  bring together Producers. Policy Makers, Academics, **Users**
- Shift of focus from production to use

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Symbiosis International University – Lavale, Pune, India

Symbiosis School of Banking and Finance (SSBF) & Symbiosis School of Sports Sciences(SSSS) and New Hostel Block

Largest Institutional Building to Adopt LC3 in Construction

Use of LC3 cement can reduce 7% of the embodied nearly 100 tons CO_2eq of the overall building construction

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

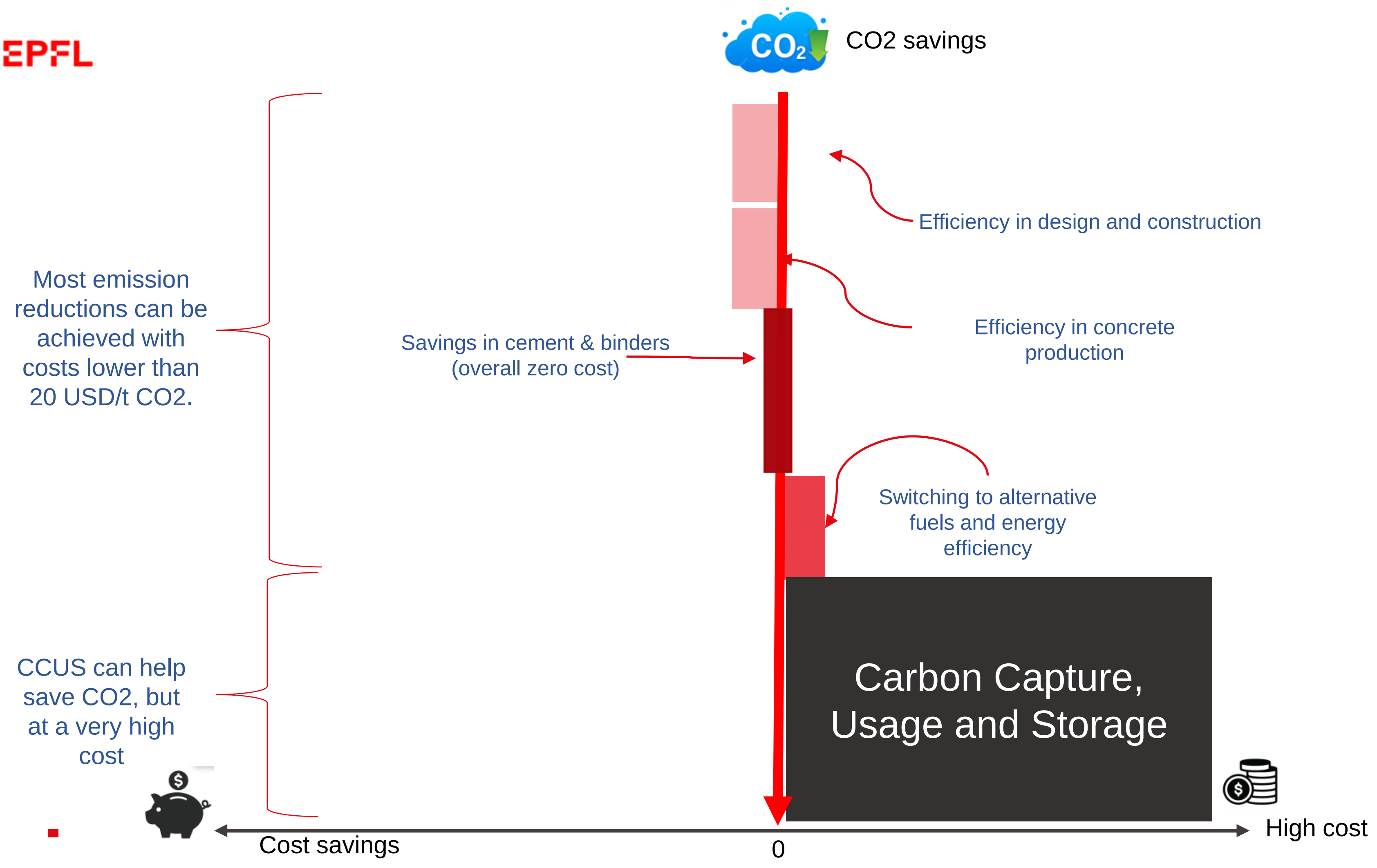
- Aggregate grading
- Good admixtures
- Use filler

Chain of deciders
Implementation very difficult

Reduce concrete in building

Big changes in mindset needed

More efficient (re)use of buildings


CO2 savings
Efficiency in design and construction
Efficiency in concrete production
Savings in cement & binders (overall zero cost)
Switching to alternative fuels and energy efficiency
Carbon Capture, Usage and Storage
Most emission reductions can be achieved with costs lower than 20 USD/t CO2.
CCUS can help save CO2, but at a very high cost
Cost savings
0
High cost

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Thank You

Karen Scrivener

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polytechnique
fédérale
de Lausanne