LC^3: A breakthrough technology to reduce CO_2 emissions from cementitious materials

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EPFL LMC

https://www.mcc-berlin.net/en/research/co2-budget.html

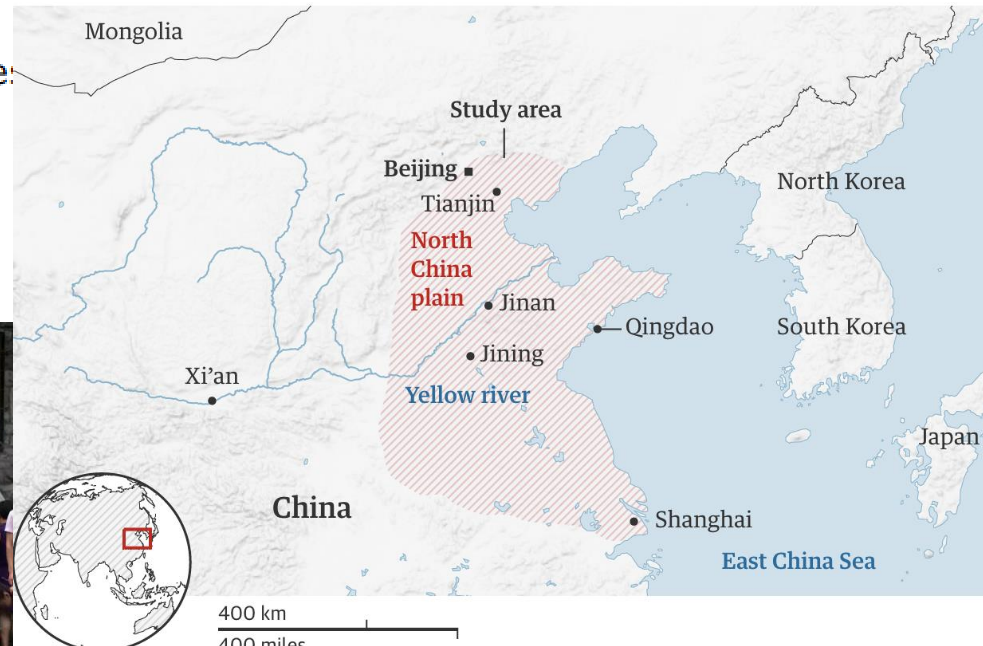
Drastic consequences!

nature COMMUNICATIONS

ARTICLE
DOI: 10.1038/s41467-018-05252-y OPEN

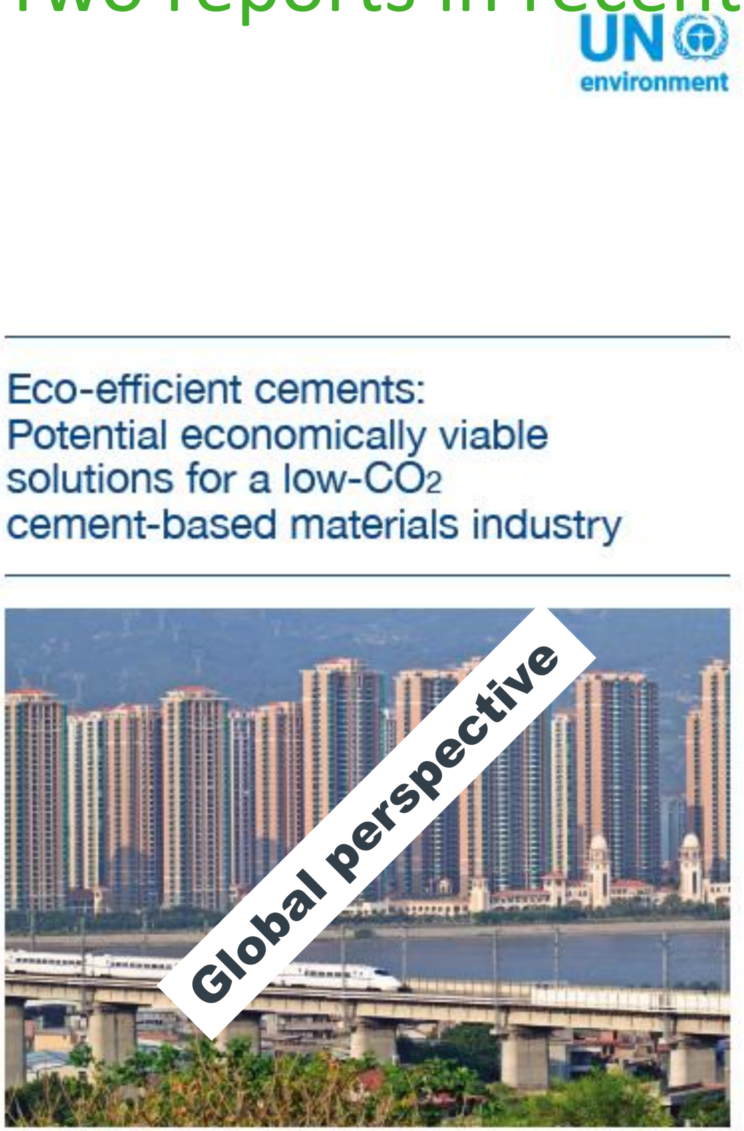
North China Plain threatened by deadly heatwaves due to climate change and irrigation

Suchul Kang[1] & Elfatih A.B. Eltahir[2]

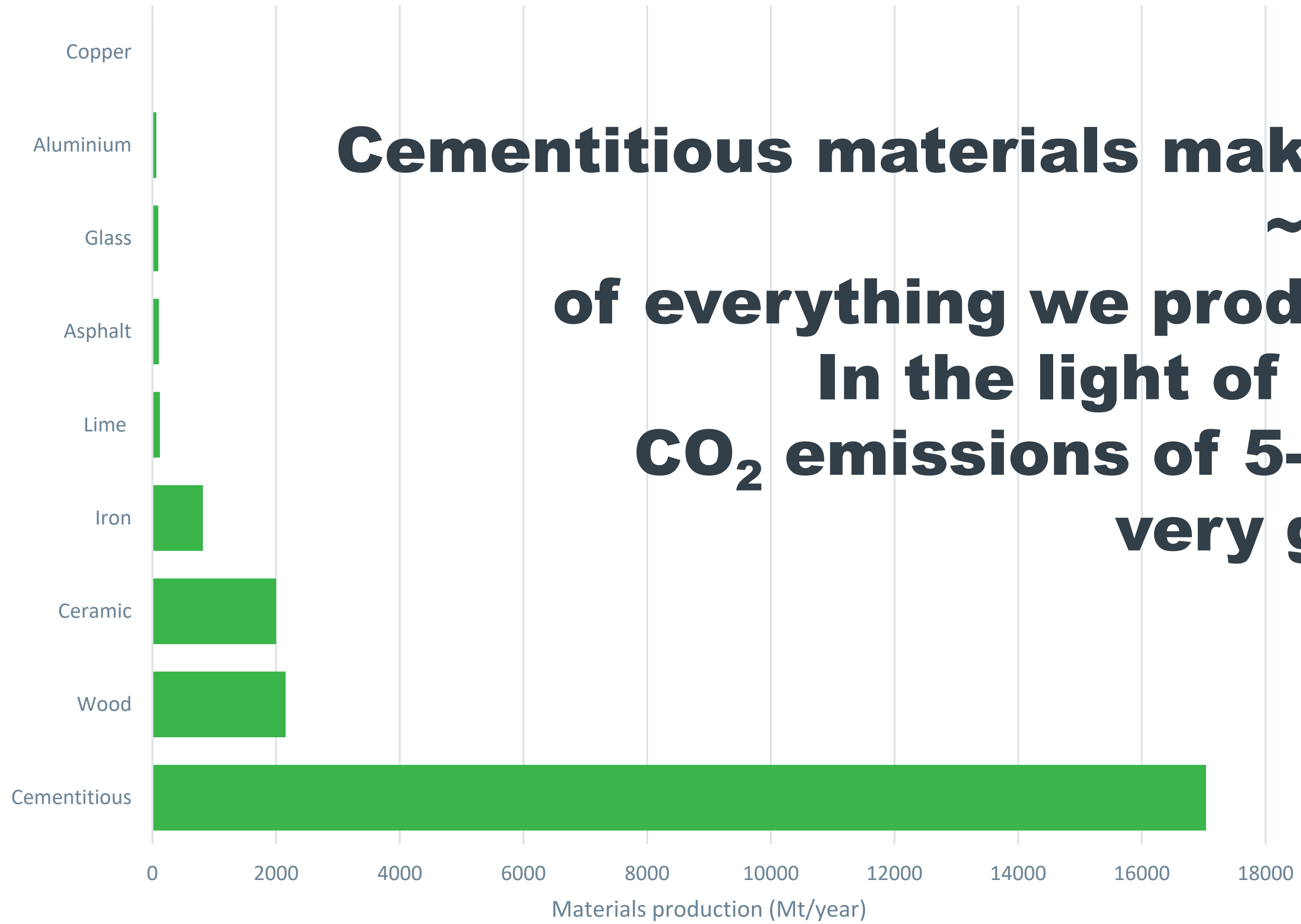


Guardian graphic. Source: Nature Communications

Two reports in recent years



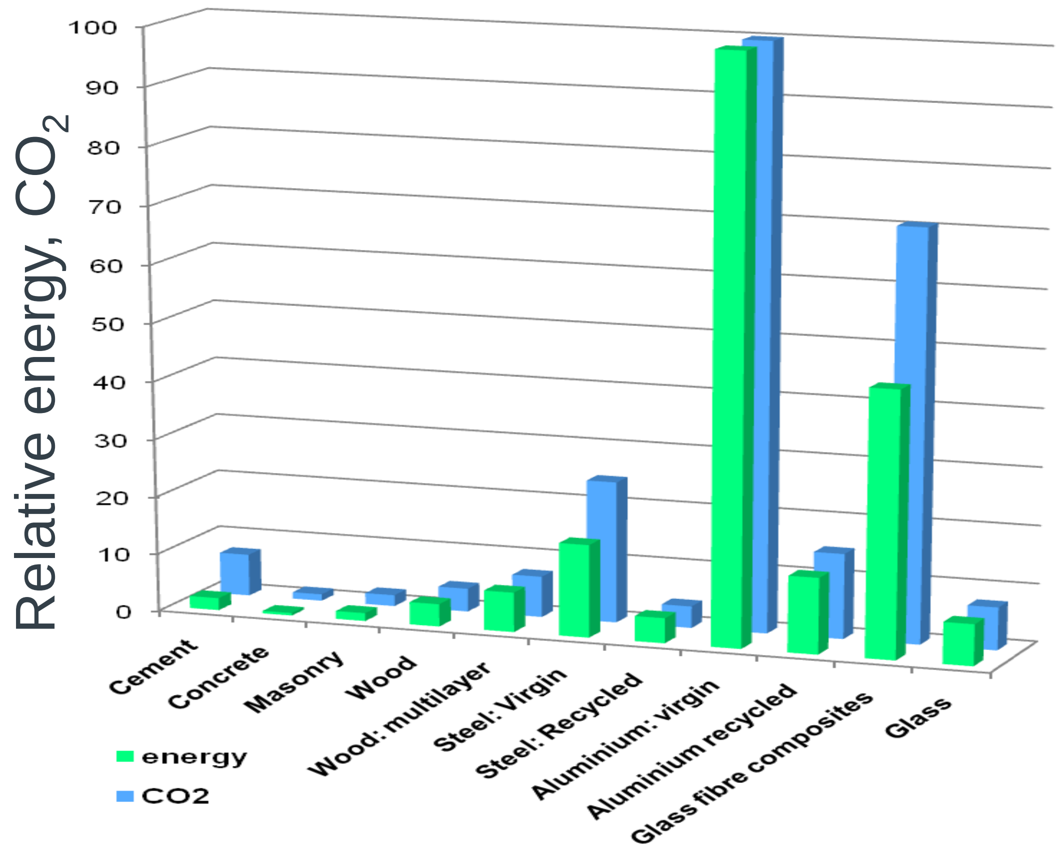
Cement Based Materials: cannot be replaced by alternatives



Cementitious materials make up ~50% of everything we produce. In the light of this, CO_2 emissions of 5-10% very good

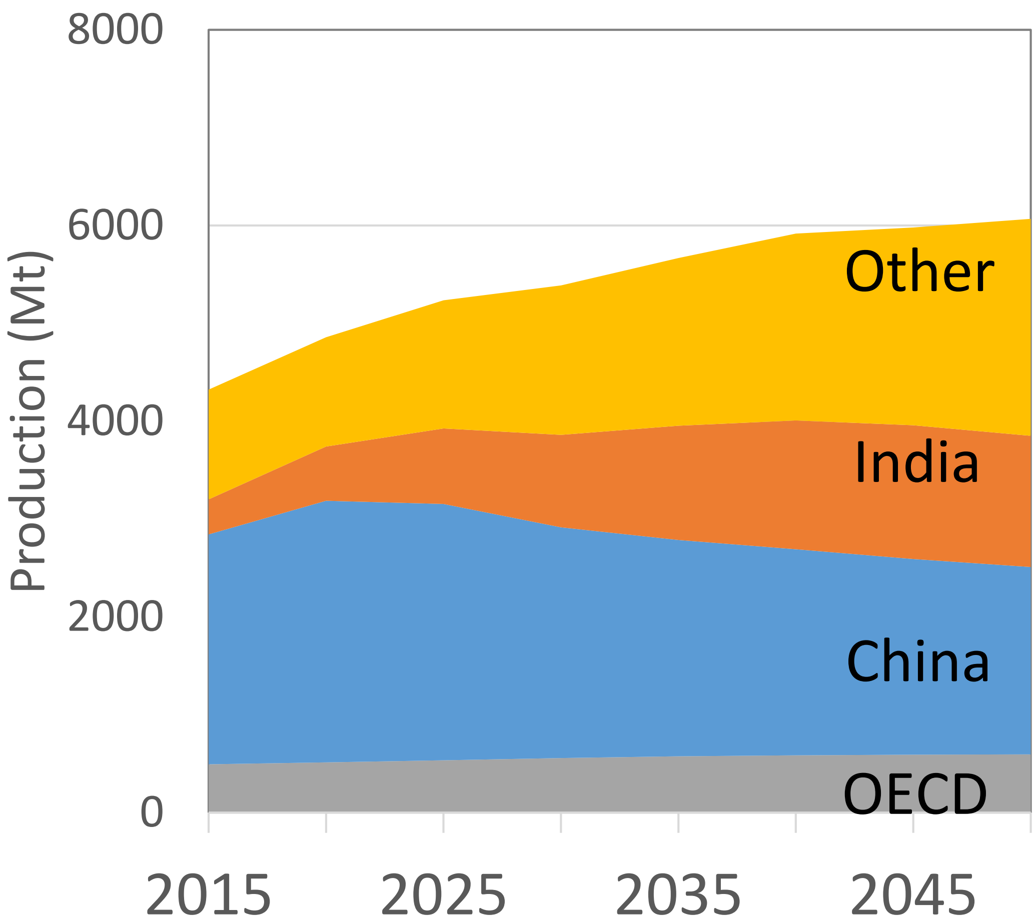
Concrete is an environmentally friendly material

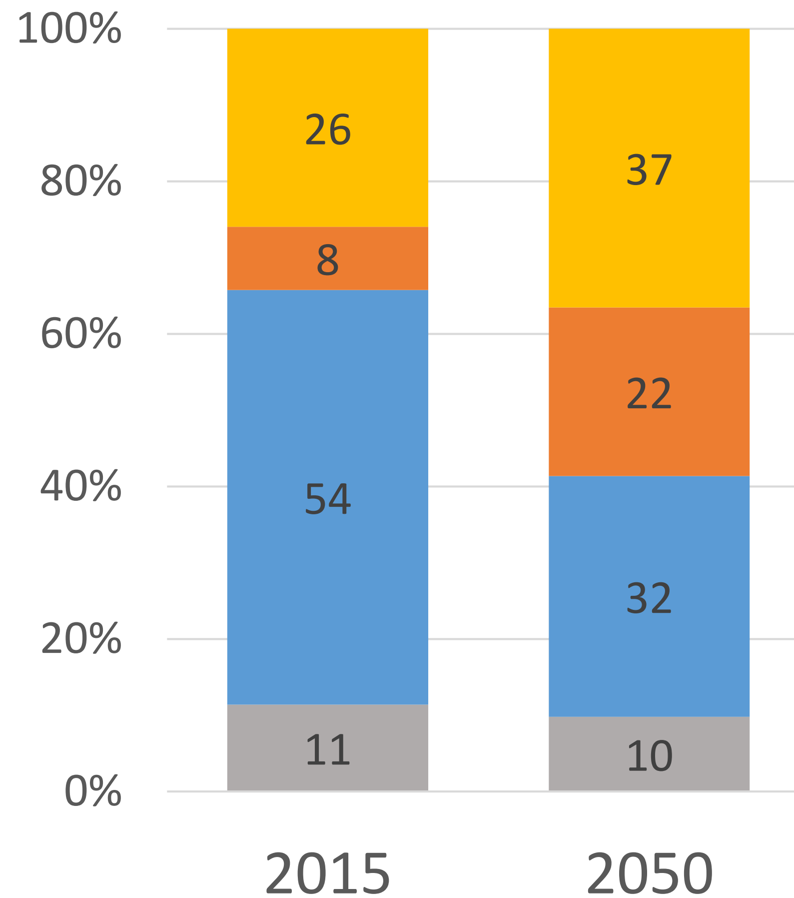
Material	MJ/kg	$kgCO_2/kg$
Cement	4.6	0.83
Concrete	**0.95**	**0.13**
Masonry	3.0	0.22
Wood	8.5	0.46
Wood: multilayer	15	0.81
Steel: Virgin	35	2.8
Steel: Recycled	9.5	0.43
Aluminium: virgin	218	11.46
Aluminium recycled	28.8	1.69
Glass fibre composites	100	8.1
Glass	15.7	0.85



ICE version 1.6a
Hammond G.P. and Jones C.I
2008 Proc Instn Civil Engineers
www.bath.ac.uk/mech-eng/sert/embodied/

Forecast growth





We need solutions for people in developing countries

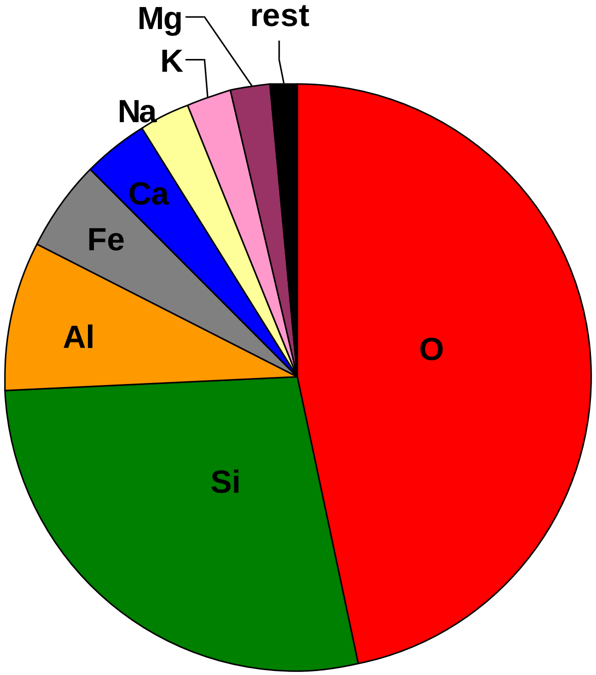
How to meet this challenge sustainably

Solutions need to be:

- Practical,
  usable by unskilled workers

- Economically viable

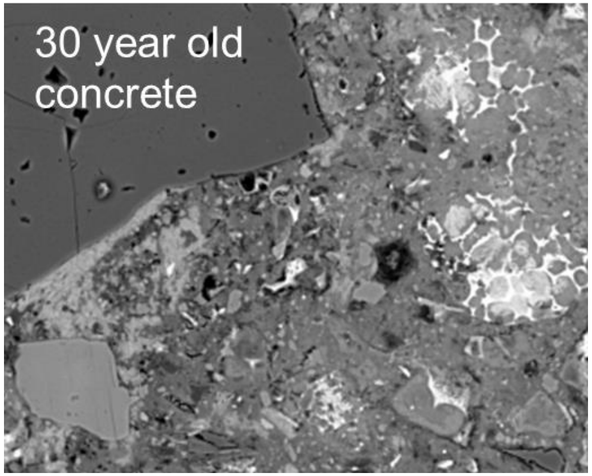
What is available on earth?

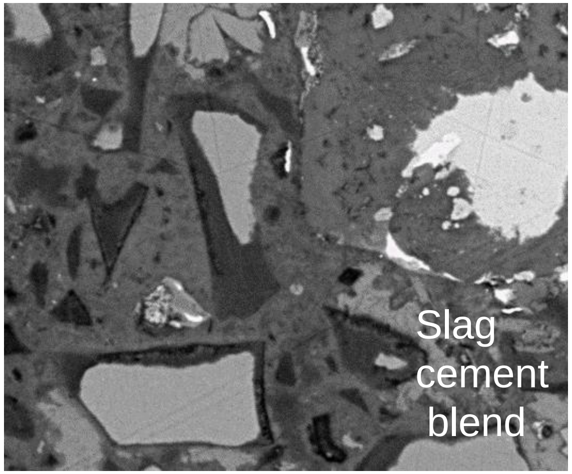


Na_2O, K_2O — **Too soluble**

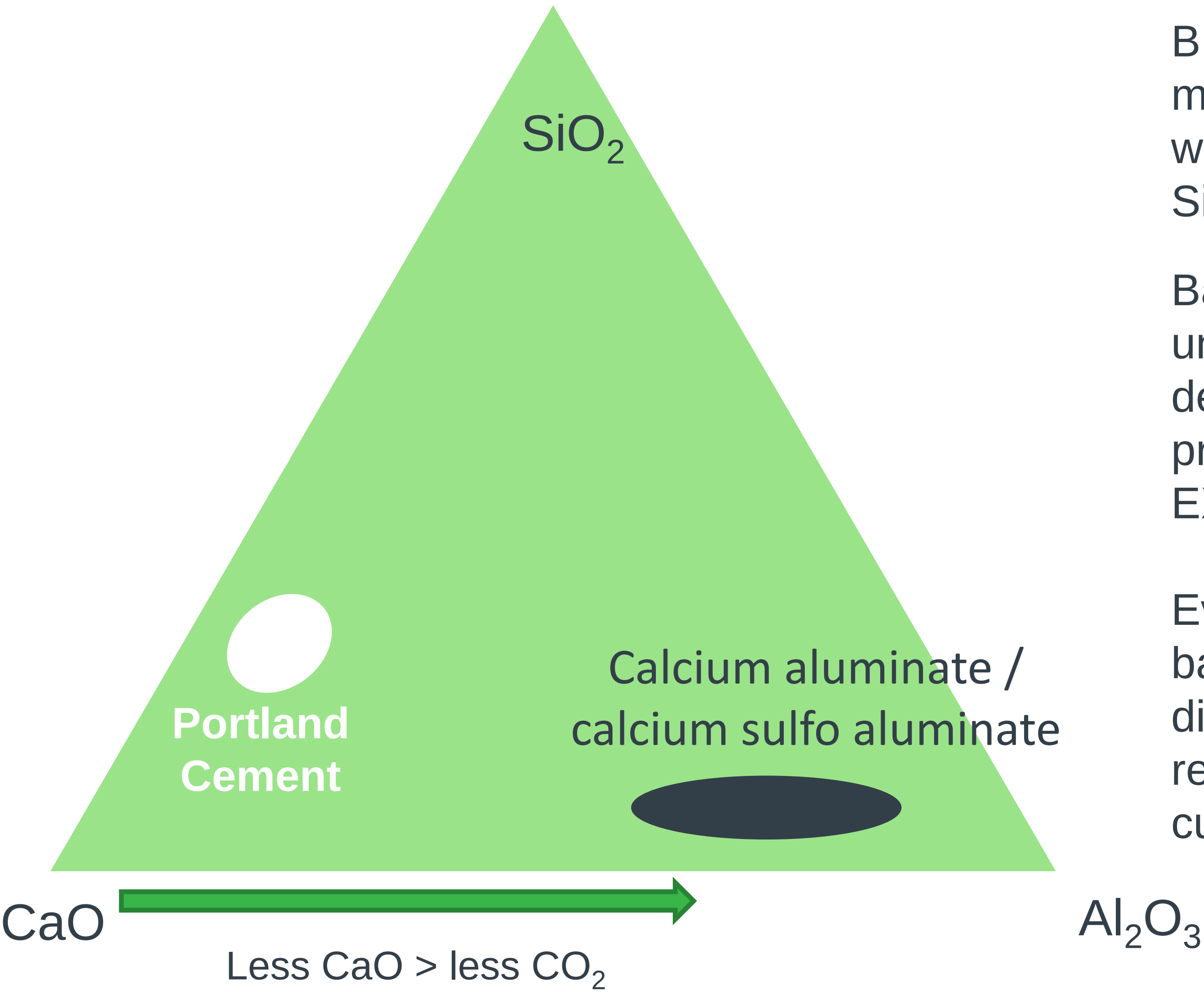
Fe_2O_3, MgO — **Too low mobility in alkaline solutions**

CaO, SiO_2, Al_2O_3 — **The most useful**





Hydraulic minerals in the 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.

Portland based cement will continue to be dominant

- Incredible economy of scale
  Clinker very low cost
- Raw materials abundant nearly everywhere
- Easily to manipulate open time
- Robust

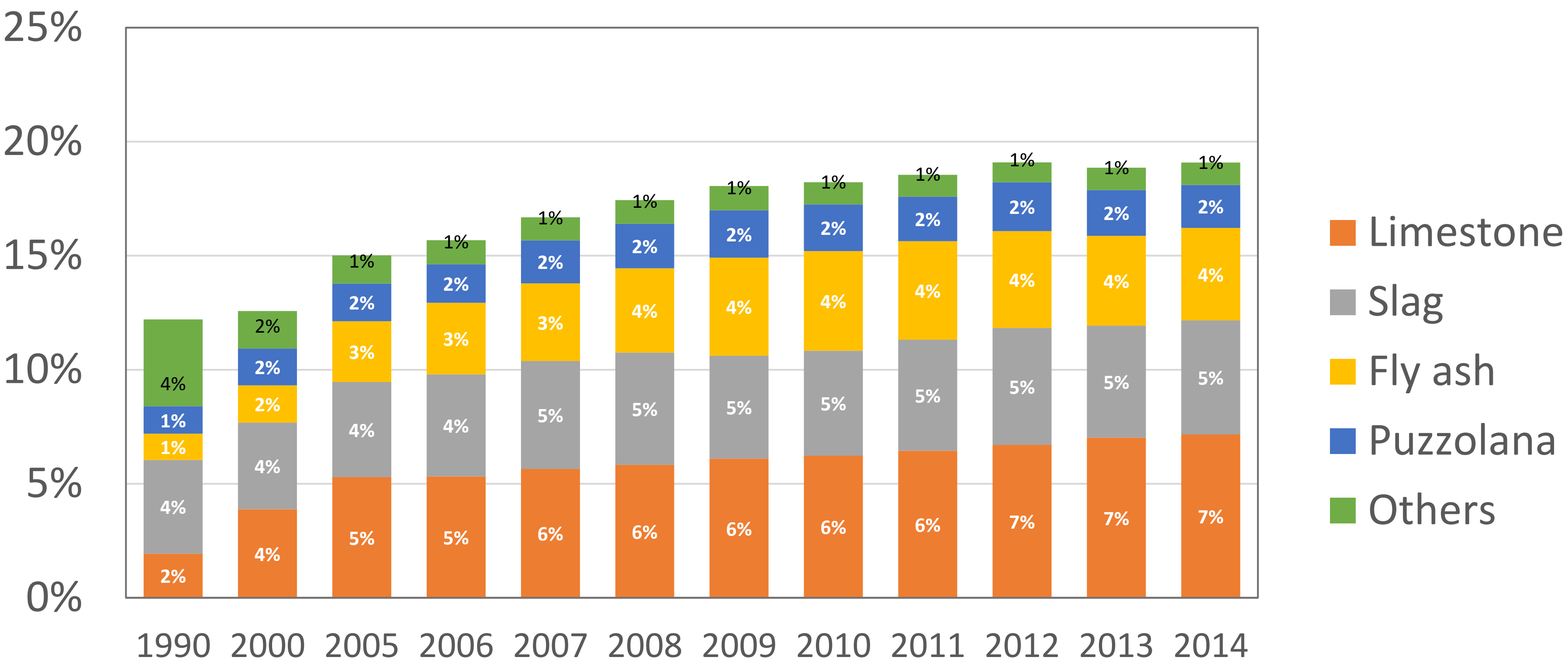
Extending use of blended cements

Limestone Calcined Clay Cement LC3

LOW CARBON LOW COST LOW CAPITAL

Evolution of Clinker substitution

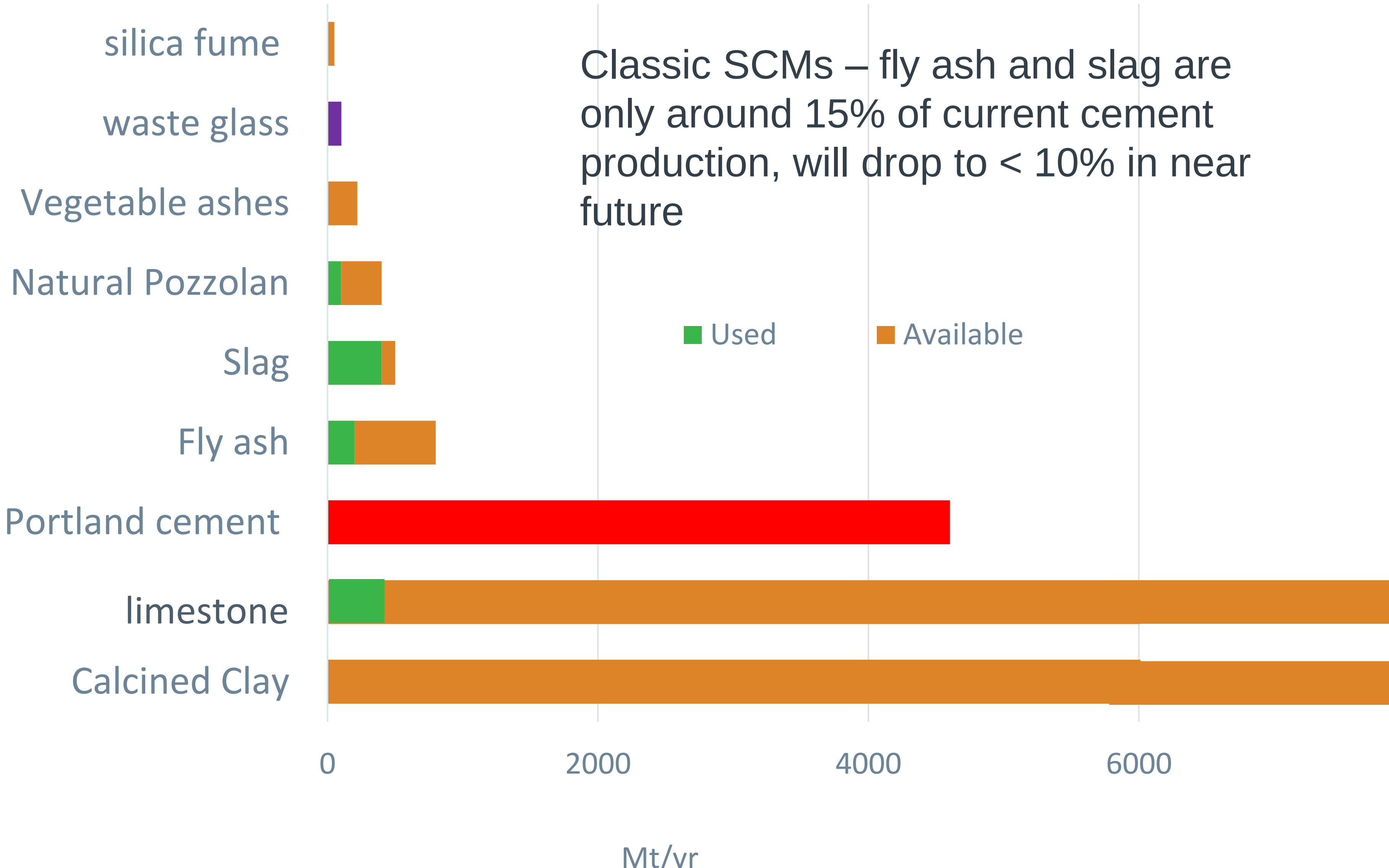
Clinker substitution most successful strategy to reduce CO_2



- Almost no progress in last 8 years
- Only 3 substitutes used in quantity

Availability of SCMs

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



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

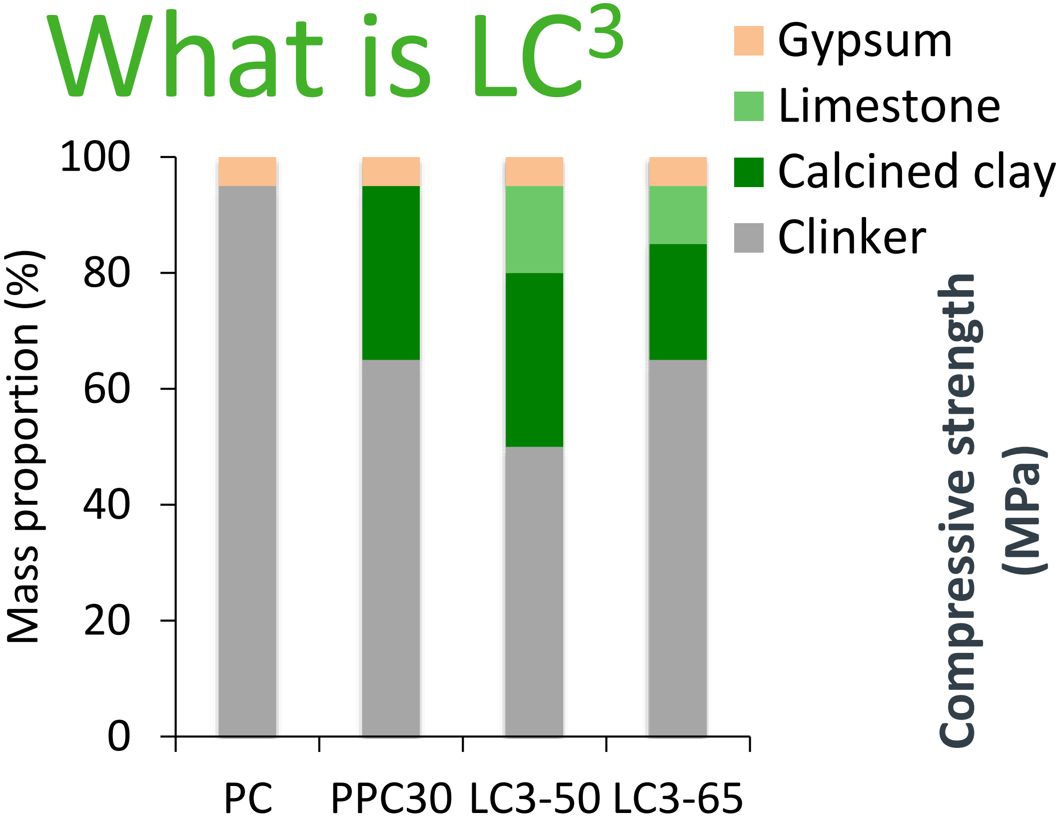
Swiss Agency for Development and Cooperation SDC

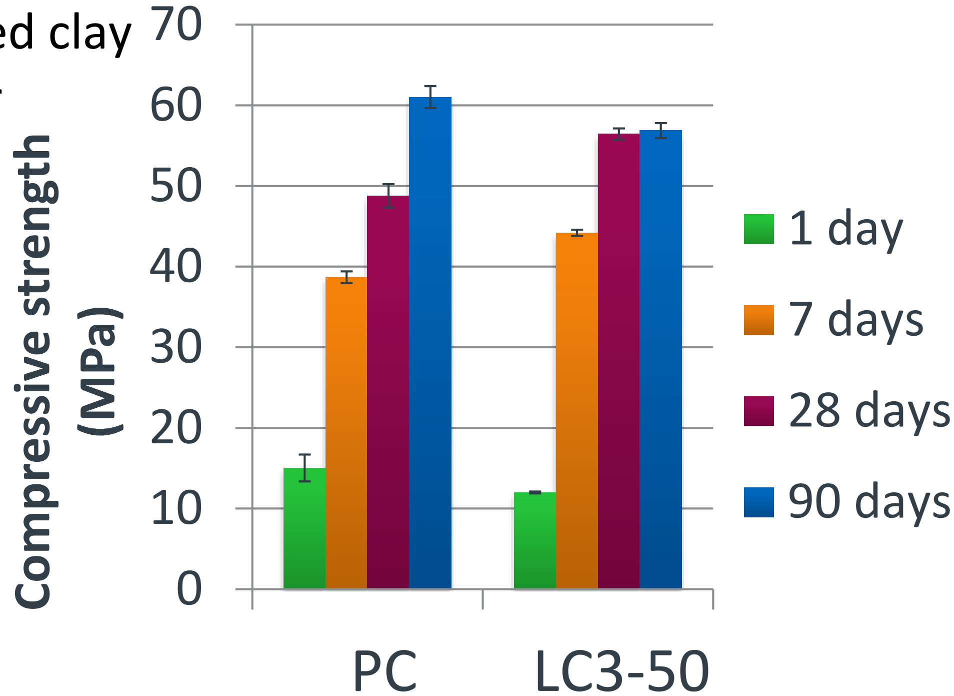
Limestone Calcined Clay Cement LC3

LC^3 project partners

- EPFL
- UCLV, Cuba; Fernando Martirena
- TARA, India; Soumen Maity
- IIT Delhi, India; Shashank Bishnoi
- IIT Madras, India; Ravindra Gettu, Manu Santhanam
- Sinoma, China; Sui Tongbo

What is LC^3





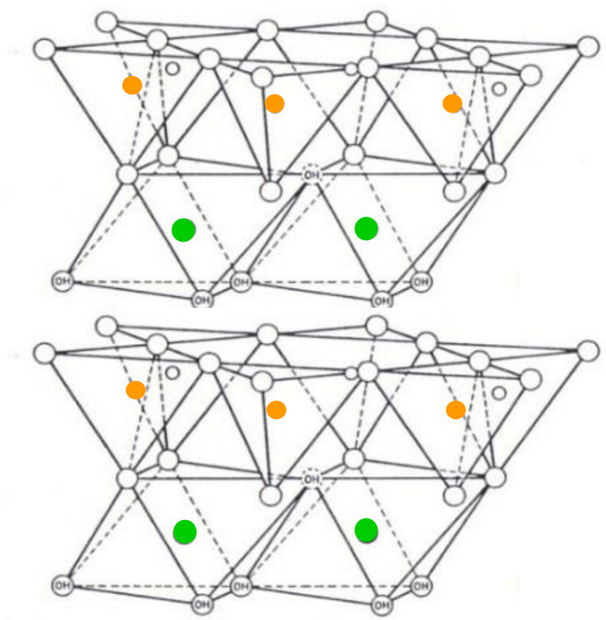
LC^3 is a family of cements, the figure refers to the **clinker** content

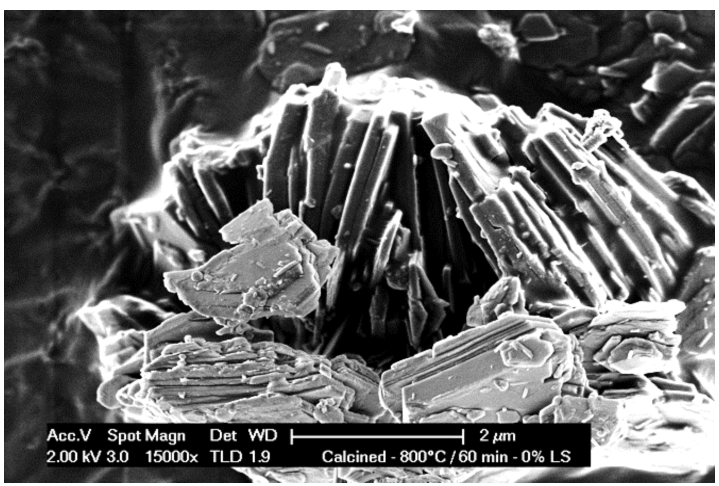
- 50% less clinker
- 40% less CO_2
- Similar strength
- Better chloride resistance
- ASR resistant

Why can we get such high replacement levels

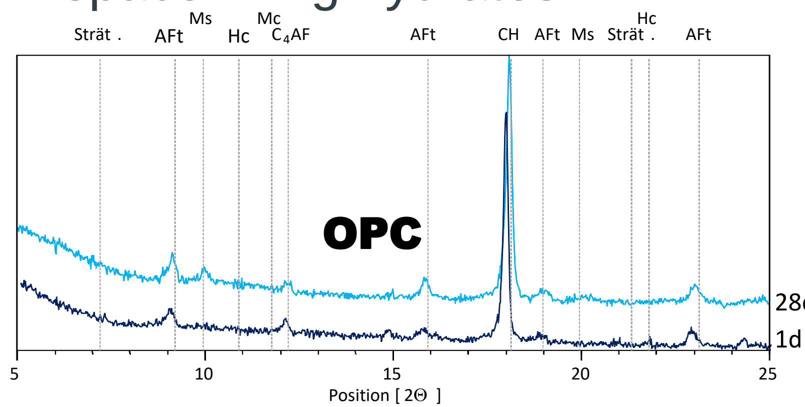
» Calcination of kaolinite at **700-850°C** gives metakaolin: much more reactive than glassy SCMs

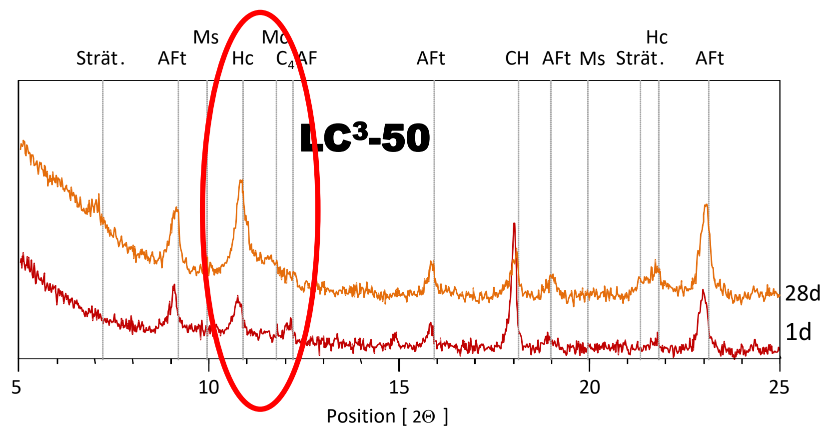
- aluminium
- silicon





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

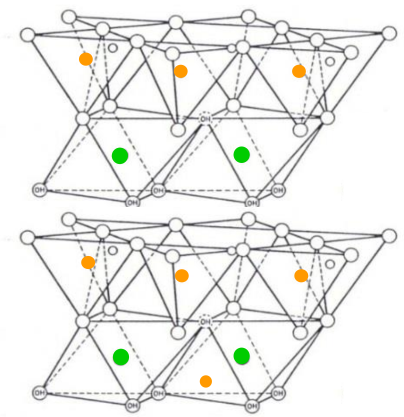




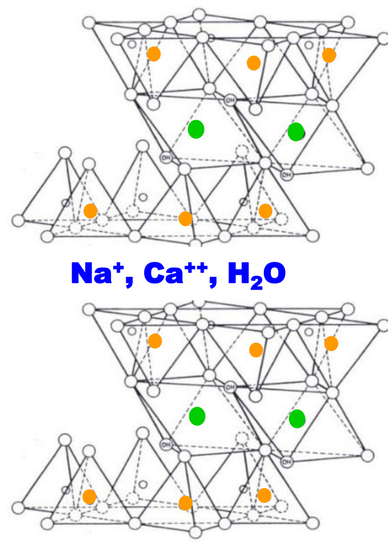
What kinds of clay are suitable?

Three basic clay structures

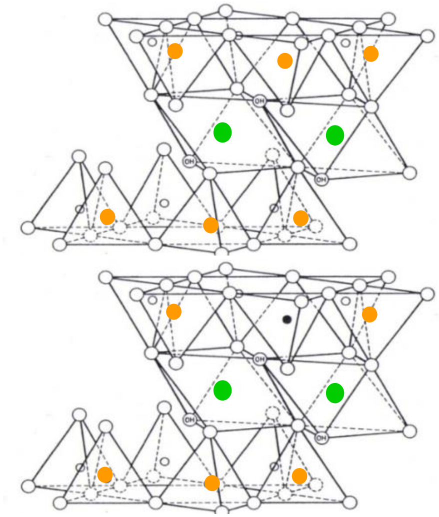
Kaolinite (1:1)



Montmorillonite (2:1) (Smectites)



Illite (Micas) (2:1)



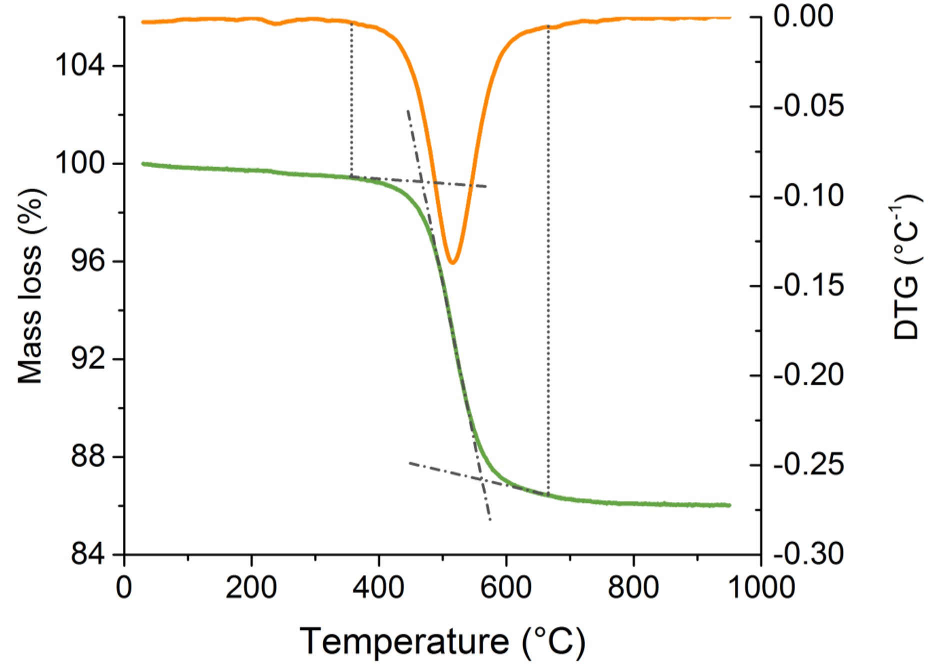
- aluminium
- silicon

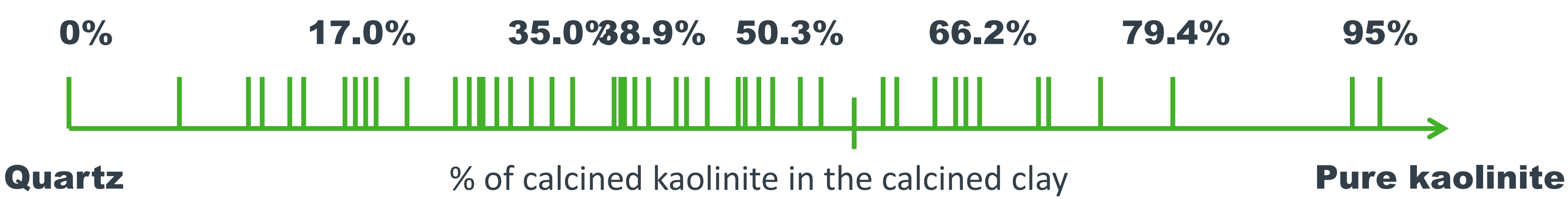
“Metakaolin”, sold as high purity product for paper, ceramic, refractory industries
Requirements for purity, colour, etc, mean expensive 3-4x price cement

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

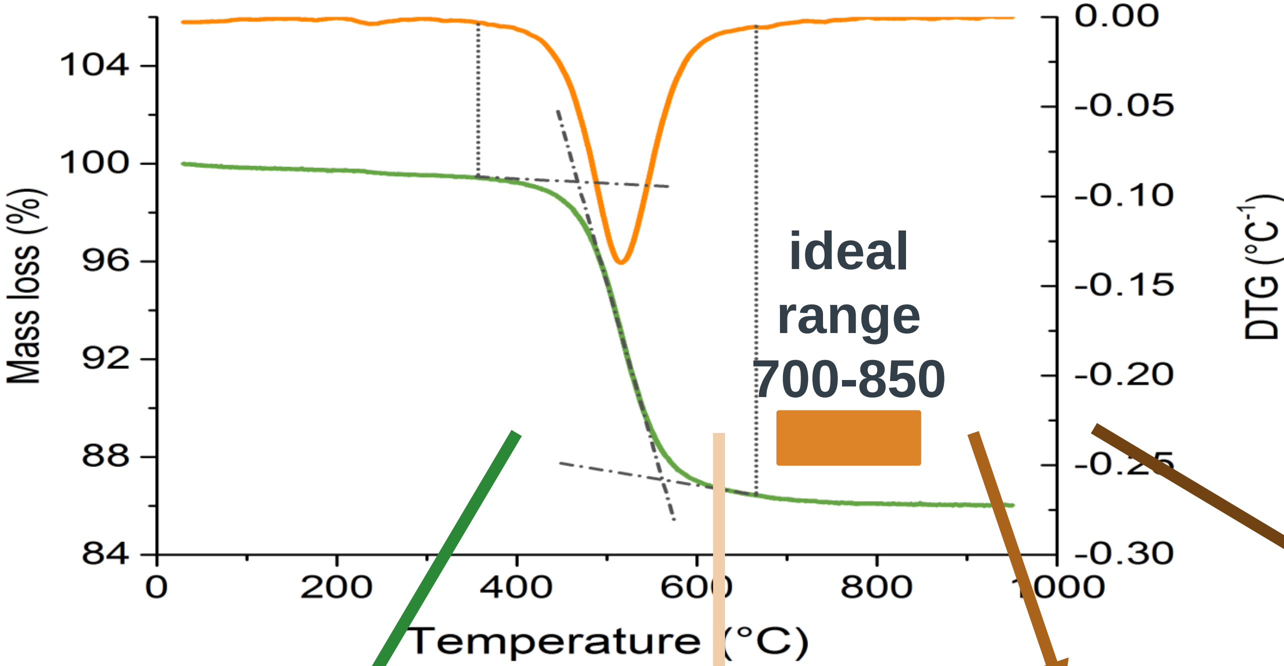
Over 50 clays studied from around the world

Different calcination conditions
Different compositions, impurities
Different physical properties





Calcination Temperature window 700-850°



<600
Not reactive

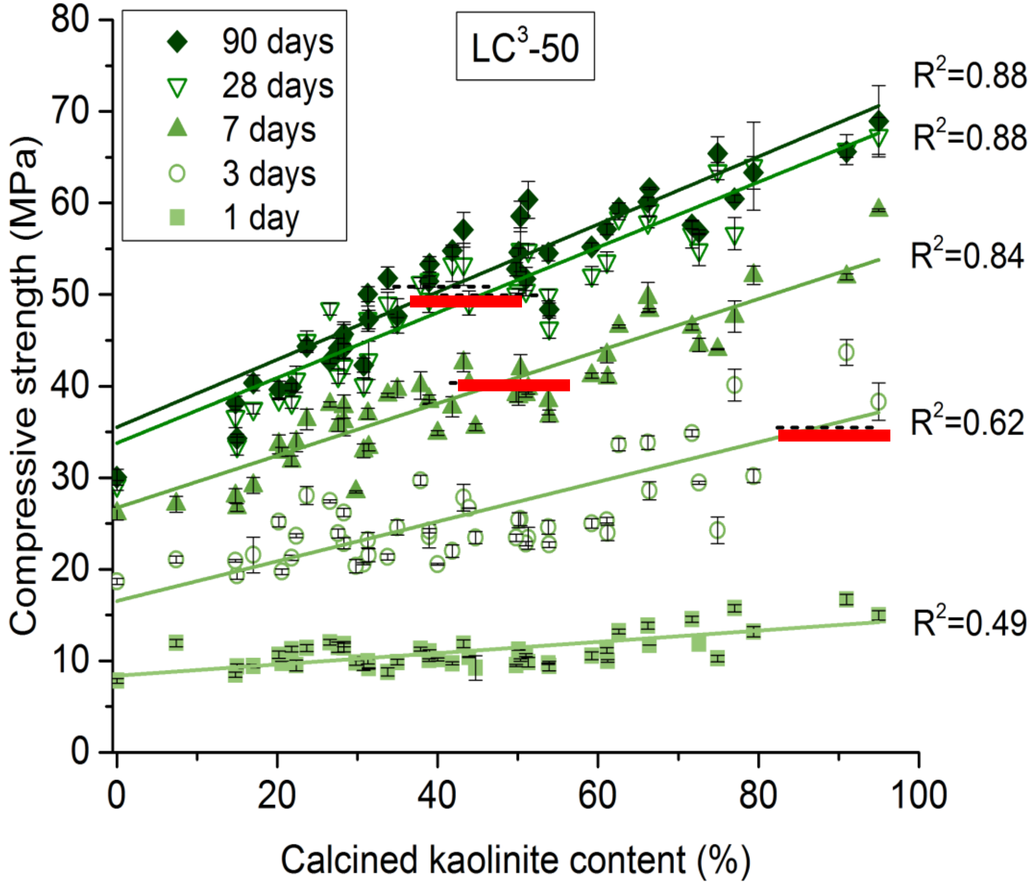
600-700
dehydroxlation complete but reactivity increases

850-1000
Surface area reduced reactivity decreases

>1000
crystalline phases formed no reactivity

Benchmark test of clay strength

- Compressive strength EN 196-1 at 1, 3, 7, 28 and 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

Ideal kaolinite content 40-60%

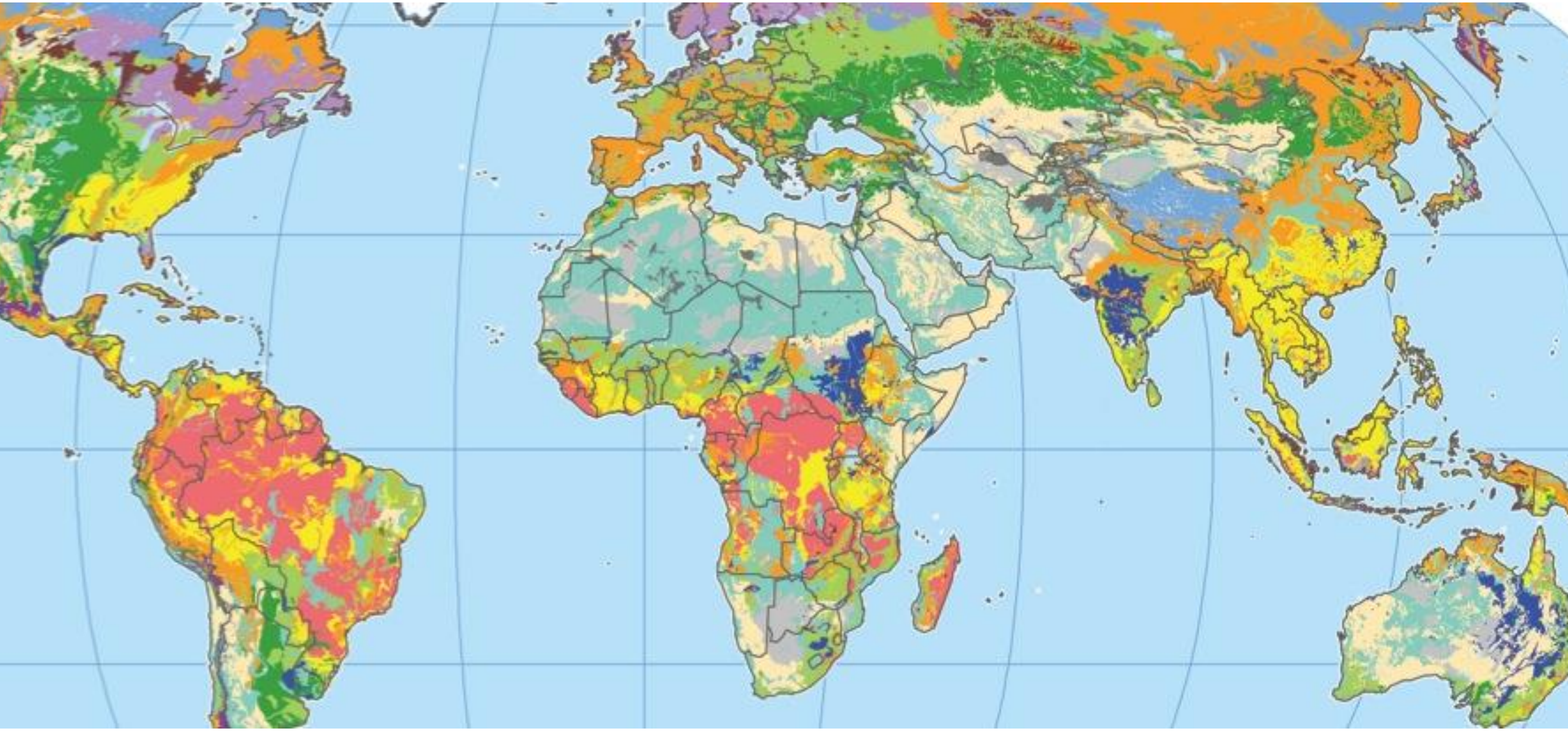
Higher contents, possible to use more limestone

Even better economics and ecology

Lower contents can be enriched by separation

separated fine quartz
can be sold as separate product

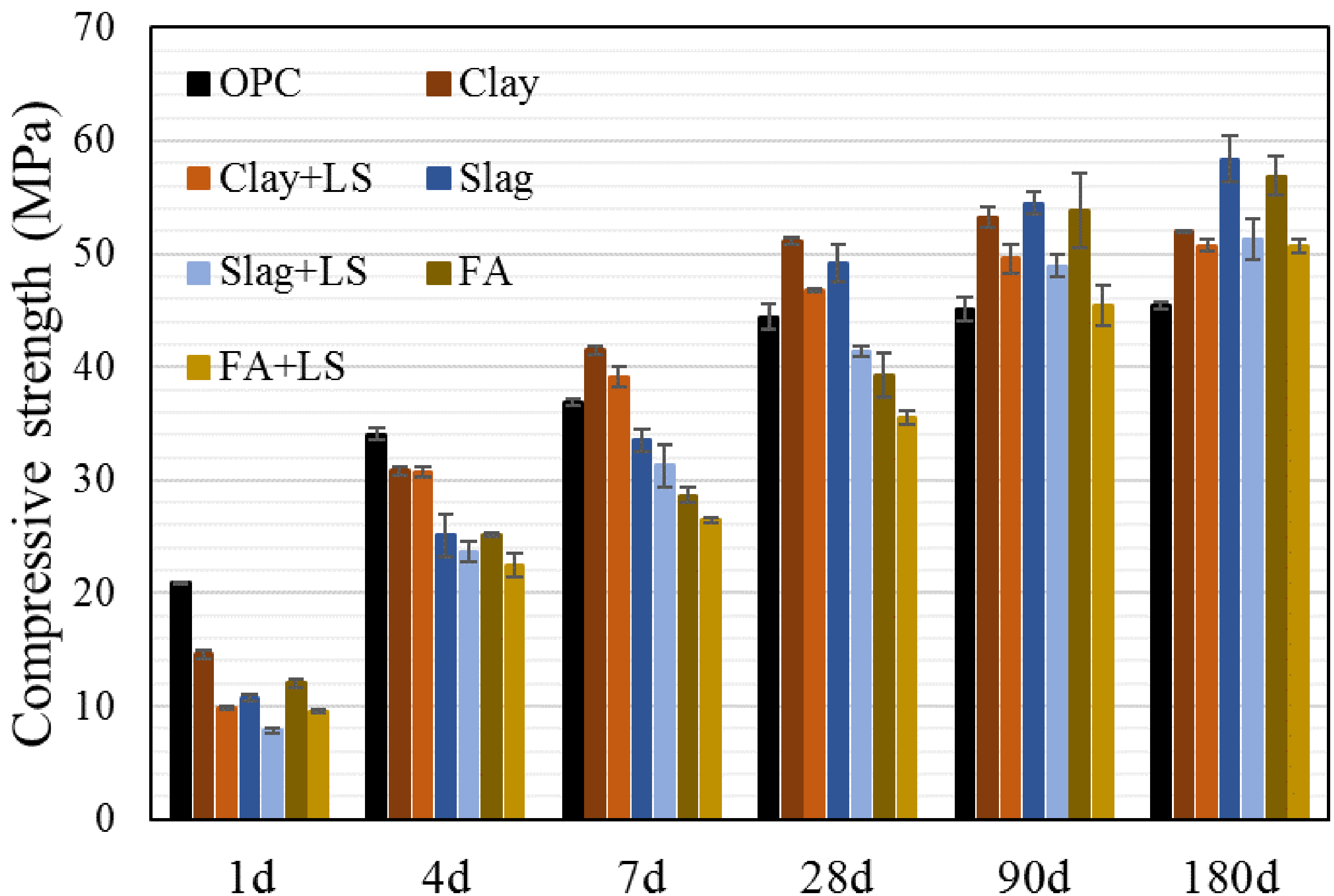
Availability of suitable clays, yellow pink and light green regions, and others



Suitable clays presently stockpiled as waste

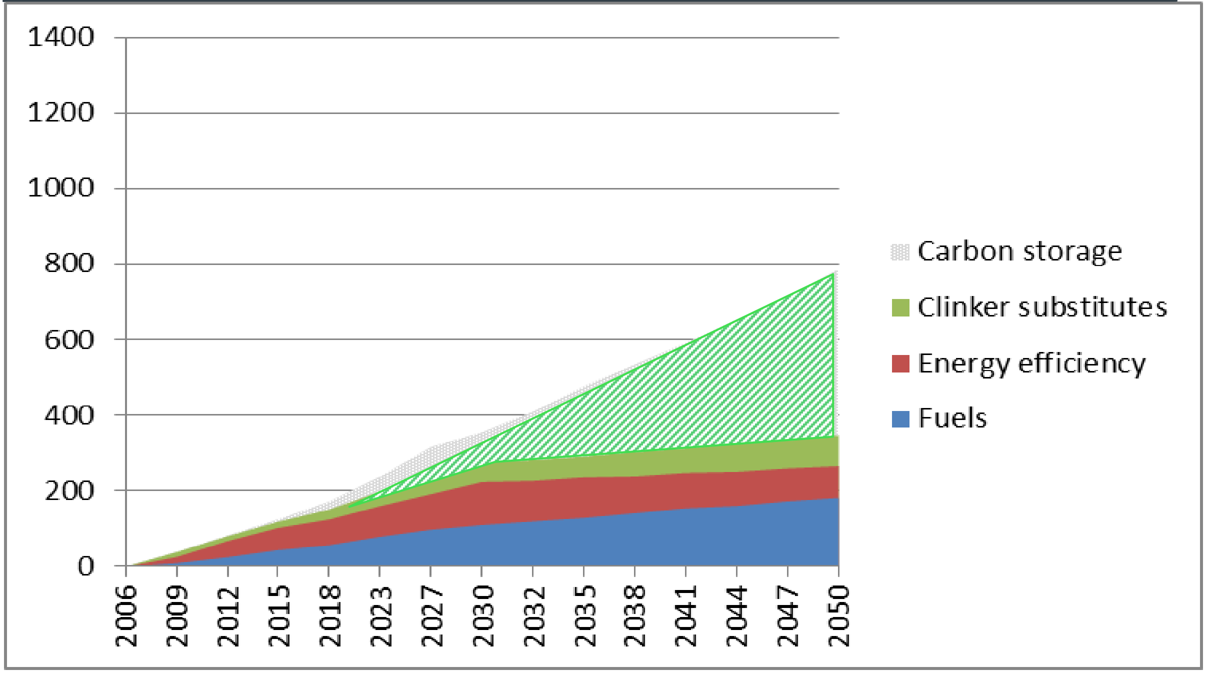
Comparison of calcined kaolinitic clay, slag and fly ash

Binary systems 70% clinker
Ternary systems, with limestone 50% clinker



Potential impact of LC^3 technology

	Global cement production Billion tons/year	Clinker factor, global average %	Global SCM volume Billion tones/year	Global CO_2 reduction Million tones/year
2006	2.6	79	0.5	
2050 (CSI study)	4.4	73	1.2	200
2050 (with LCC)	4.4	60	1.8	600



IEA: International Energy Agency **study for CSI:** Cement Sustainability Initiative **of WBCSD:** World Business Council for Sustainable Development

Global potential of LC^3
Δ = 400 million tonnes per yr

> whole of CO_2 emissions of France

LC^3 has been produced and used in full scale trials

Uses existing technology
Rotary kiln
Flash calciner
etc

Cuba – 1st Industrial trial

Jan 2013: Clay sourcing Pontezuela (300 t)

↓

March 2013: Clay calcination Siguaney (110 t)

↓

August 2013: Cement grinding (130 t)

↓

Sept-Dec. 2013: Cement use in construction

↓

Jan-July 2014: Evaluation of concrete made with LC3

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Agencia Suiza para el Desarrollo y la Cooperación COSUDE

FNSNF
Fonds national suisse
Schweizerischer Nationalfonds
Fondo nazionale svizzero
Swiss National Science Foundation

EPFL
École Polytechnique Fédérale de Lausanne

CIDem
centro de investigación y desarrollo de estructuras y materiales

GECEM


10 ton in bags


120 ton in silo

Industrial block manufacture plant

Prefabrication plant Cuba

House built at Santa Clara, Cuba with LC3

INDIA: Calcination

Blending and grinding

Evaluation in building materials

Evaluation in building materials

Industrial production

KJS Concrete Pvt. Ltd., Dadri

Limestone Calcined Clay Cement LC3

LOW CARBON LOW COST LOW CAPITAL

Demonstration structure

Around 14 tonnes of CO_2 saved
Compared to existing solutions

Limestone Calcined Clay Cement LC3

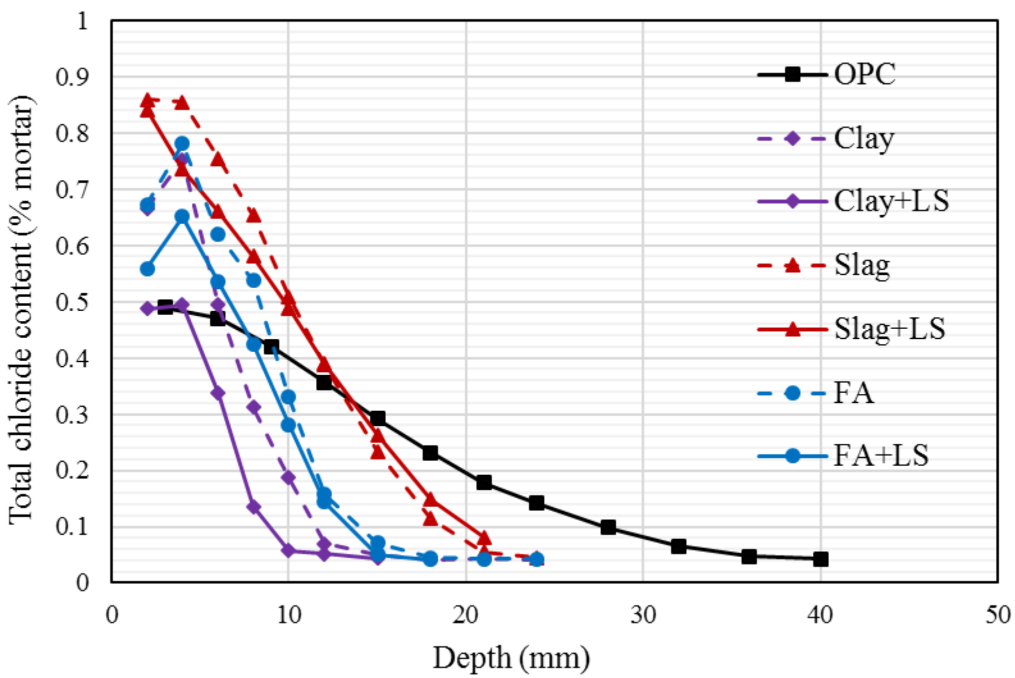
LOW CARBON LOW COST LOW CAPITAL

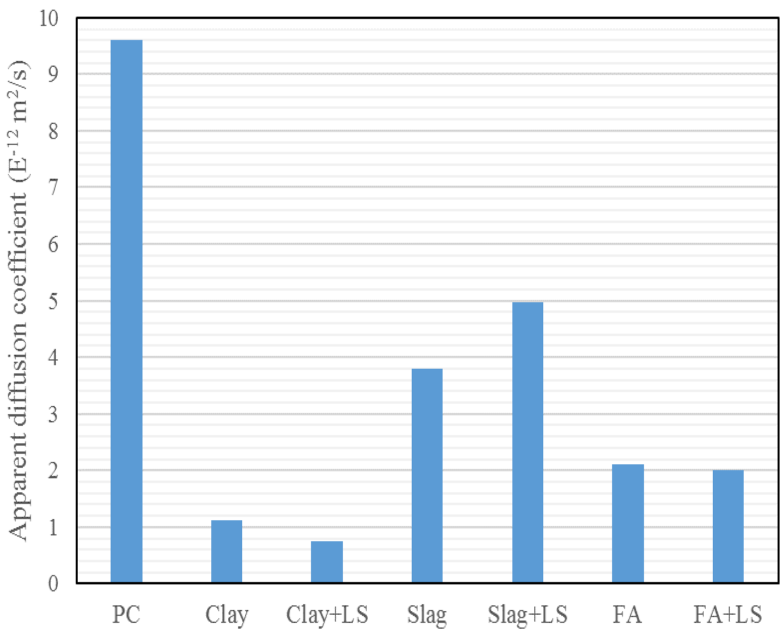
Hollow Core Slabs

Key Advantages

- Chloride resistance
- ASR mitigation

Chloride ponding ASTM

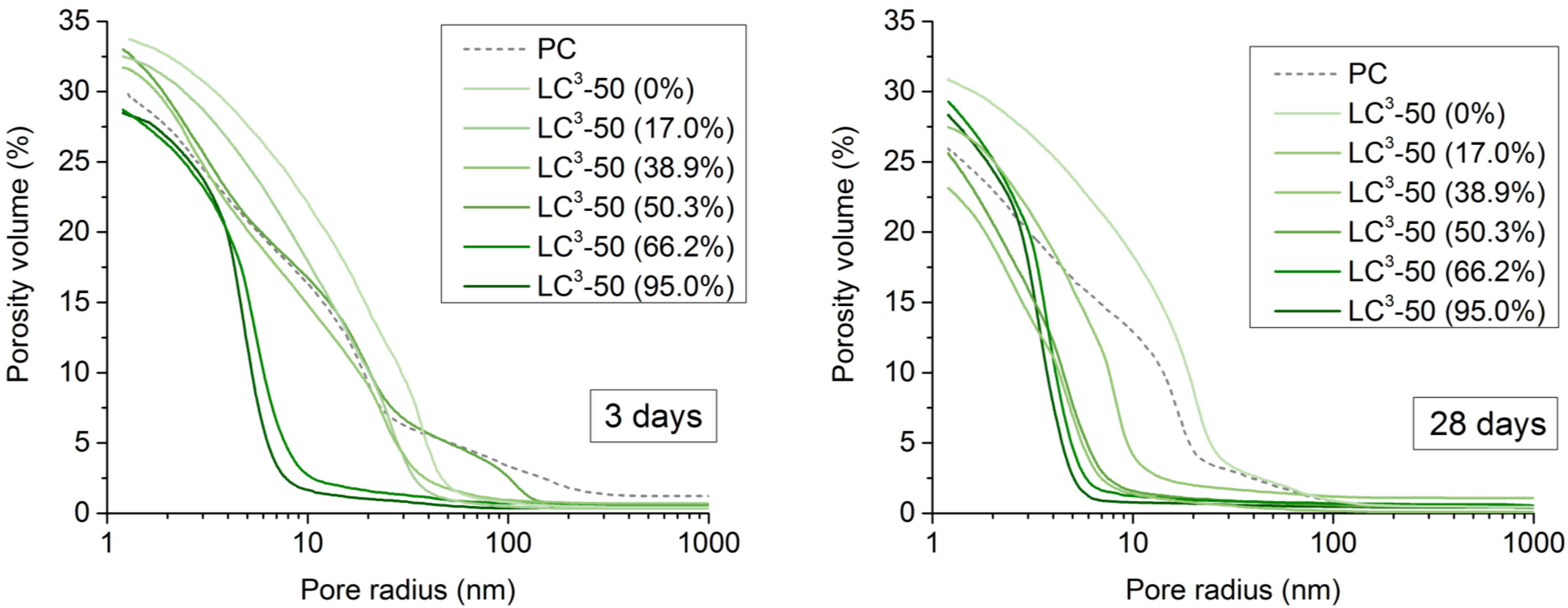




Apparent diffusion coeffs.

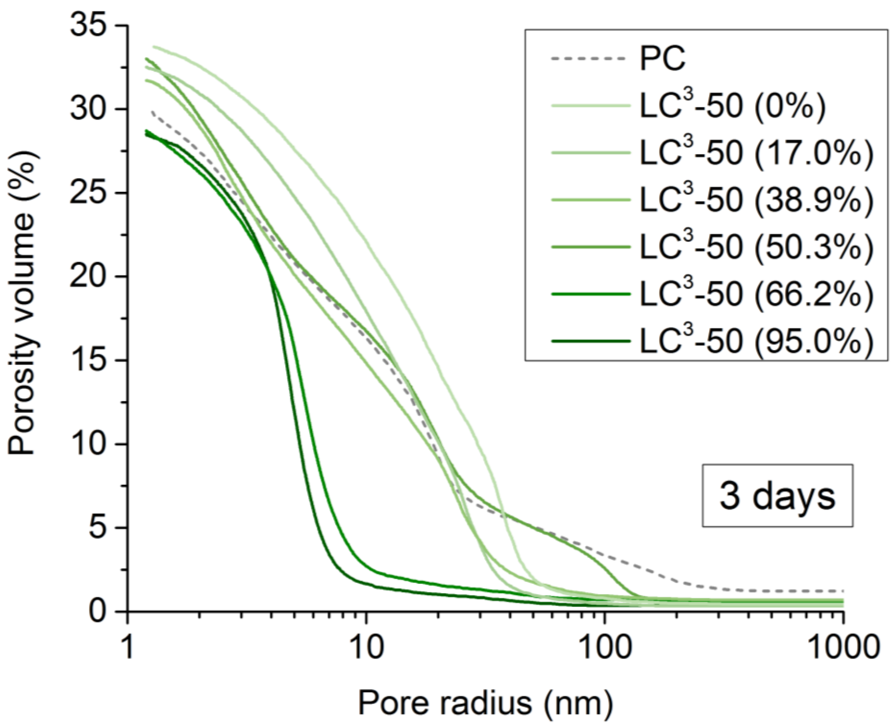
Porosity characterization by MIP

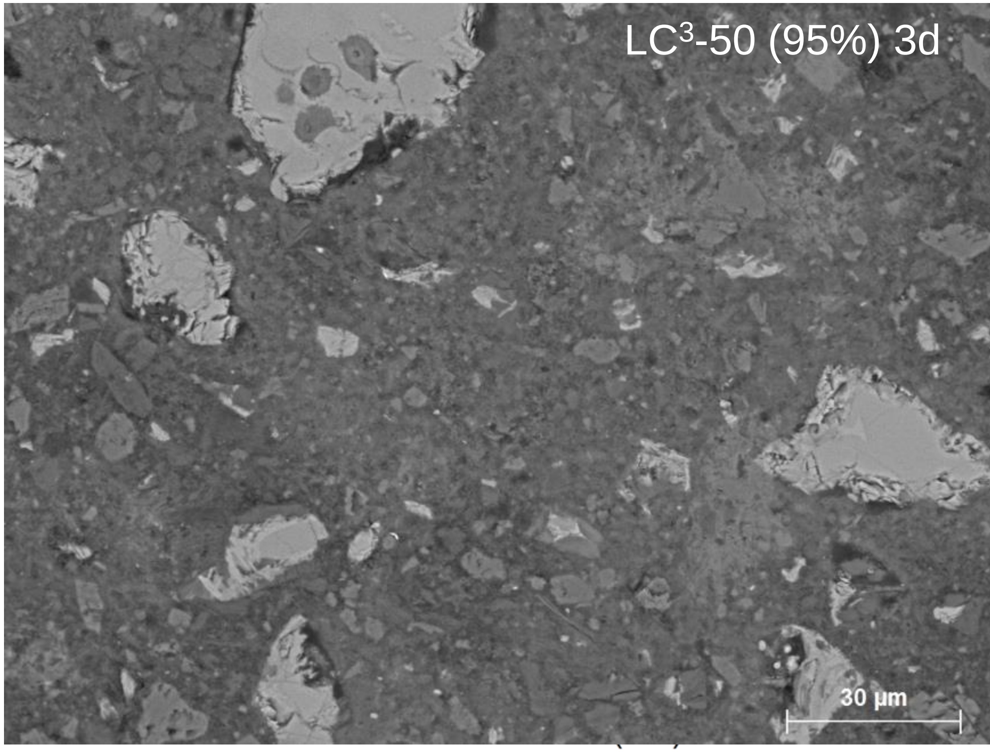
- Significant refinement of porosity already at 3 days of hydration

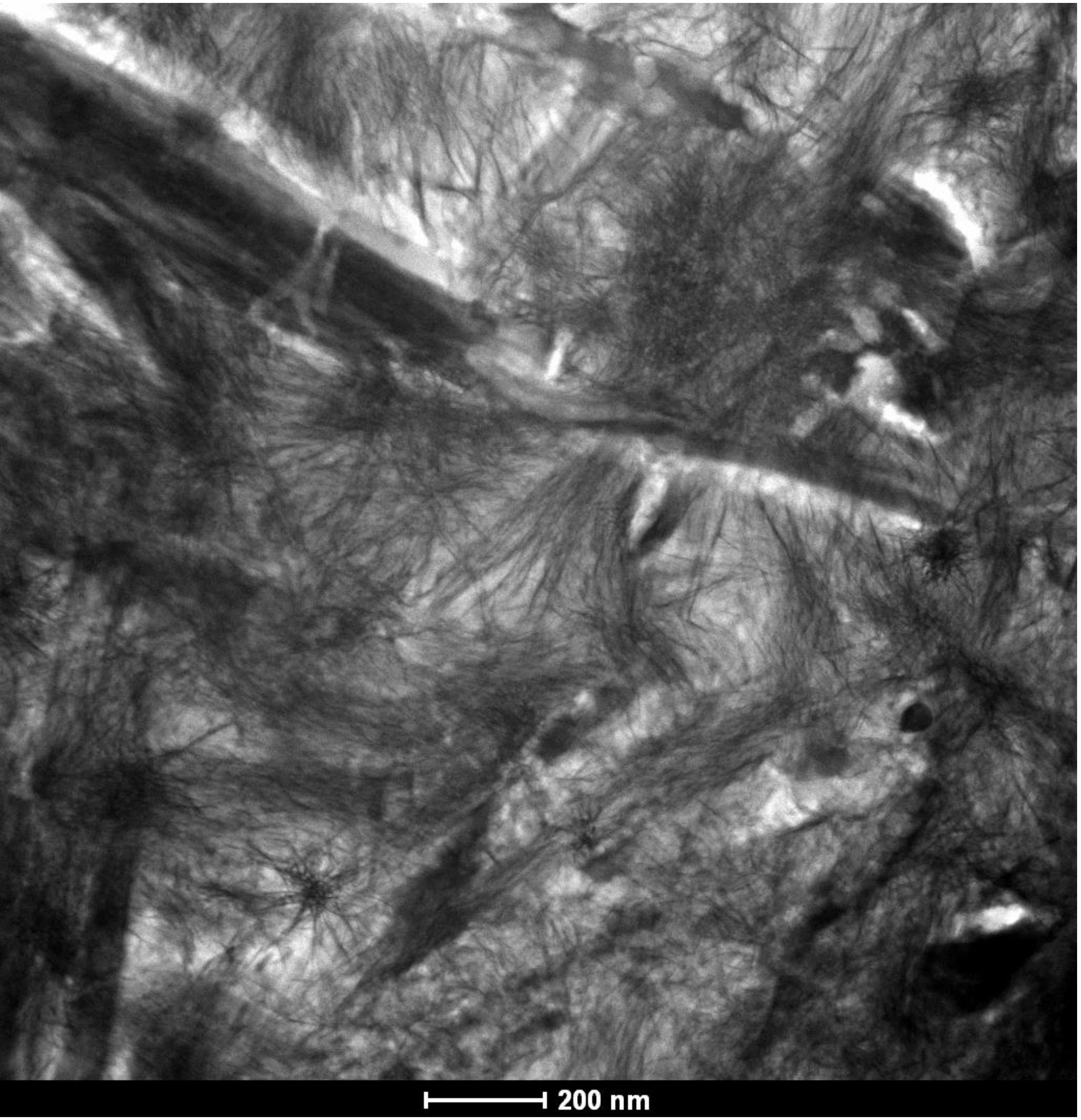


Porosity characterization by MIP

➢ Significant refinement of porosity already at 3 days of hydration



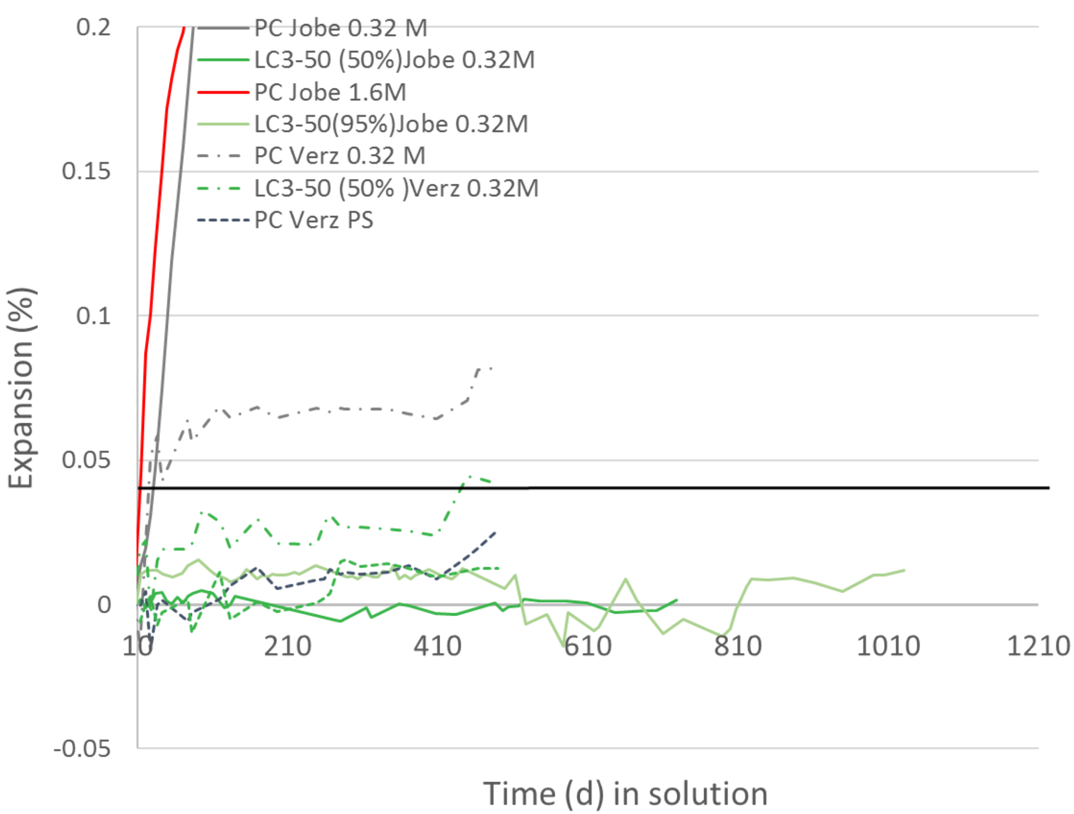




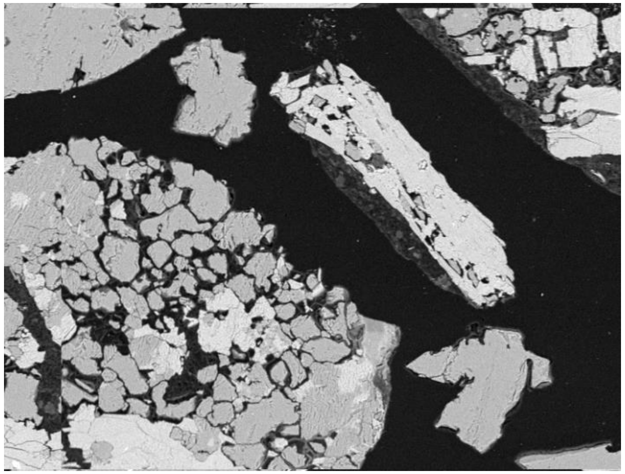
Very dense microstructure

Strong pore refinement

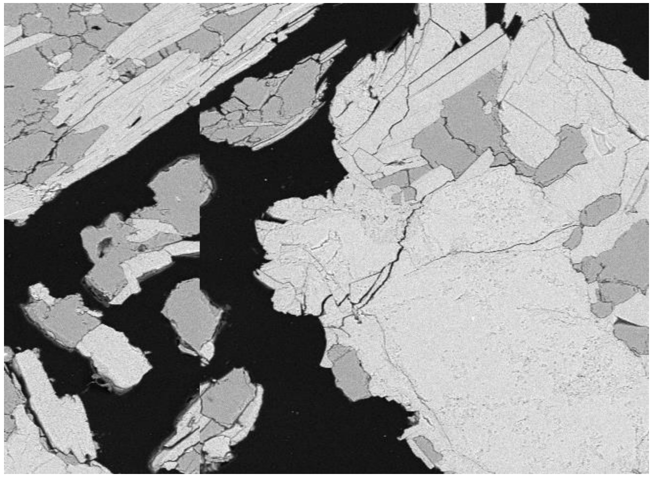
Alkali silica reaction



Impact of alumina on aggregates



No alumina



Alumina in solution

Chappex 2012

Perceived problems

- Workability
- Carbonation
- Colour

LC3

- Limestone and calcined clay are both much softer than clinker
- With intergrinding, high blaine and clinker is likely to be underground. But situation can be improved by separate grinding or addition of calcined clay at separator
- However effect of limestone and impurities in clay has positive influence
- Good flowable concrete can be obtained with use of superplasticizers
- In some formulation SP dosage may even be less
- **No segregation, no bleeding**
- Further improvements possible with PSD optimisation, grinding aids, etc

Carbonation

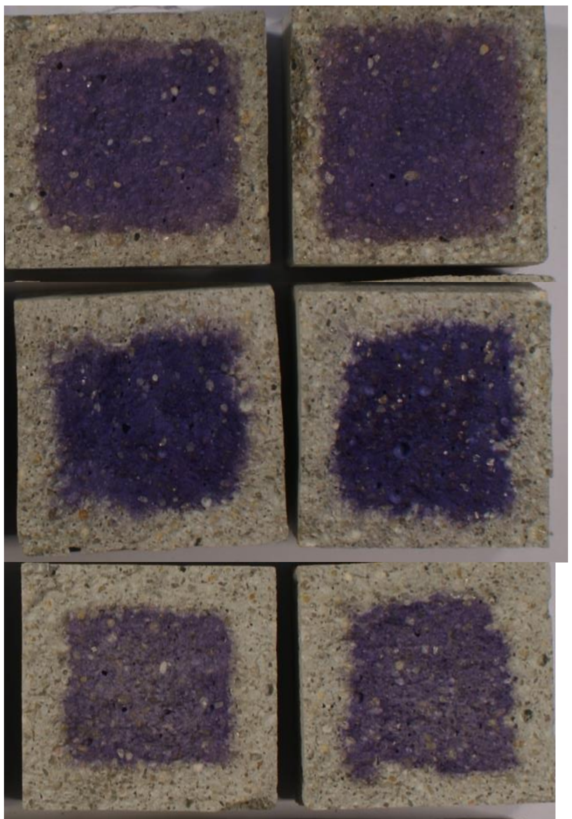
Indoor

3D | 28D

PC

PPC30

LC^3-50



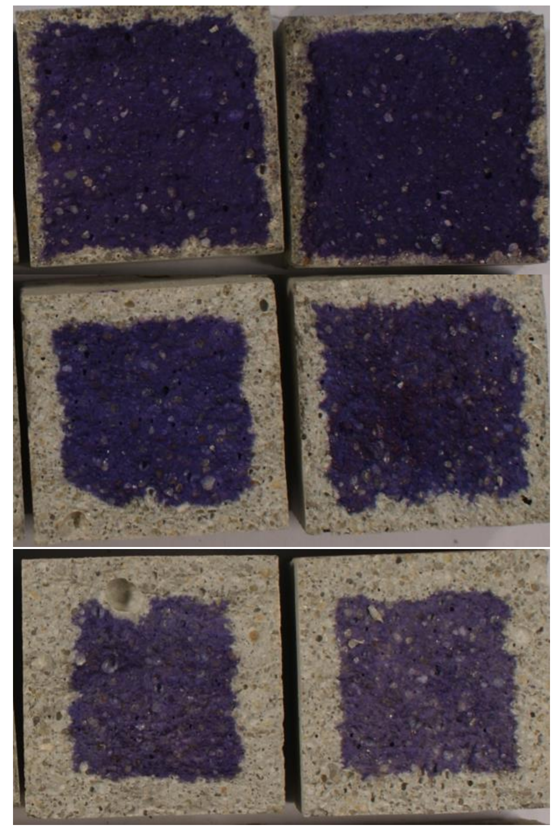
Outdoor

3D | 28D

PC

PPC30

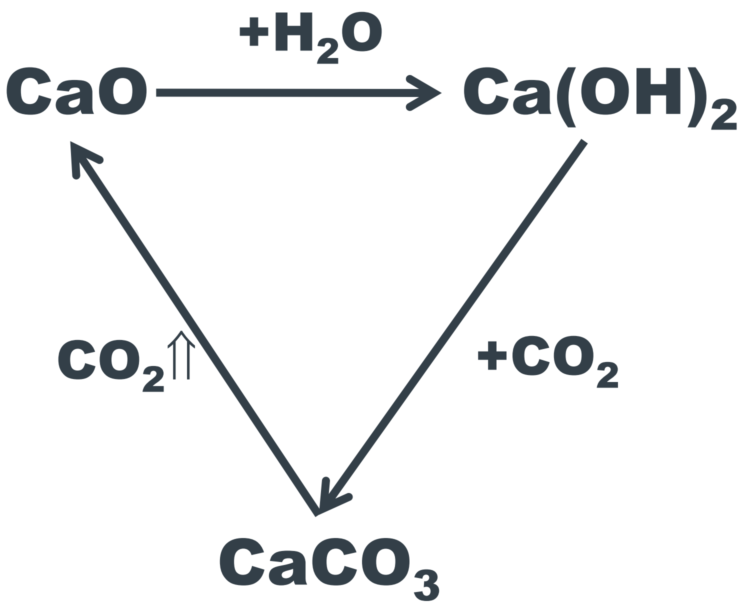
LC^3-50



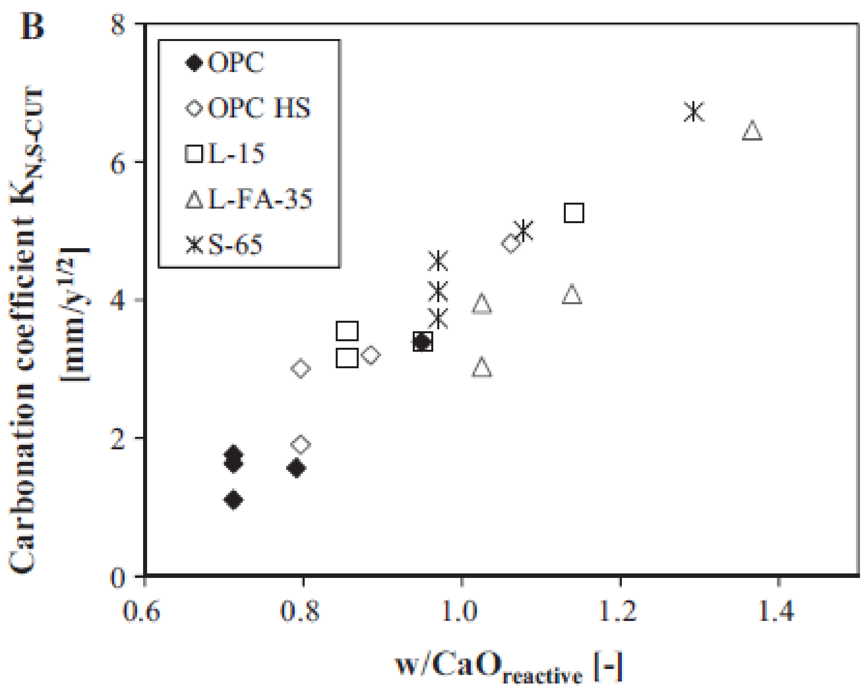
2 years natural conditions : similar to other blends

Carbonation

Reducing calcium content; reduces buffer to carbonation



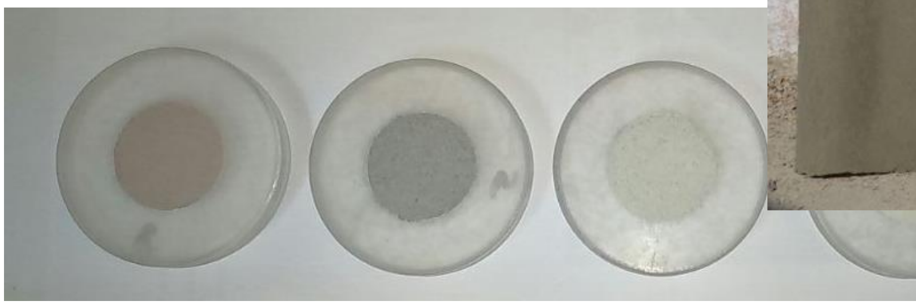
All CaO content can react with CO_2, not just portlandite



Leemann, et al(2015) :

What about colour

» Intensity determined by iron concrete



» Red to grey by kiln atmosphere

FLSmidth 2013

Colour control. IPIAC technology

Concluding remarks

- Future cements will be based on Portland cement clinker with increasing levels of incorporation of SCMs
- Calcined clays are the only realistic option for extending the use SCMs
- Possible to obtain similar mechanical properties to OPC / CEM I with 50% clinker and clays with >40% kaolinite
- Calcined clays have very positive impact on:
  - Chloride ingress
  - ASR
- If we are serious about more sustainable concrete we need to use cements with lower CO_2 emissions, e.g LC^3 clinker/ calcined clay / limestone blends
- Europe has an important role to play in facilitating uptake ***worldwide***: standards and research

Limestone Calcined Clay Cement LC3

LOW CARBON LOW COST LOW CAPITAL

Thank you

More information on: www.LC3.ch

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