Limestone Calcined Clay Cement LC3 www.LC3.ch LOW CARBON LOW COST LOW CAPITAL

LC^3: a realistic option for reducing CO2 emissions of cementitious materials fast and at scale

Professor Karen Scrivener, FREng, EPFL, Switzerland

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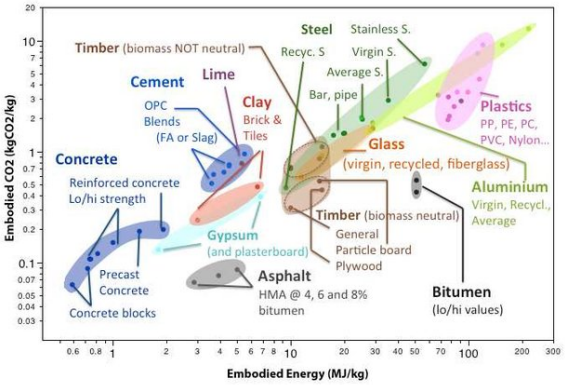
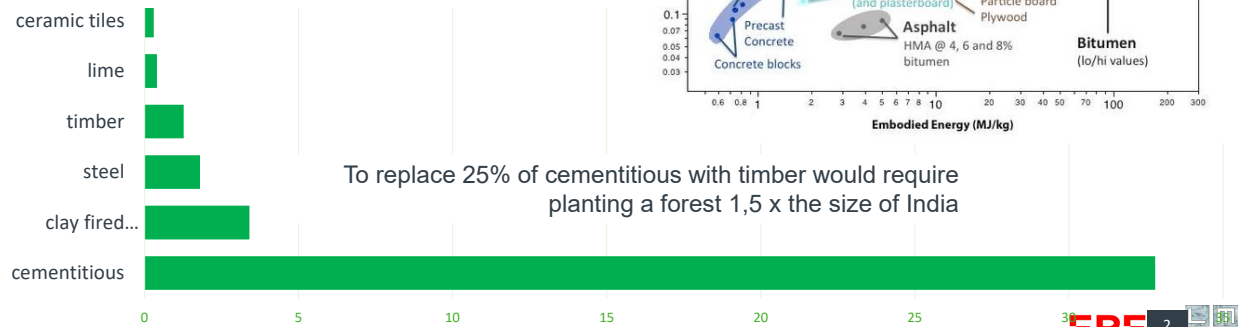
Cementitious Materials: Concrete, Mortar

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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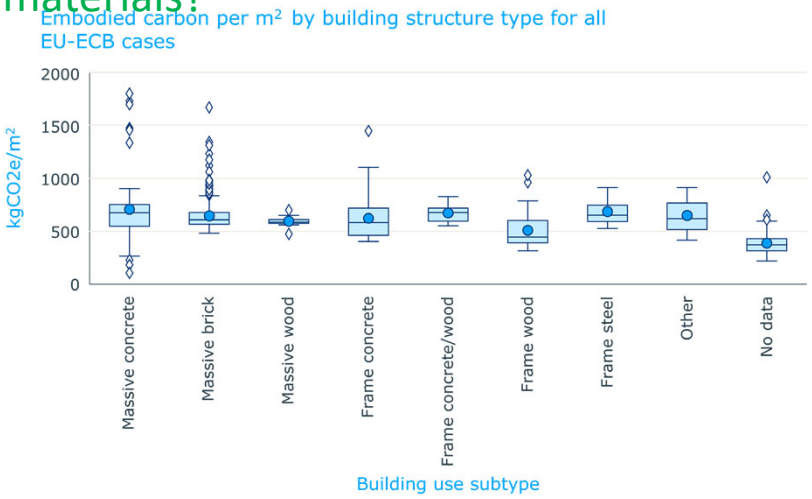
Would it help to replace concrete by other materials?



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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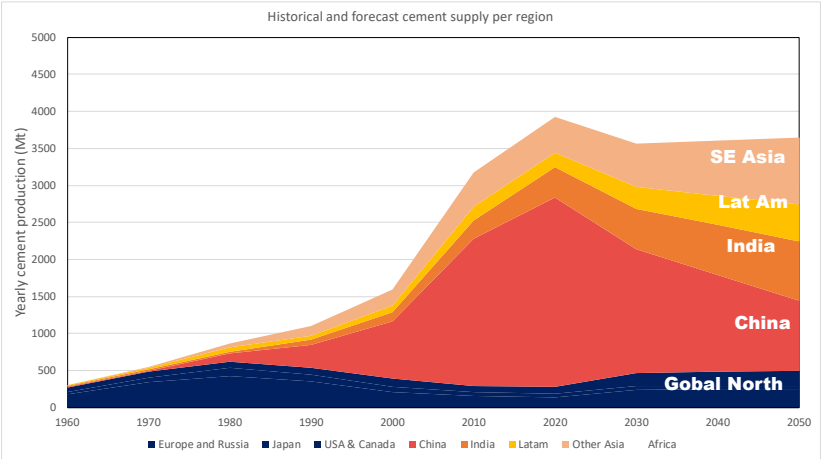
Demand in global south



We need solutions for people in developing countries

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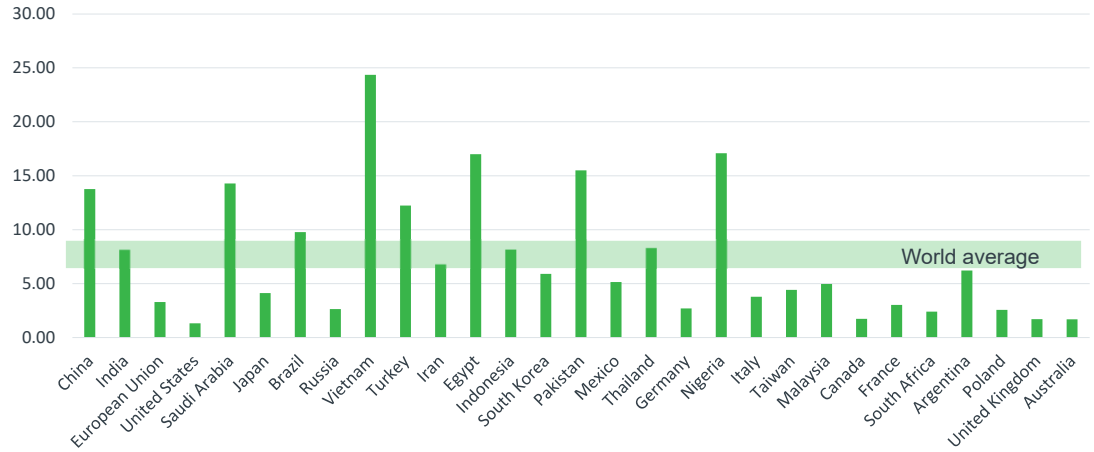
Contribution of cement to CO_2 emissions

Countries ranked by amount of cement production



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

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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

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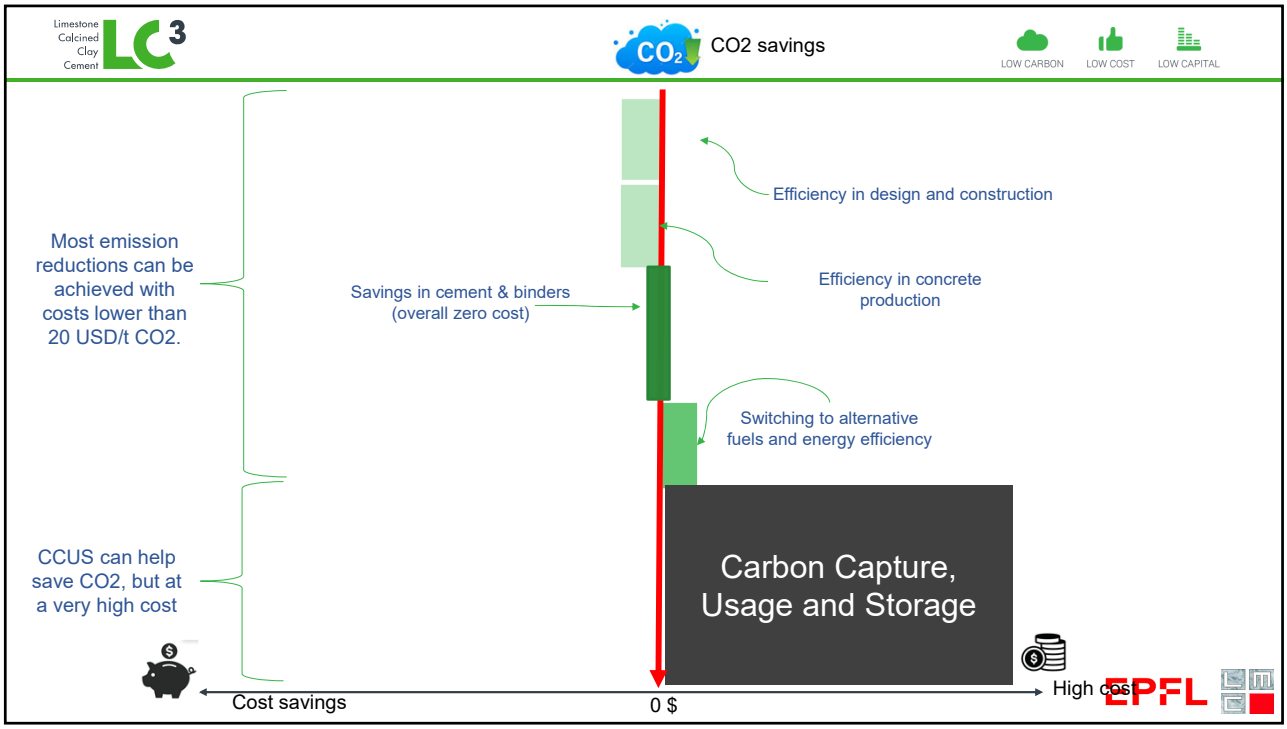
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LC3
CO2 savings
LOW CARBON
LOW COST
LOW CAPITAL
Most emission reductions can be achieved with costs lower than 20 USD/t CO2.
Efficiency in design and construction
Savings in cement & binders (overall zero cost)
Efficiency in concrete production
Switching to alternative fuels and energy efficiency
CCUS can help save CO2, but at a very high cost
Carbon Capture, Usage and Storage
Cost savings
0 $
High cost
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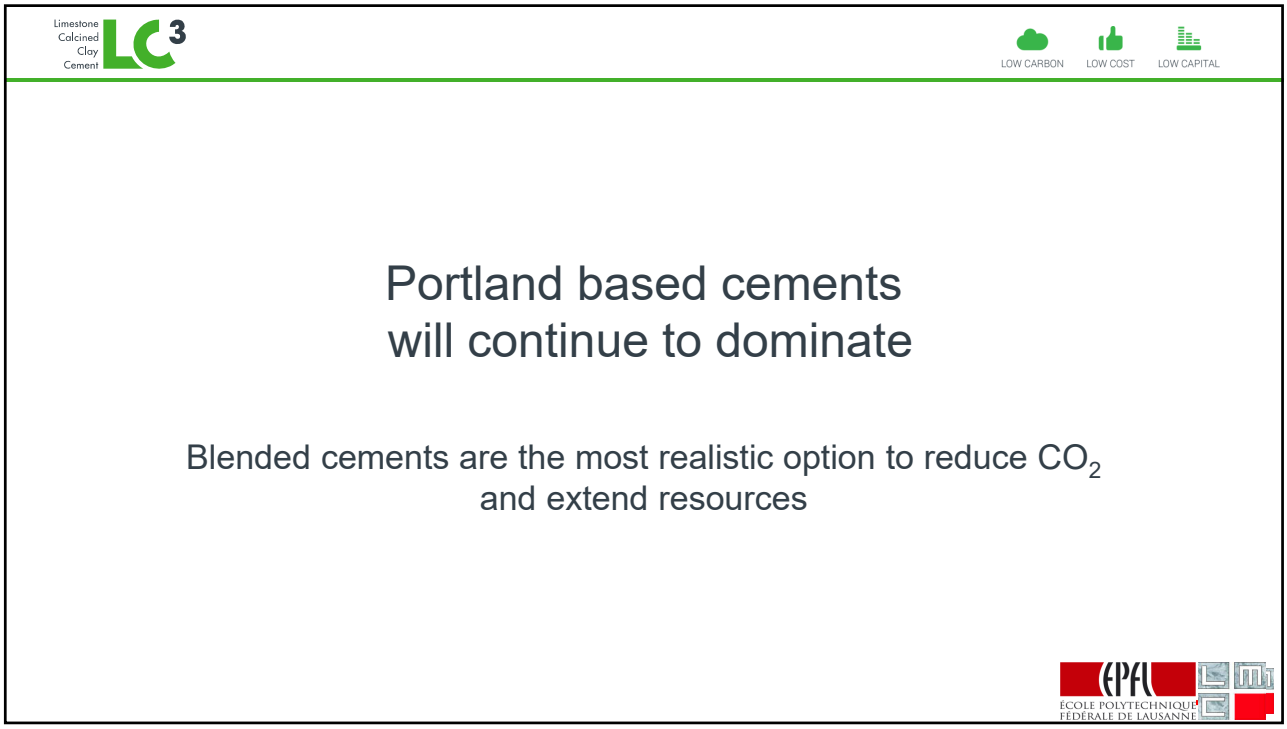
Limestone Calcined Clay Cement
LC3
LOW CARBON
LOW COST
LOW CAPITAL
Portland based cements will continue to dominate
Blended cements are the most realistic option to reduce CO_2 and extend resources
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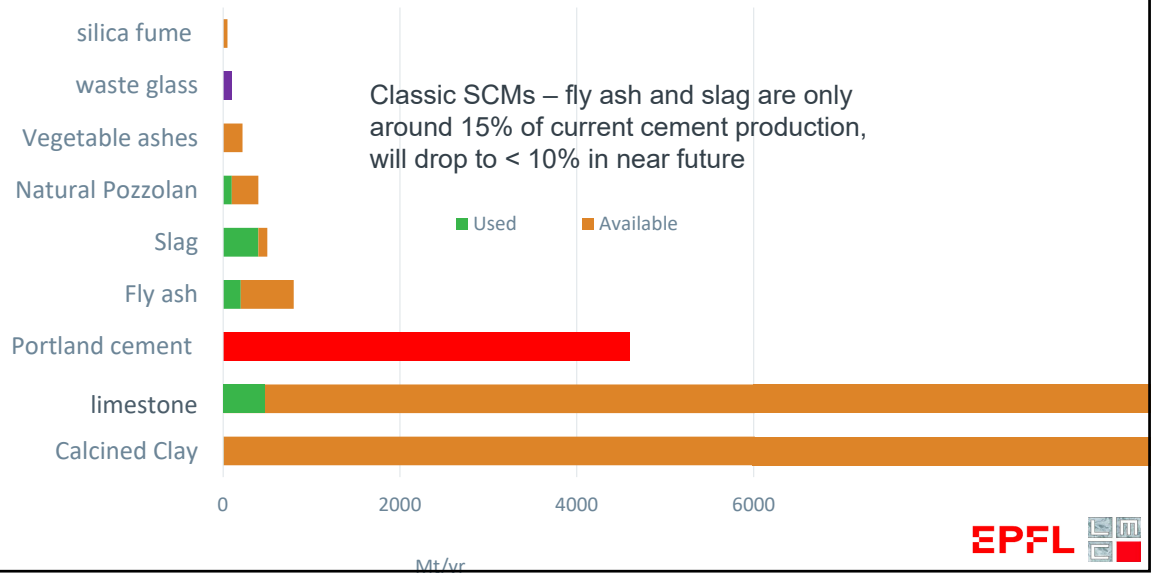
Availability of SCMs



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 LC^3 project supported by SDC. **Started 2013**

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Agency for Development and Cooperation SDC

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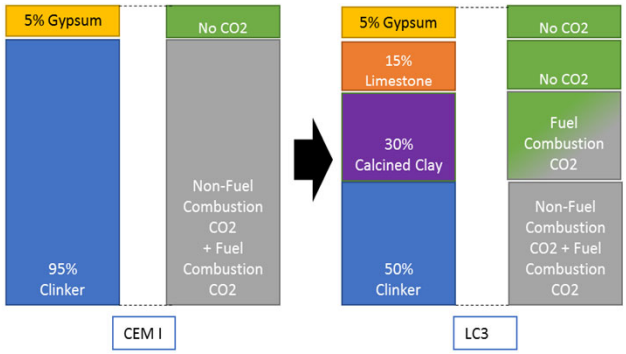
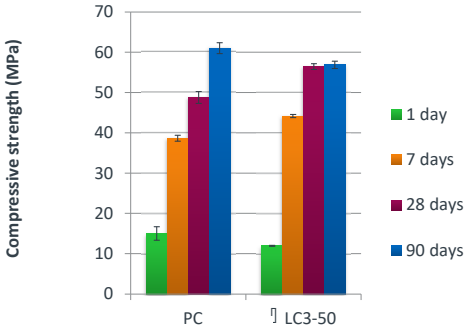
What is LC³



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

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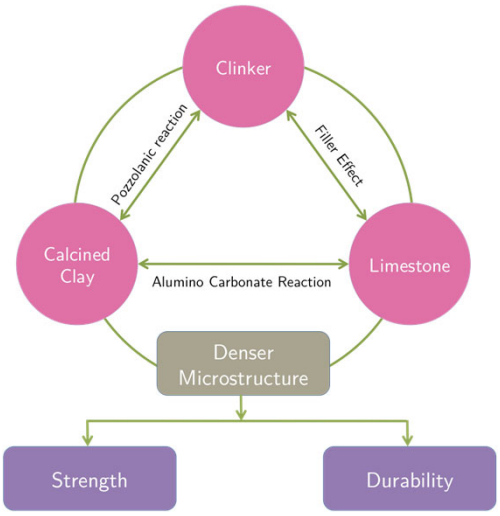
Synergy



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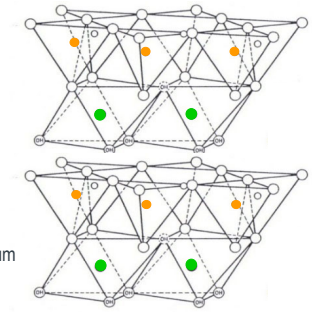
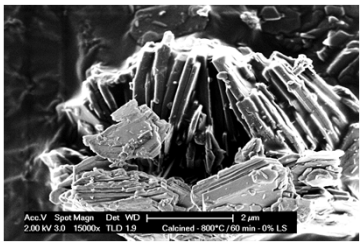
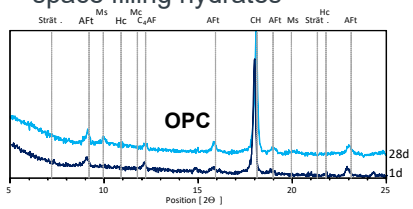
Why can we get such high replacement levels?

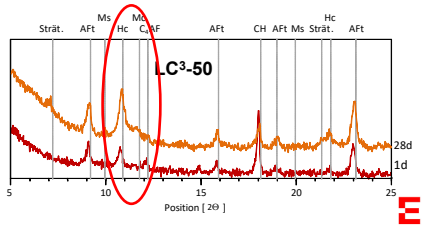
» Calcination of kaolinite at **700-850°C** gives metakaolin: much more reactive than glassy SCMs





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





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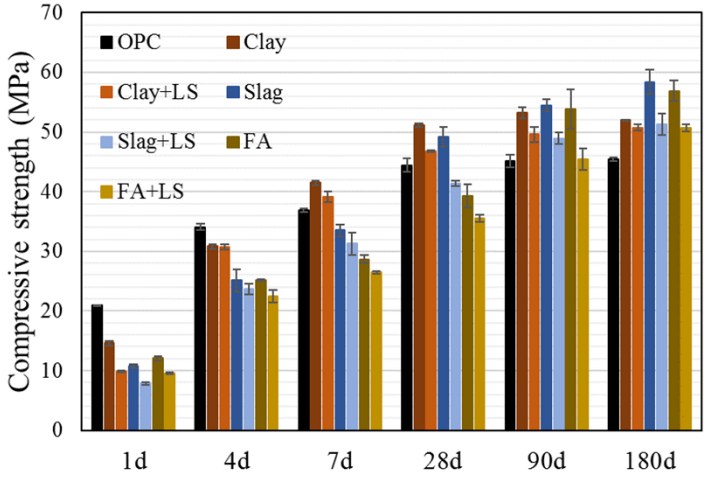
Comparison of calcined kaolinitic clay, slag and fly ash



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

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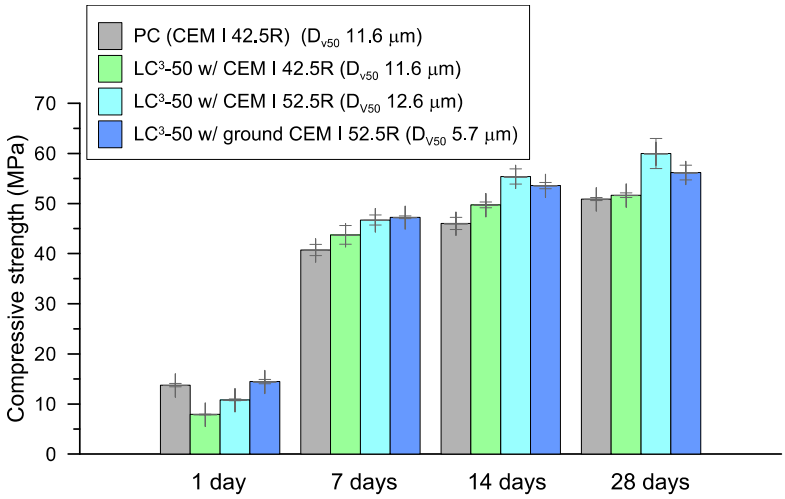
Possible to get early strength by grinding finer



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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)

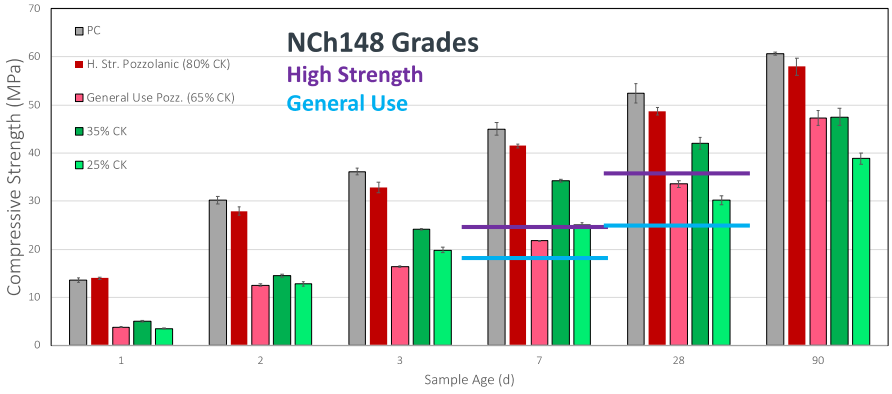
General use (65% CK)

LC³-35 (35% CK)

LC³-25 (25% CK)

Clinker savings

40-45%



The reactivity of SCMs matters!

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What kinds of clay are suitable?

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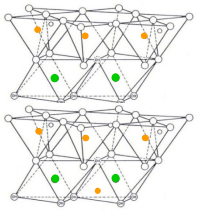
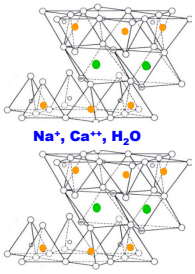
Three basic clay structures

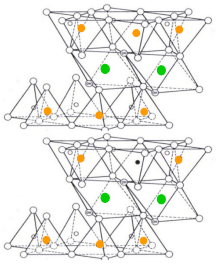
Kaolinite (1:1)



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

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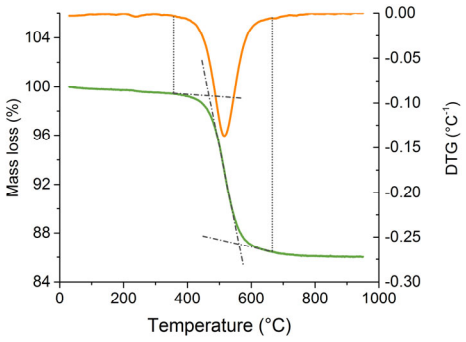
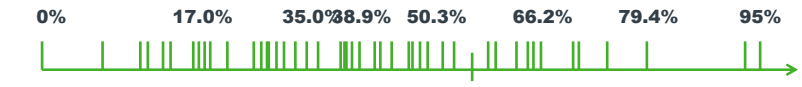
Over 70 clays studied from around the world

Different calcination conditions
Different compositions, impurities
Different physical properties





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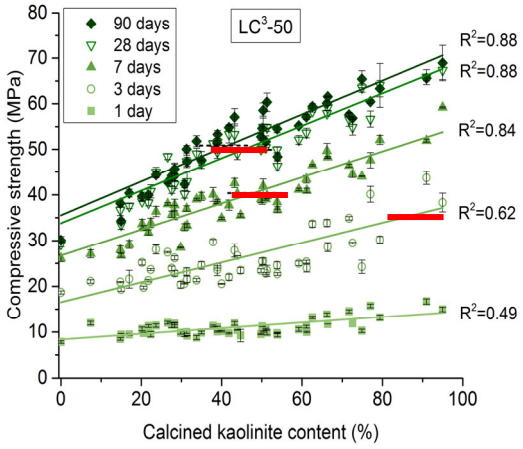
Benchmark test of clay strength

- 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

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Ideal kaolinite content 30-60%

- 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*

- These kind of materials are not documented in official reserves of “kaolin”
- The amounts of suitable materials 100s of times higher than such reserves

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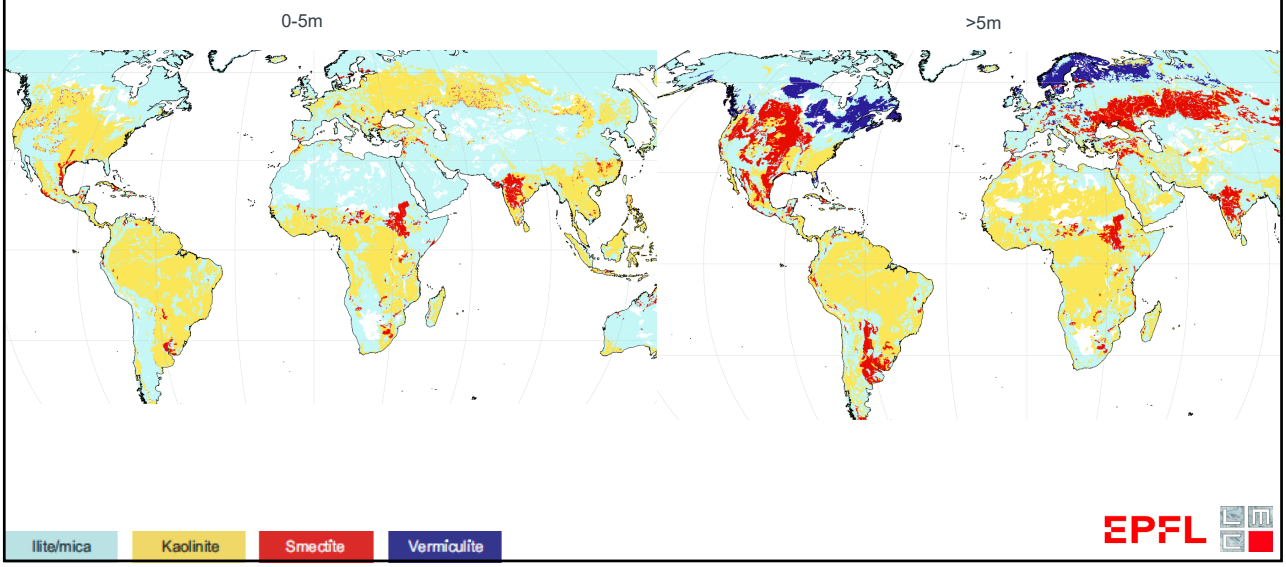
Distribution of Kaolinitic clays

Ito and Wagai, Scientific data 2017



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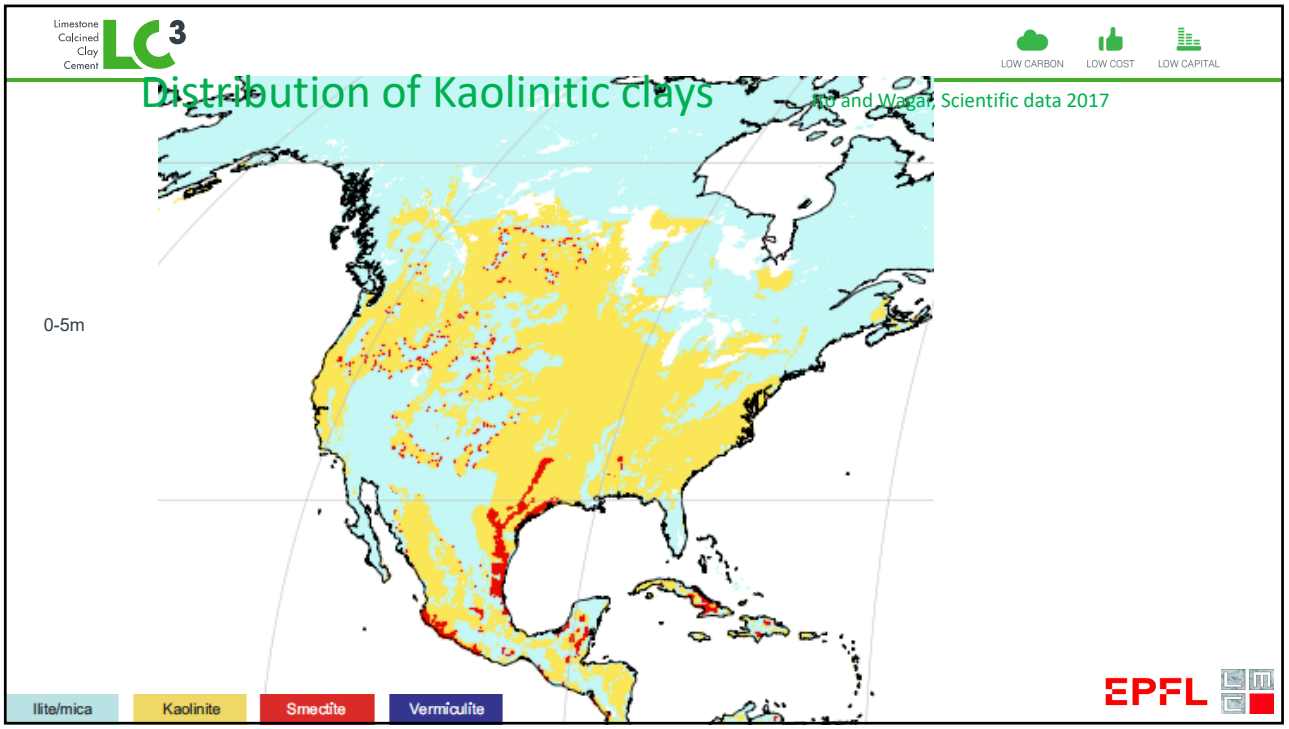
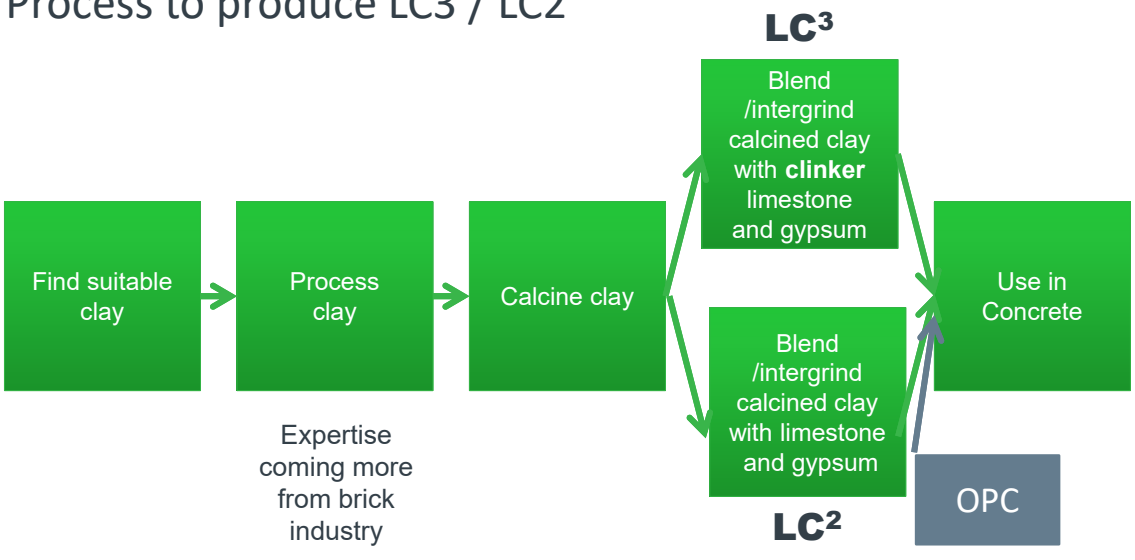
Distribution of Kaolinitic clays

Dai and Wagai, Scientific data 2017



Process to produce LC3 / LC2



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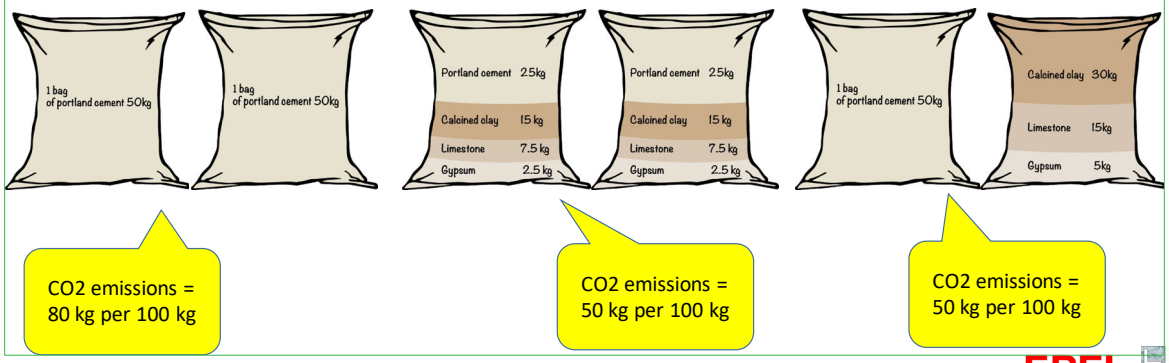
LC3 Blend at cement plant

LC2 Blend at ready mix plant

Ordinary Portland Cement : 100 kg = 2 bags
Conventional solution

LC3: 100 kg = 2 bags
(pre-mixed at factory) Needs new standards in most countries
Clinker factor = 50 %

LC2: 100 kg = 1 bag Portland + 1 bag LC2
(mixed at concrete ready mix site) Already possible with existing standards in most countries, Clinker Factor also 50 %



CO2 emissions = 80 kg per 100 kg

CO2 emissions = 50 kg per 100 kg

CO2 emissions = 50 kg per 100 kg

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Calcination of clay

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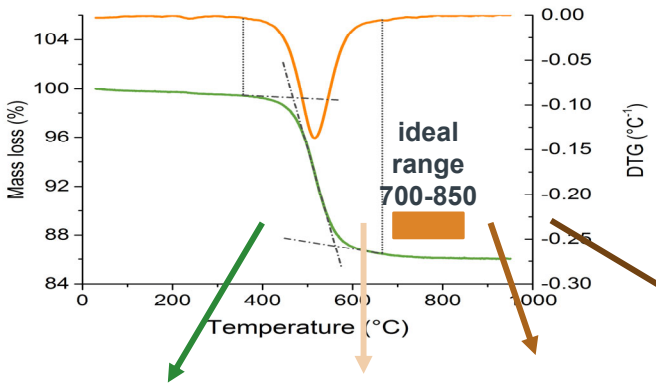
Temperature window 700-850°



<600 Not reactive

600-700 dehydroxlation complete but reactivity increases

850-1000 Surface area reduced reactivity decreases

>1000 crystalline phases formed no reactivity

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Calcination methods:

Rotary kiln

- Advantages
  - Robust
  - Tolerant to moisture content up to 20%
  - Fairly large particles (few mm) can be calcined efficiently
  - Easy colour control technology
- Disadvantages
  - Reputed to have higher energy consumption

But real kiln built in Ivory Coast has energy of 550 kCal/ kg, 2.3 MJ/kg

Flash calcination

- Advantages
  - Calcination more energy efficient
  - Lower opex?
- Disadvantages
  - Very low moisture (<5%)
    - Dryer and dry storage silo required
  - Small particles
    - crusher

To date testing many clays indicates no significant difference in reactivity

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Demonstration structure

Around 14 tonnes of CO_2 saved
Compared to existing solutions

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New Calcination plant Ivory Coast

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Colour control at Ivory Coast plant

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Key Advantages

- Chloride resistance
- Suppression of alkali silica reaction

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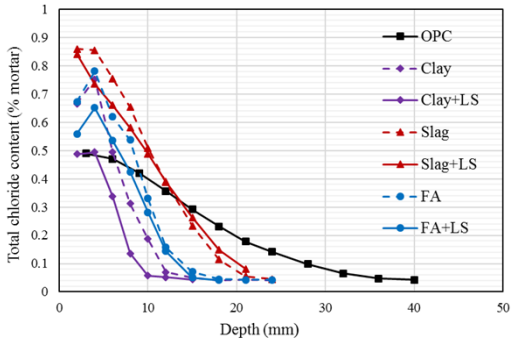
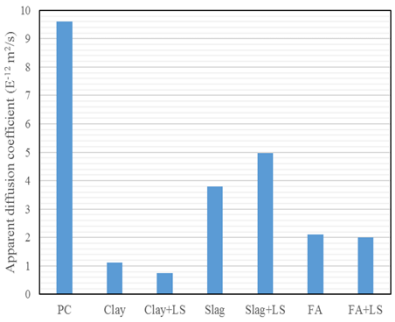
Chloride ponding ASTM





Apparent diffusion coeffs.

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Perceived problems

- Workability
- Carbonation

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Percieved problems

- Workability, good properties can be controlled by admixtures
- New admixtures now available
- Good cohesion, well suited for SCC

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Self compacting concrete: cohesion

50% FA: 1.5% WRA

50% LC^2: 1.2% WRA

Harsh Vardhan et al. 2020

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Good quality low-tech concrete

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Carbonation

- As for all blended cements carbonation is faster – less CaO buffer
- But results are within requirements for normal design life 50-100 years

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Field data on carbonation

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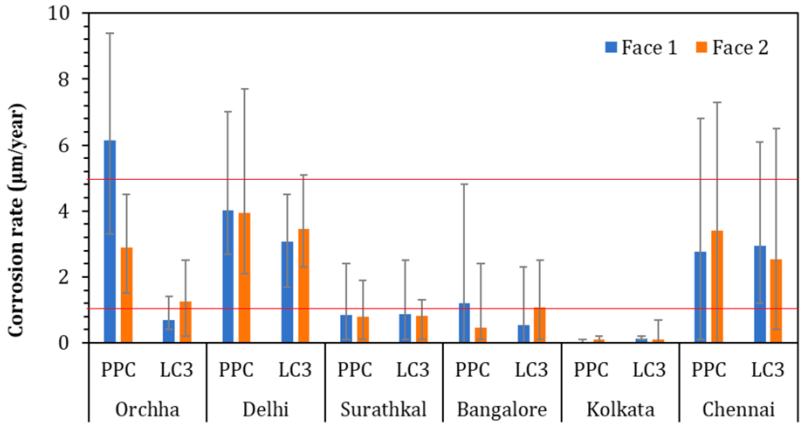
Field data on carbonation



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Impact Engineering properties

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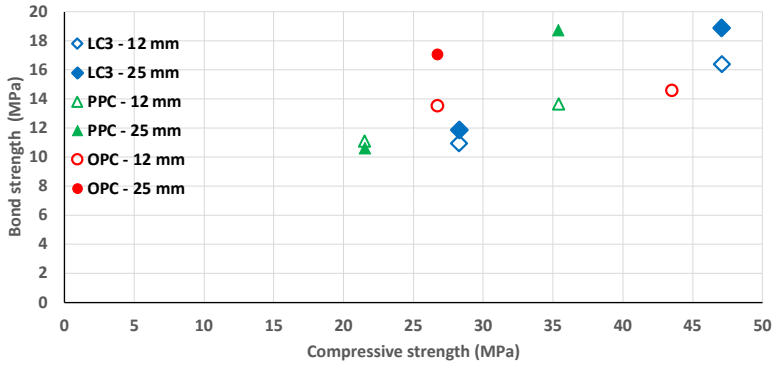
Bond with reinforcement



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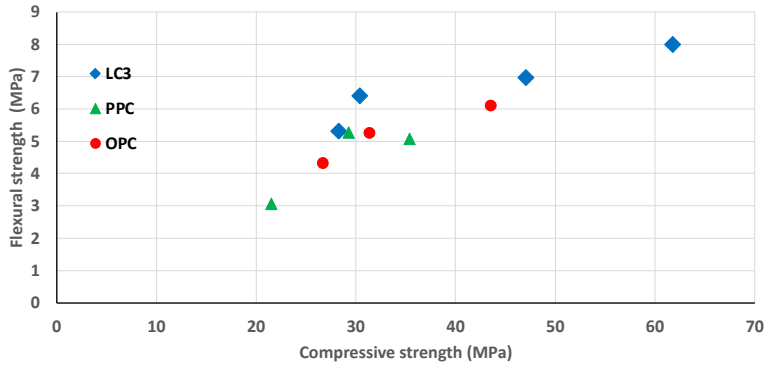
Flexural strength



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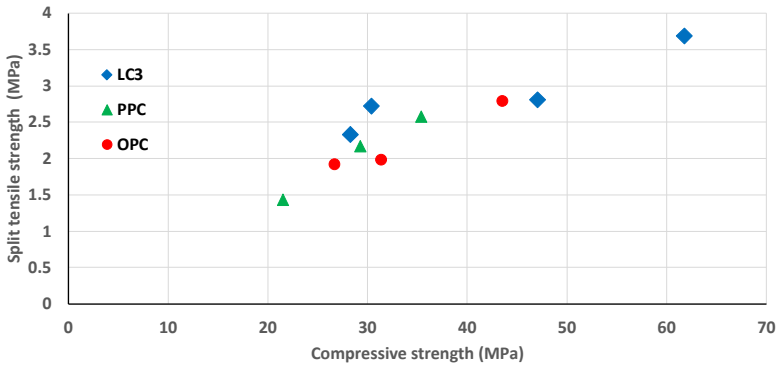
Split tensile strength



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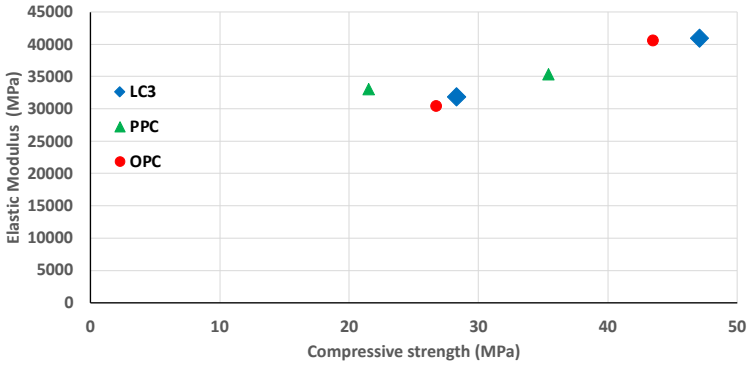
Elastic Modulus



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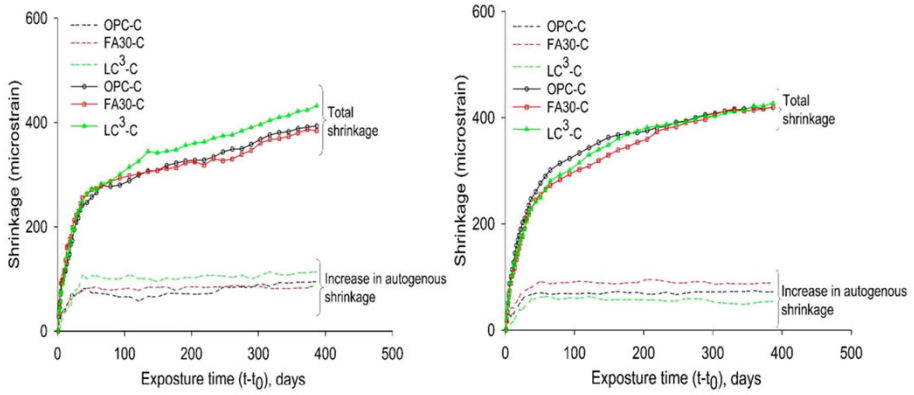
LOW CARBON LOW COST LOW CAPITAL

Shrinkage of concrete



Dhandapani at al. 2018

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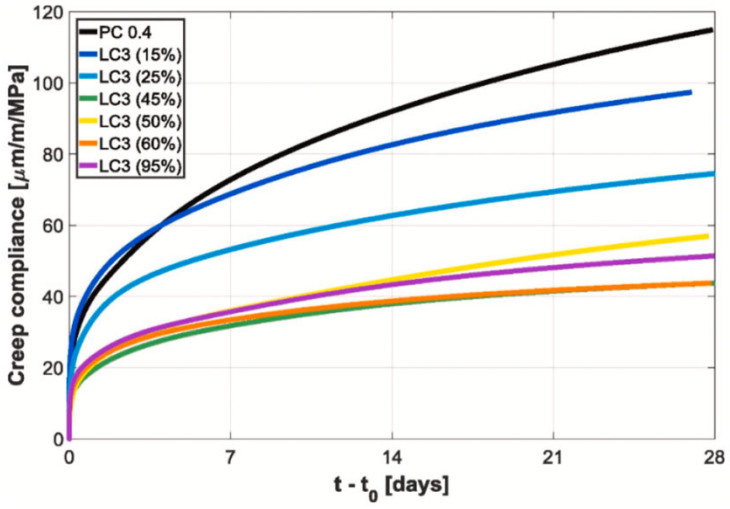
Creep, significantly lower



Ston et al. 2019

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Limestone Calcined Clay Cement LC3

LOW CARBON LOW COST LOW CAPITAL

Impact on CO_2 emissions

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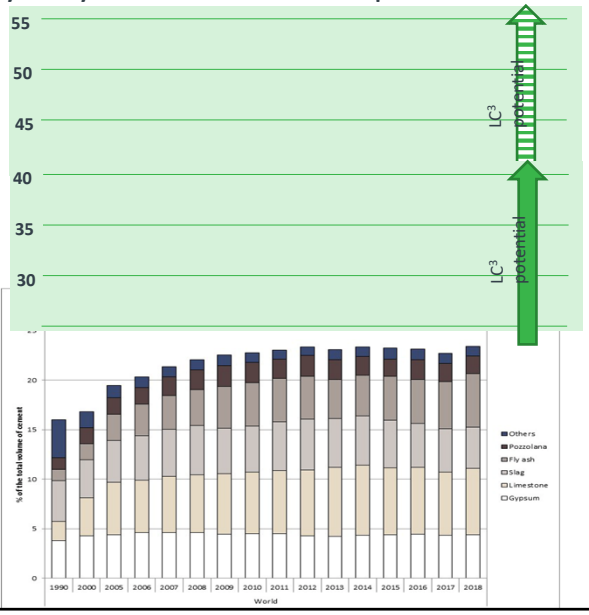
Limestone Calcined Clay Cement LC3

LOW CARBON LOW COST LOW CAPITAL

DEMJO1

Calcined Clay only SCM which can expand substitution



> 800 million Tonnes CO_2/yr

> 400 million Tonnes CO_2/yr

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Limestone Calcined Clay Cement LC3

LOW CARBON LOW COST LOW CAPITAL

ASTM C595/C595M already covers blended cements such as LC3

- **Type IT—Ternary blended cement** : ternary blended cement, n—a blended hydraulic cement consisting of Portland cement with either a combination of two different pozzolans, slag and a pozzolan, a pozzolan and a limestone, or a slag and a limestone.
  - Cem IT (AX) (BY)
    - A and B: slag (S), pozzolan (P) or Limestone (L)
    - X and Y: targeted percentage of components A and B respectively
- LC3 could be designated as: Ternary cement type IT (P30)(L15)
  - Requirements:
    - Limestone (L) ≤ 15% mass
    - Pozzolan (P) ≤ 40% mass
    - Limestone (L) + Pozzolan (P) + slag (S) ≤ 70% mass
    - Clinker ≥ 30% mass
  - Formulations:
    - Type IT (P30)(L15): typical LC3 combination for high early strength cement (50% clinker) (type III)
    - Type IT (P40)(L15): LC3 combination for bag cement (40% clinker) (type I)
- Options for the production of this cement (an the cement factory)
  - Co-grinding all components together
  - Separate grinding
    - Cement type III (high early strength)
    - LC2 (60% P-35%LL-5% gypsum)
    - Cem type III (HE) and LC2 will be blended and homogenized at plant
  - Both cements have to comply with composition of ASTM C595/C595M – 14

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Slide 49

DEMJO1 scm?

Demenge Jonathan EDA DEMJO, 4/1/2022

Limestone Calcined Clay Cement LC3

LOW CARBON LOW COST LOW CAPITAL

Prescriptive standards more and more complex

- New RILEM technical Committee TC PHC,

  to lay the groundwork for new performance standard
  - Strength, better mortar formulations
  - Simple tests for dimensional stability
  - “minimum C-S-H content
  - durability

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Limestone Calcined Clay Cement LC3

LOW CARBON LOW COST LOW CAPITAL

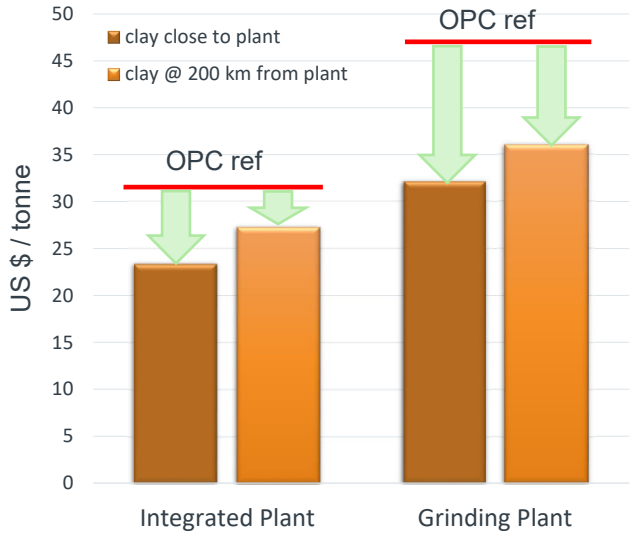
Financial Feasibility

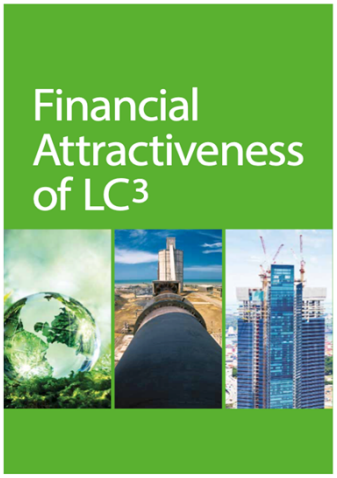
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Limestone Calcined Clay Cement LC3

LOW CARBON LOW COST LOW CAPITAL

Lower cost: Cementis study





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

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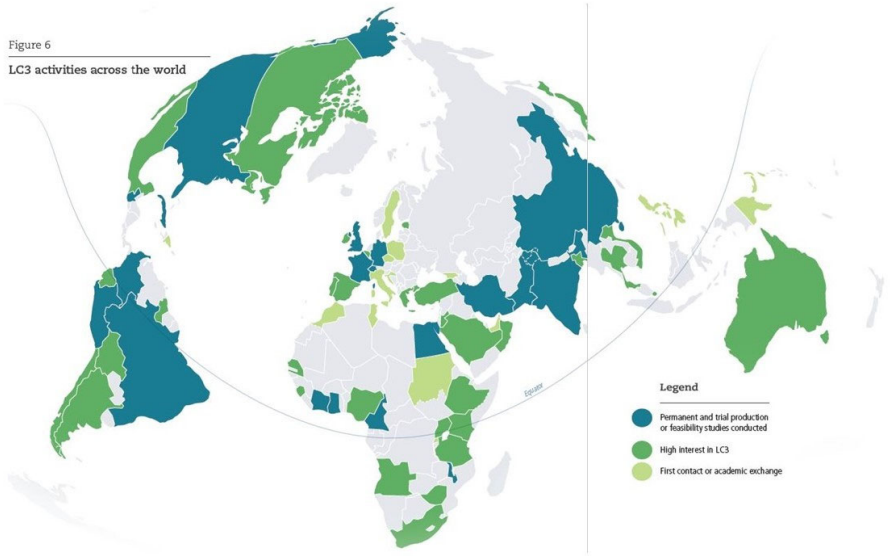
Limestone Calcined Clay Cement LC3

LOW CARBON LOW COST LOW CAPITAL

LC3 activities across the world



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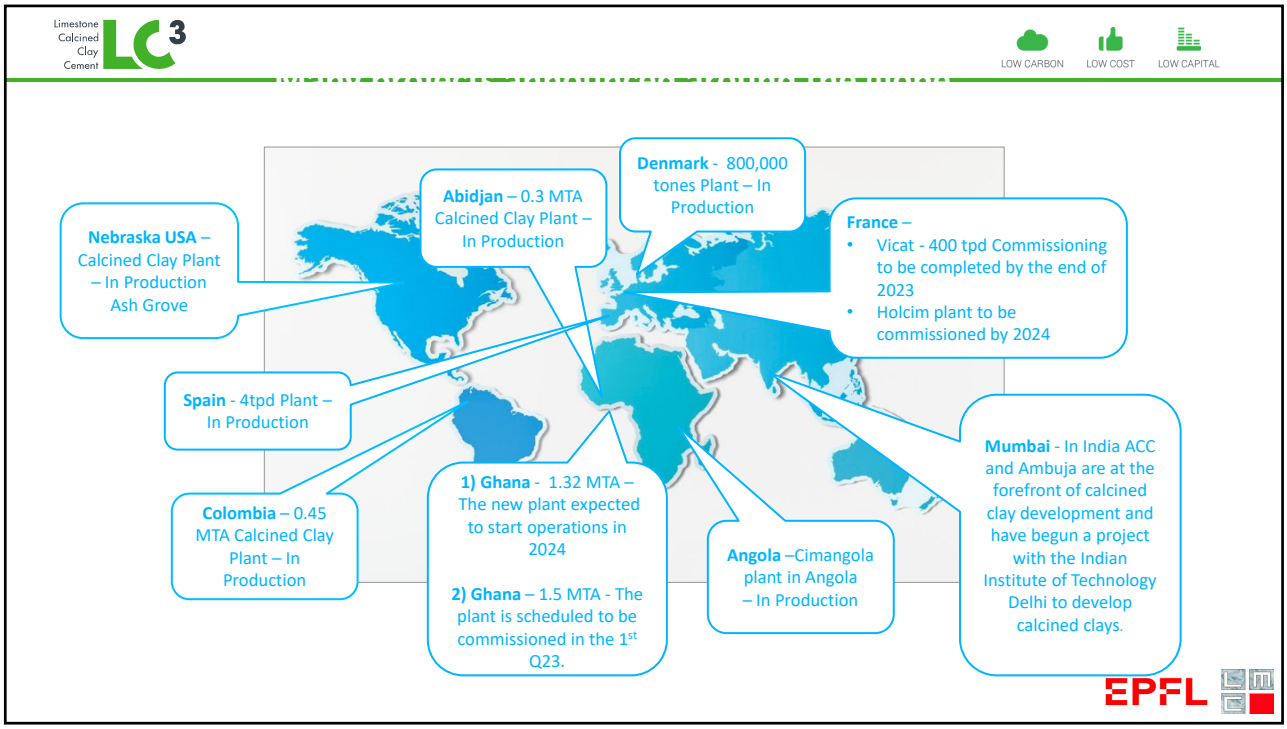
Limestone Calcined Clay Cement
LC3
LOW CARBON
LOW COST
LOW CAPITAL
Nebraska USA – Calcined Clay Plant – In Production Ash Grove
Abidjan – 0.3 MTA Calcined Clay Plant – In Production
Denmark - 800,000 tones Plant – In Production
France –
Vicat - 400 tpd Commissioning to be completed by the end of 2023
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.
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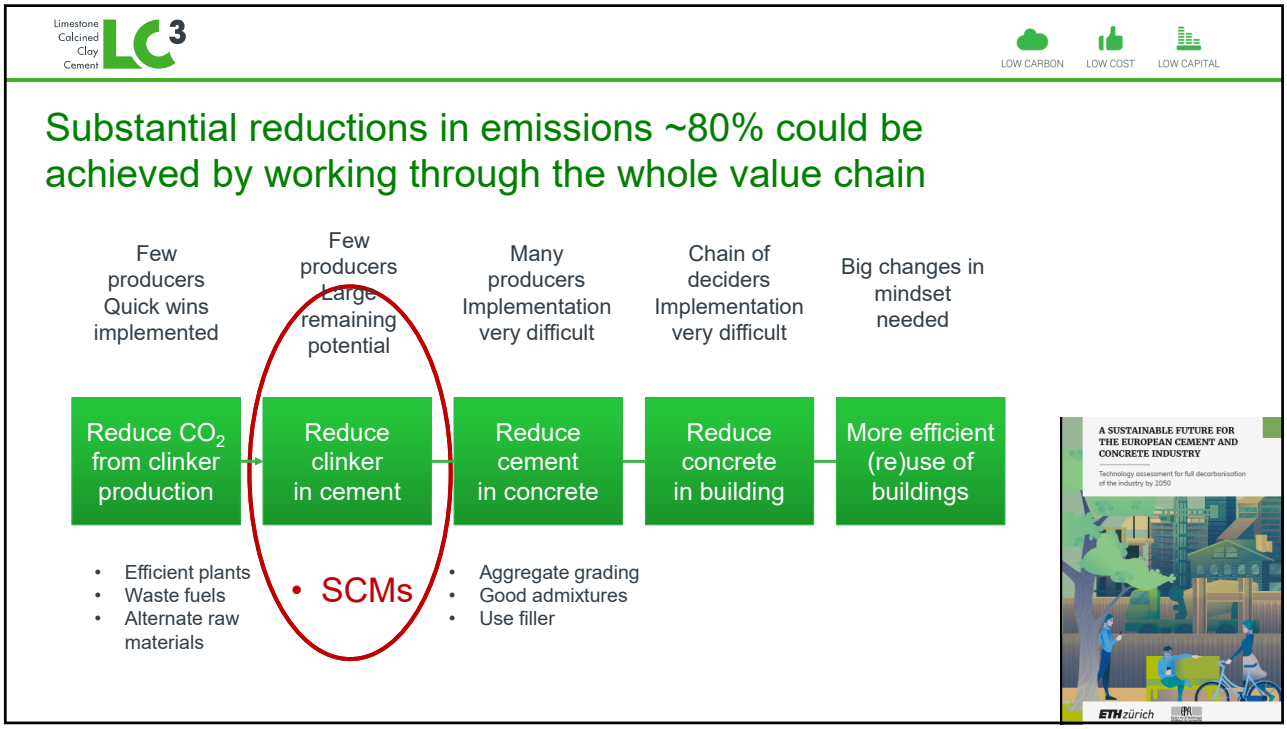
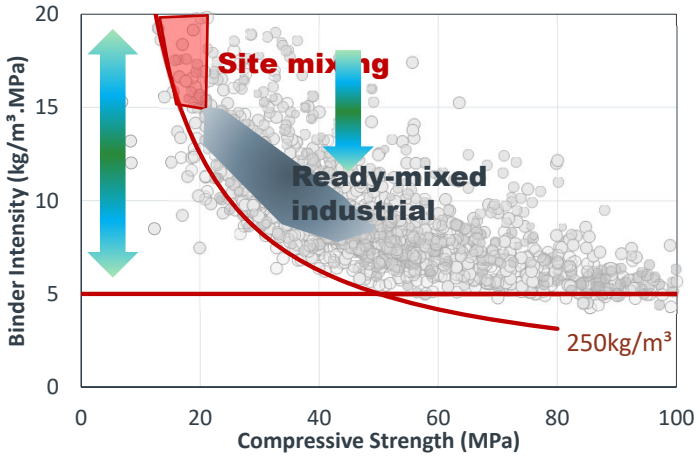

Limestone Calcined Clay Cement
LC3
LOW CARBON
LOW COST
LOW CAPITAL
Substantial reductions in emissions ~80% could be achieved by working through the whole value chain
Few producers Quick wins implemented
Few producers Large remaining potential
Many producers Implementation very difficult
Chain of deciders 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
A SUSTAINABLE FUTURE FOR THE EUROPEAN CEMENT AND CONCRETE INDUSTRY
Technology assessment for full decarbonisation of the industry by 2050
ETH zürich

Limestone Calcined Clay Cement LC3

LOW CARBON LOW COST LOW CAPITAL

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

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Limestone Calcined Clay Cement LC3

LOW CARBON LOW COST LOW CAPITAL

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**

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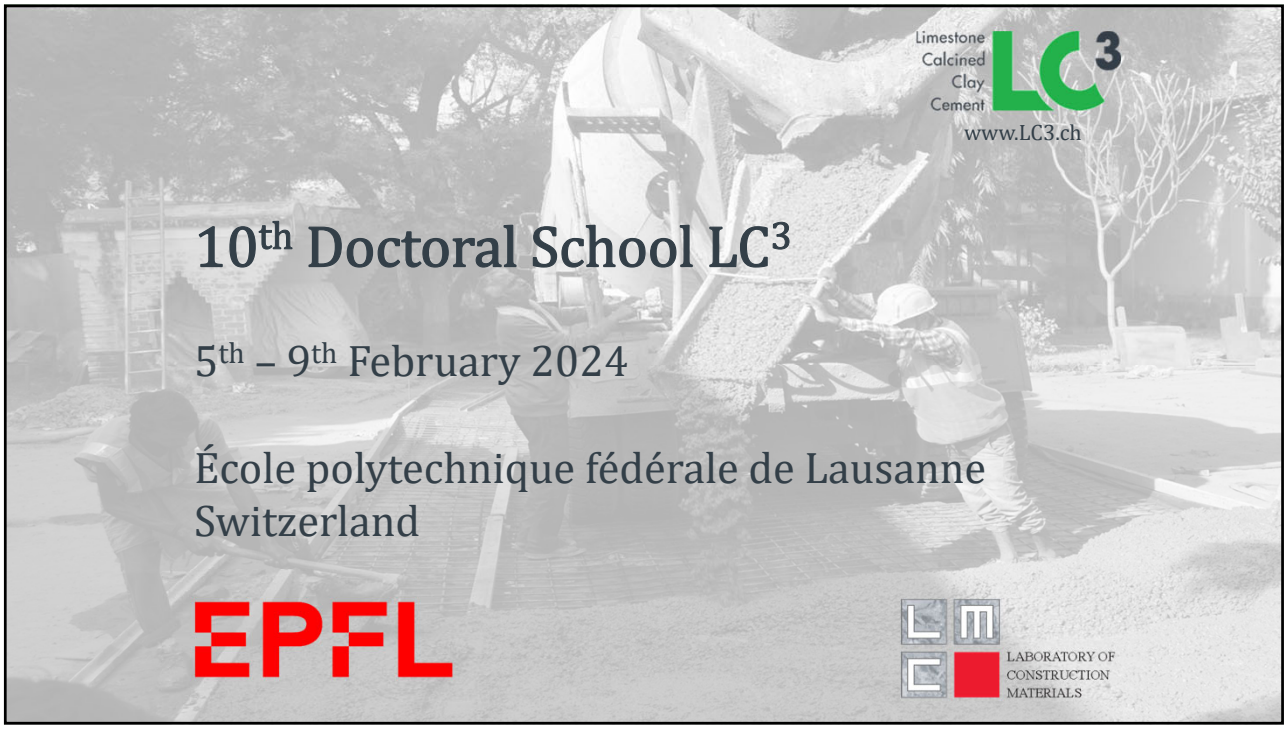
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www.LC3.ch
10th Doctoral School LC3
5th – 9th February 2024
École polytechnique fédérale de Lausanne
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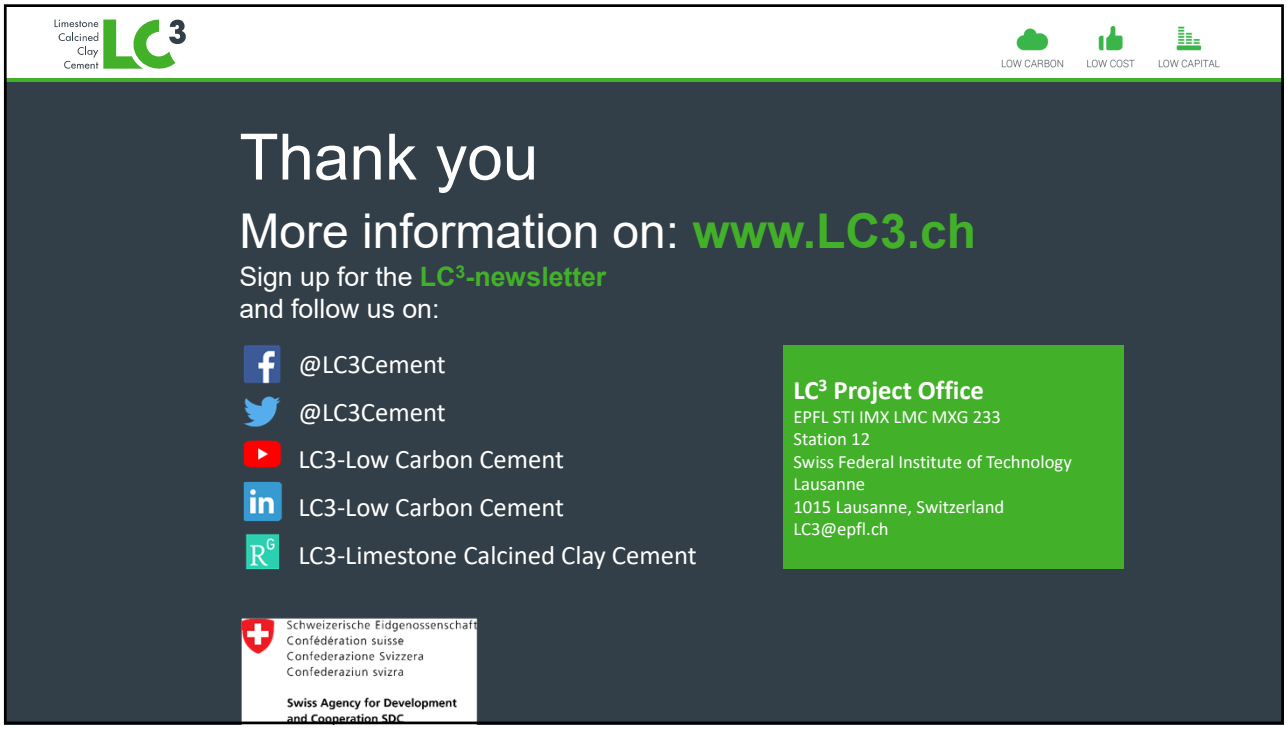
LABORATORY OF CONSTRUCTION MATERIALS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Confédération suisse
Confederazione Svizzera
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Swiss Agency for Development and Cooperation SDC

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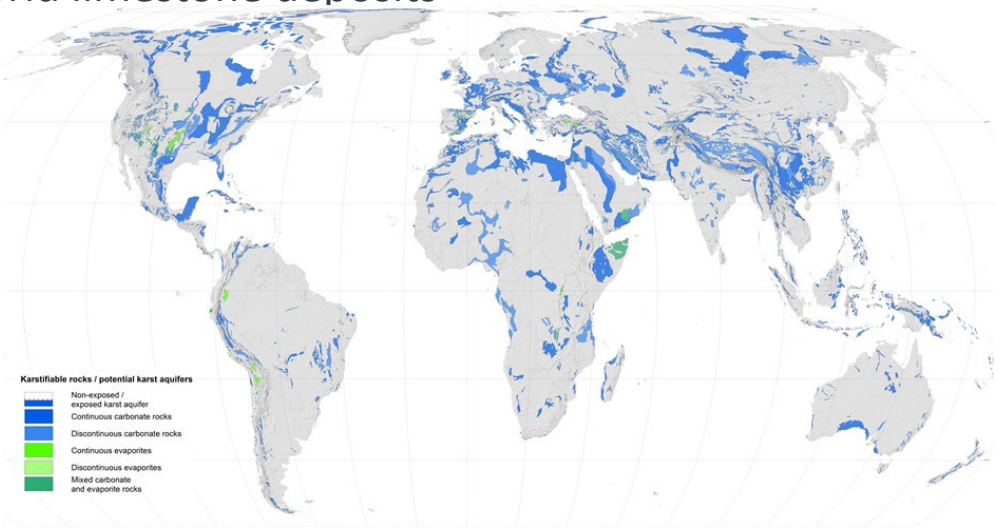
World limestone deposits



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