Institute for Building Materials
Physical Chemistry of Building Materials

Less clinker in cement, less paste in concrete: a two-fold strategy towards decarbonization

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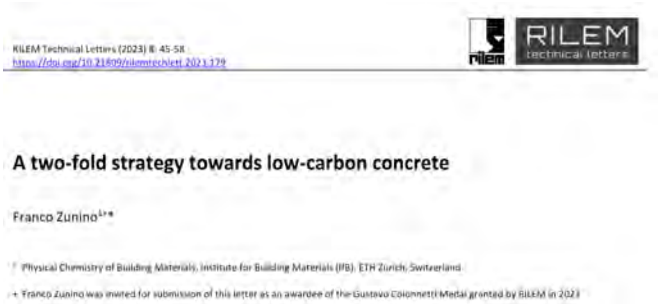
NRMCA Concrete Innovation Sessions

1

About this presentation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A two-fold strategy towards low-carbon concrete

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* Franco Zunino was invited for submission of this letter as an awardee of the Gustavo Colonnetti Medal granted by RILEM in 2023

RILEM Technical Letters (2023) 8: 45-58 (open access!)

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2

Concrete is not sustainable… right?

Concrete

2nd

Most used resource after H_2O

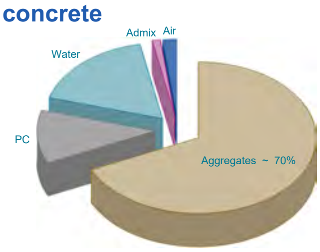
Portland cement

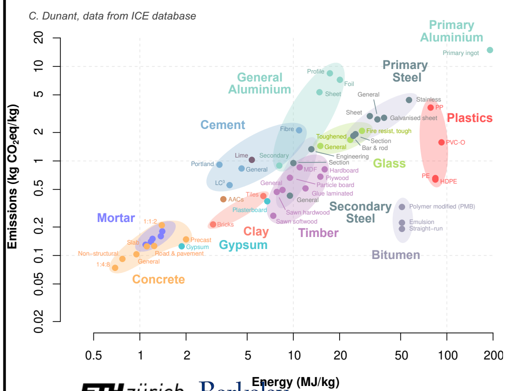
~ 7%

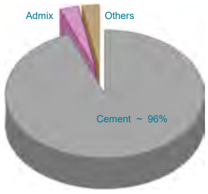
Industrial energy use

~ 8%

Anthropogenic CO_2







Clinker dominates the CO_2 footprint of concrete

Concrete is a **low carbon** construction material, problem is **amount**

Cementitious materials **will remain dominant** in construction

We **need to improve** an already well-performing material!

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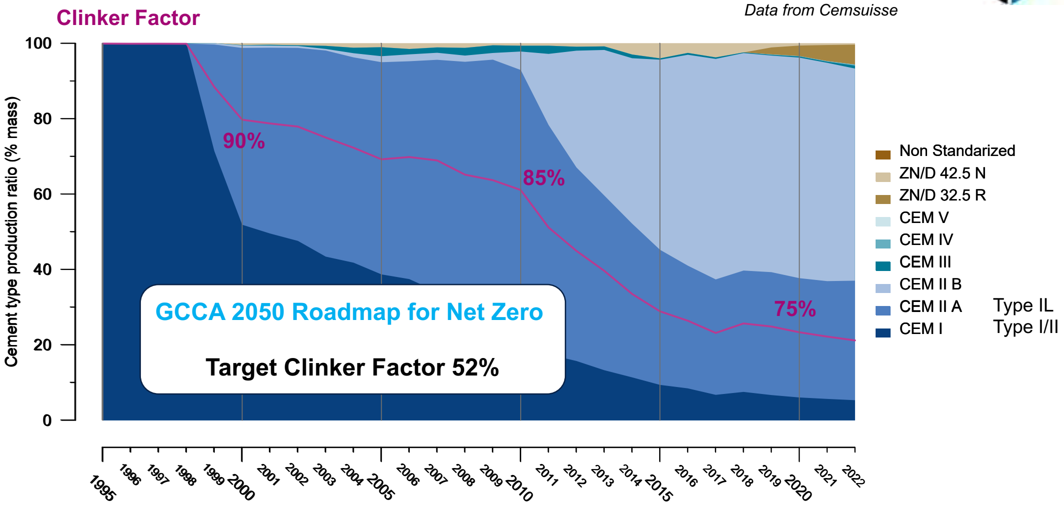
3

The Swiss market for cement

Data from Cemsuisse



- Widespread adoption of Type IL is a crucial step, but not sufficient
- We need to continue reducing the overall clinker factor in cement (new SCMs)

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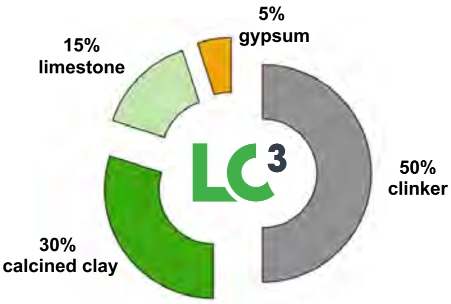
4

What we have achieved with calcined clays



Calcination

Kaolinite → Metakaolin

AS_2H_2 → AS_2 +2H

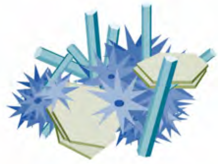
A: Al_2O_3
S: SiO_2
H: H_2O

Metakaolin

- Reactive
- Abundant

✓ 50% clinker
✓ 30-40% less CO_2 compared to PC
✓ Equivalent performance to PC
✓ Enhanced durability

CEM II/C-M (Q-LL) *(EN 197-5)*
CEM IT (P30)(L15) *(ASTM C595)*



Fundamental science

Technology and Applications

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5

Reactivity of SCMs saves clinker

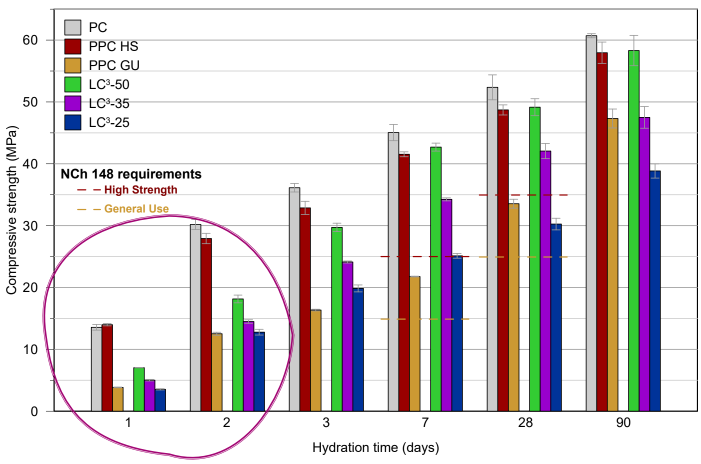
LC3 versus portland pozzolanic cements (NP) from the Chilean market

PPC HS : 80% CK
PPC GU : 65% CK

PPC HS → LC3-35

PPC GU → LC3-25

ASTM C1897



Save 40-45% clinker with LC3 compared to NP

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6

Moving the spotlight on cement back to concrete

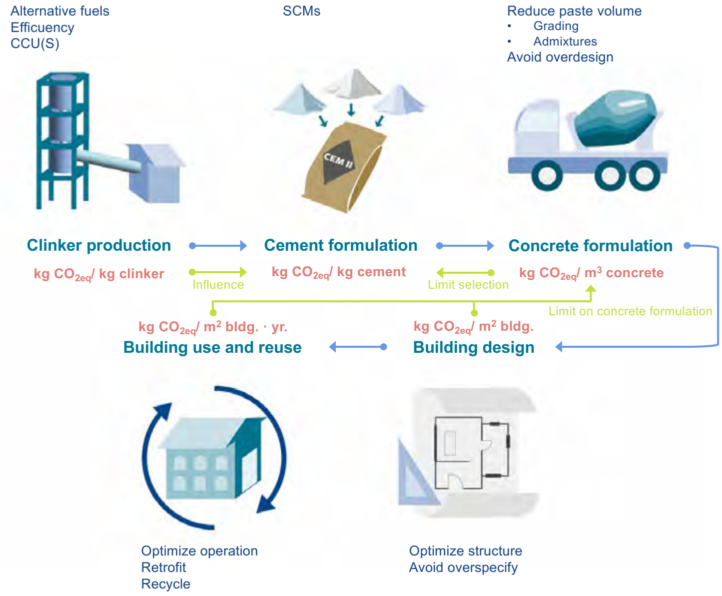
7

Levers to decarbonize the concrete industry

Solid fundamental scientific understanding

+

Environmentally aware civil engineering practice



8

Concrete is the building material, not cement!

At the end of the day, what matters is the amount of CO_2 per unit volume of concrete

Clinker Factor

Paste volume

Admixtures

The golden rule is to develop and use (blended) **cements with the least amount of embodied CO_2 that have sufficient performance** to enable their use without a significant increase of binder content per m^3

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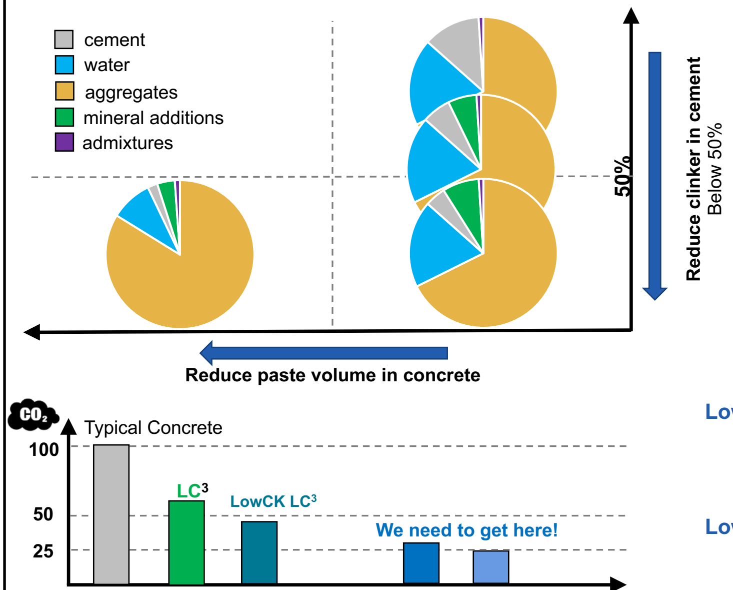
9

A two-fold strategy for low-carbon concrete



The road from traditional concrete to the green concrete of the future is paved with SCMs (clays, limestone) ….. **and high performance admixtures!**

Low Clinker → More SCMs (higher surface area)

+

Low Paste → Less lubrication between aggregate particles

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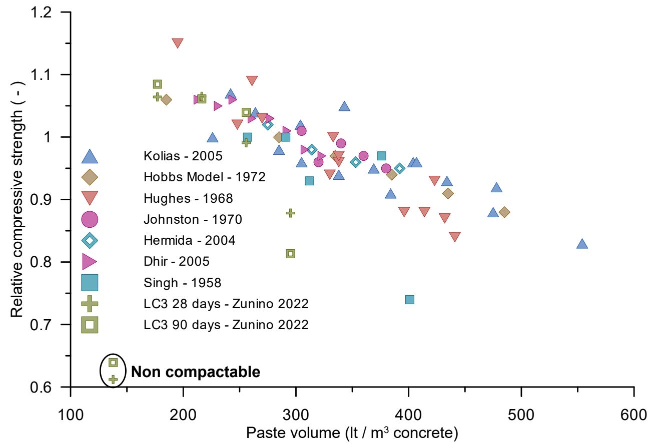
10

The misconception on the paste volume/strength relationship

At constant w/cm, strength of concrete increase with lower paste volumes



Adapted from Hermida with new data

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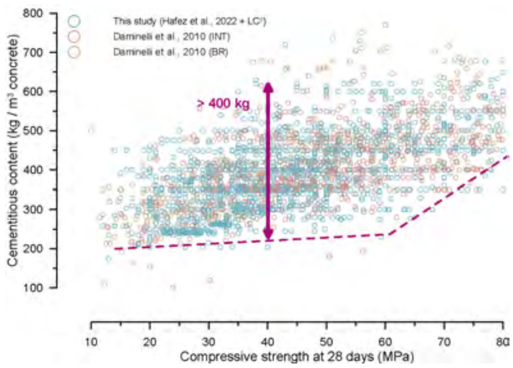
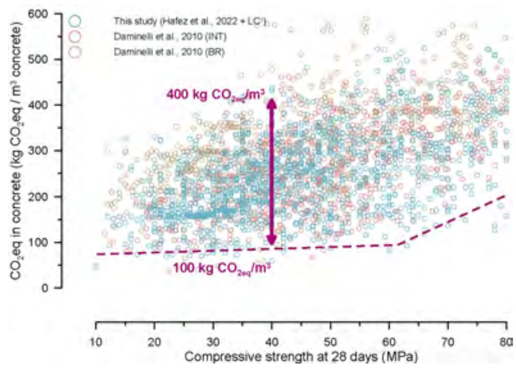
11

We can do with a significantly lower cement content

"Low binder (paste) concrete has low strength"



"High strength means higher embodied CO_2"



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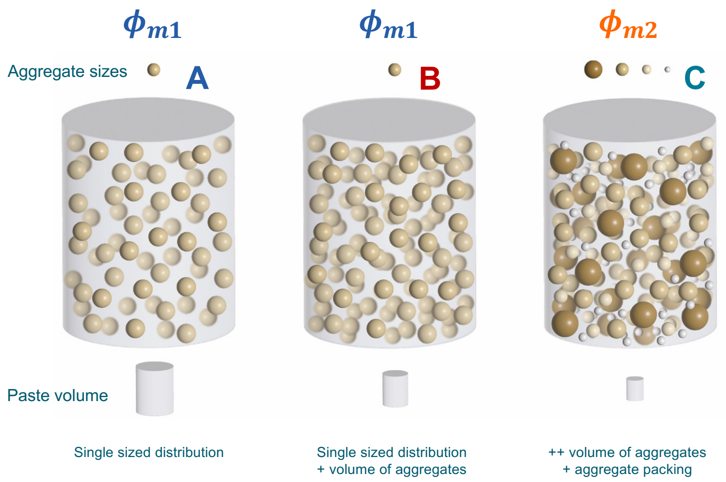
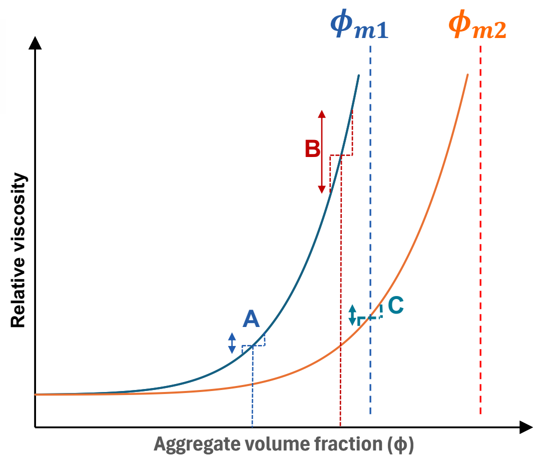
12

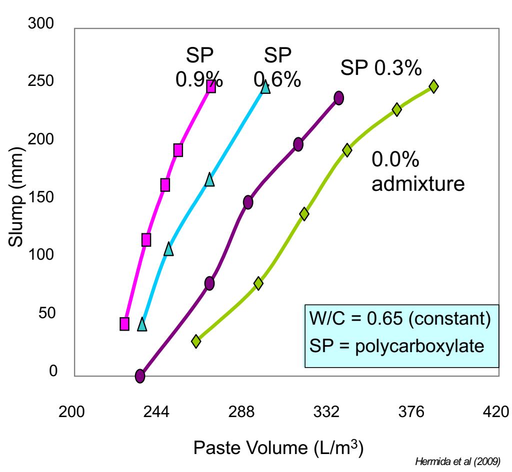
The challenge of workability robustness

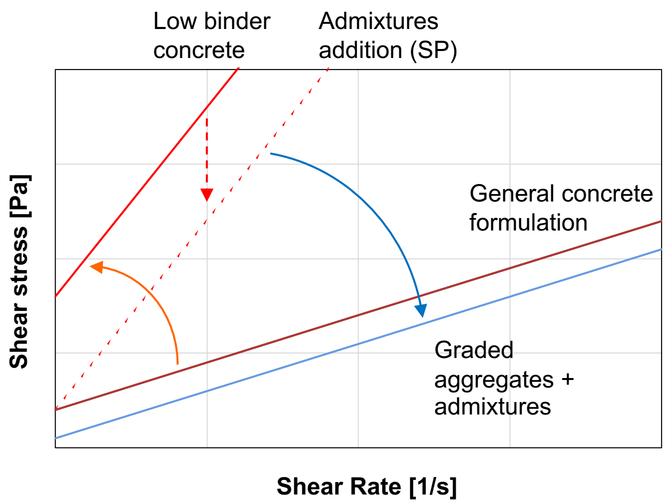




As the volume of paste goes down, workability robusteness can be retained (or increased) by optimizing the packing of the aggregate skeleton

The importance of admixtures and aggregates size distribution



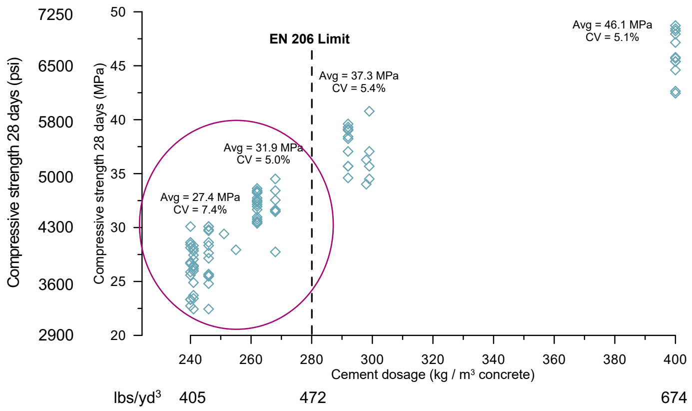


Is it possible to produce low paste volume concrete?

Ready mix concrete conforming to NCh 170

Pozzolanic cement (73% clinker content)

Slump 10 - 12 cm



1 MPa = 145 psi

1 kg / m³ = 1.69 lbs / yd³

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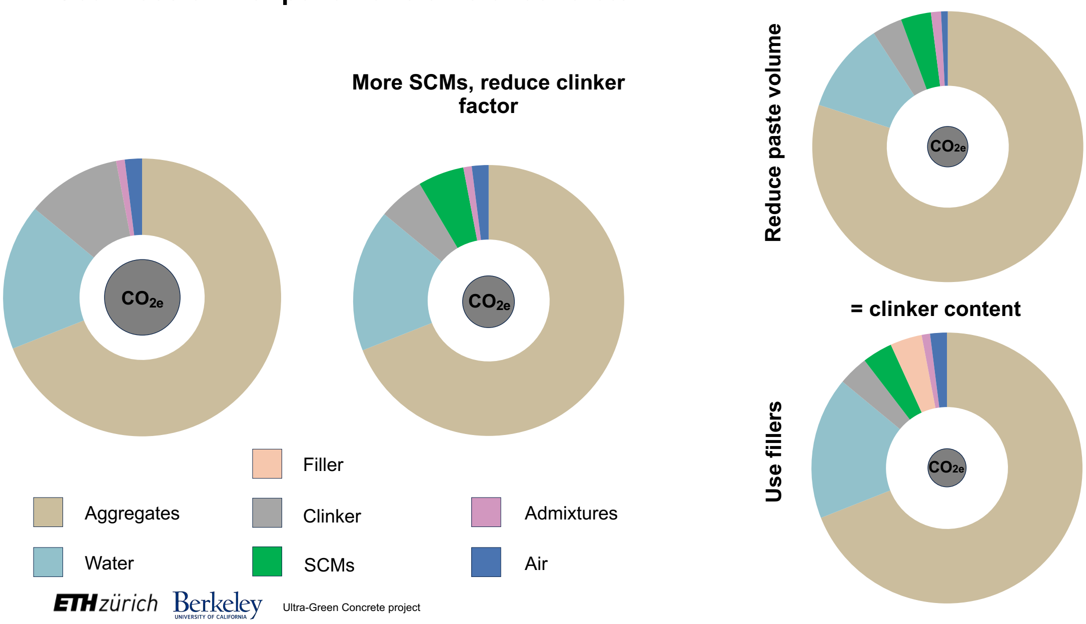
15

Several roads leading to Rome

Goal: less clinker per unit volume of concrete



Flow?

Placing?

Strength?

Durability?

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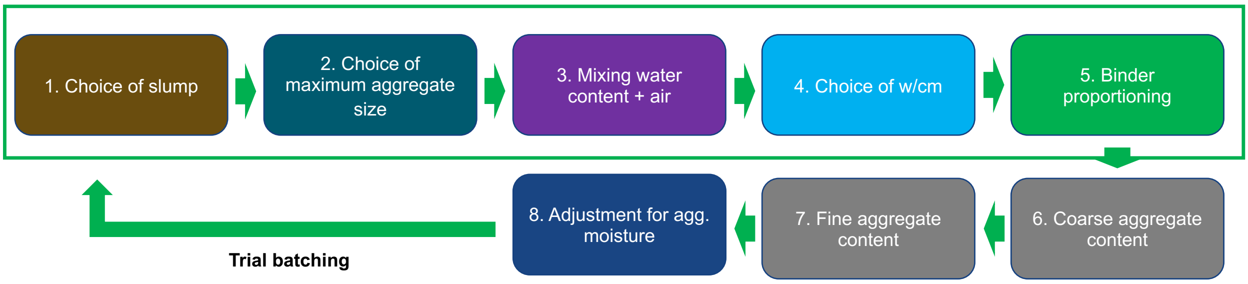
16

Opportunities to reduce CO_{2e} in the mixture design workflow

ACI PRC 211.1-91

Opportunities to reduce embodied CO_{2e} → Paste volume



- Slump (usually an input)
- D_N limited by reinforcement spacing (larger D_N → lower surface/volume ratio)
- Water volume constrained by amount of wettable surface (admixtures)
- w/cm related to cement performance, might be limited by durability constraints

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17

Technological approaches to reduce embodied carbon in concrete

Aggregates

- Get the **best (packed) grading**
- Use the **largest D_N** feasible

Chemical admixtures

- Slump and slump retention
- Early age performance

Use of SCMs

- Reduce the clinker factor of the binder
- Account for performance vs CO_2

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18

Decarbonisation potential

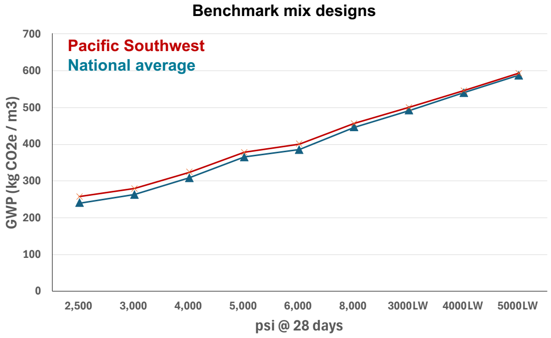
19

US ready-mix market (NRMCA)

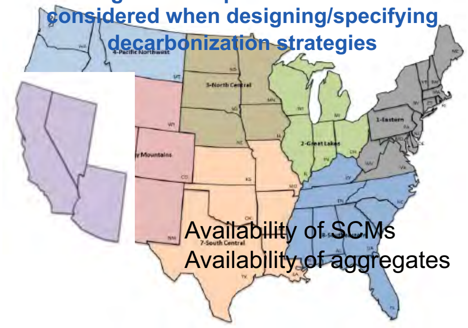
ultra green concrete

- 489 concrete plants
- 47500 m^3 average production (62200 yd^3)

Total production : 23 million m^3 (30.5 million yd^3)



Regional component should be considered when designing/specifying decarbonization strategies



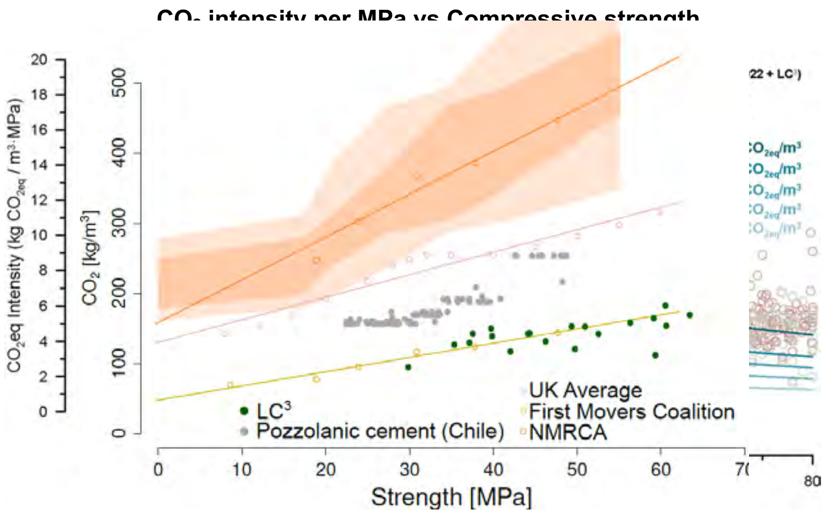
Availability of SCMs
Availability of aggregates

NRMCA Industry Wide LCA Project Report – V 3.2

20

Decarbonization potential of the two-fold strategy

The CO_2-saving contribution of low-paste volume concrete is yet to be explored!



NRMCA Industry Wide LCA Project Report – V 3.2
LCCG Market Benchmark V2-1a (2023)
ECOPact values based on published EPDs
Hasanbeigi and Sibal, What are green cement and concrete?

21

Decarbonization potential of two-fold strategy

Assumptions

OPC → LC³ (calcined clay / limestone = 2 / 1)

Workability is compensated with SP (PCE)

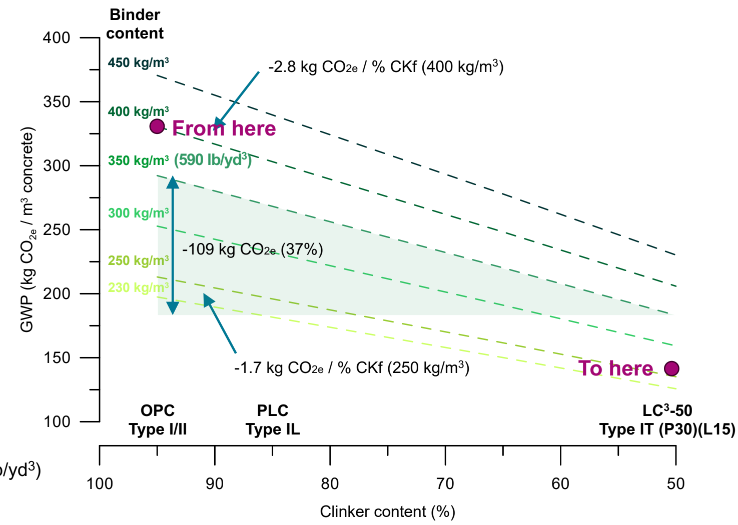
w/b fixed at 0.5

OPC has a clinker factor of 95% (5% gypsum)

Two-fold strategy

- ✓ GWP lines are not parallel, CKf has higher effect at high binder contents
- ✓ Both levers of the strategy have comparable decarbonization potential

Clinker factor	Binder content
95 → 50 %	400 → 260 kg/m³ (676 → 440 lb/yd³)
- 45 %	-140 kg/m³ (-236 lb/yd³)
-109 kg CO_{2e}	-109 kg CO_{2e}

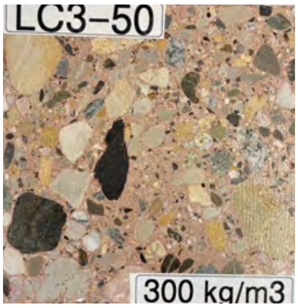


- 190 kg CO_{2e} / m³ (57%)

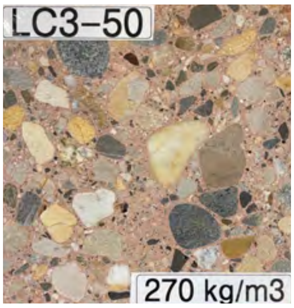
22

Concrete with <150 kg CO_{2e}/m^3 is possible

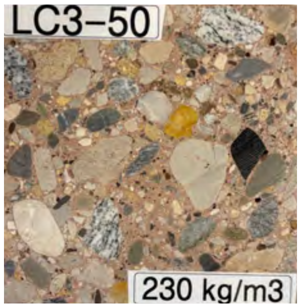
CO_2eq < 150 kg/m^3



f_{28} = 51 MPa (7400 psi)
SP = 1%



f_{28} = 49 MPa (7100 psi)
SP = 1%



f_{28} = 59 MPa (8550 psi)
SP = 1.25%

ACI 318 has a prescriptive approach to meet durability requirements (e.g., max w/cm)

Allow alternative verification through performance testing

feedback

23

We need a portfolio of decarbonization technologies….
But not all solutions are cut from the same cloth

Marginal cost of clinker production: 30 to 50 USD / t clinker

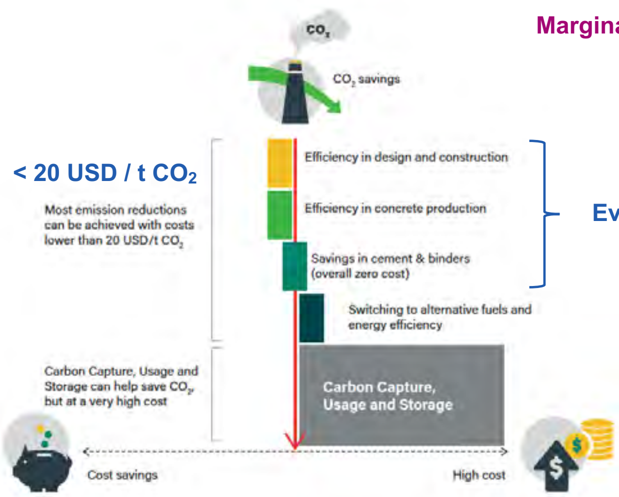


Illustration by K. Scrivener

Everyday civil engineering practice

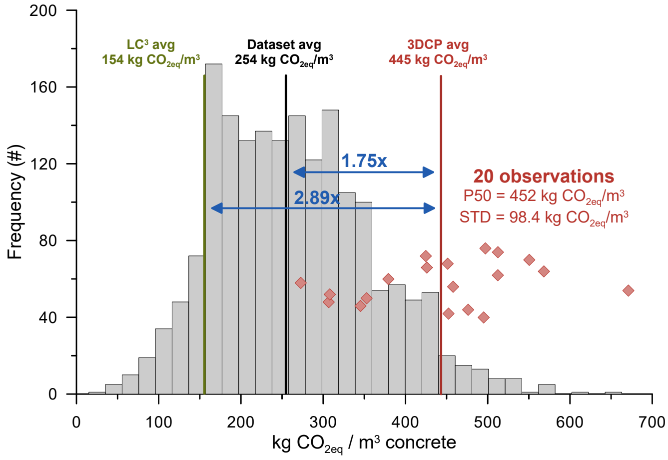
Carbon capture : 100 USD / t CO_2

Carbon transport and storage : 50-100 USD / t CO_2

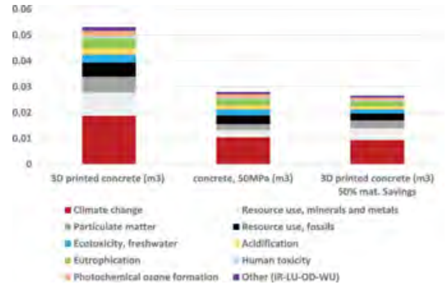
CCS ~ 70 – 130 USD / t clinker
(2-to-4 fold production cost increase)

24

Less clinker in cement
Less paste in concrete
Less concrete in the structure



Roux et al., International Journal of Life Cycle Assessment, 2022



Even if material consumption is reduced by 50%, it is unclear if 3DCP offers a substantial CO_2 saving potential

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25

Concluding remarks

- We can only move forward with cement-based materials on a worldwide scale.
- **Reducing the paste volume is an effective tool to reduce embodied CO_2** in concrete that should be considered as a fast-deployment lever.
- Ambitious, but still attainable, goals towards decarbonization of cement and concrete industry should be set. **The two-fold strategy offers a cost-effective pathway to substantially reduce CO_2 emissions.**
- **Performance-based metrics (standards and LCA) are essential** to leave space for innovation and increase the rate of technological uptake.

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26

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Thank you for your attention

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27