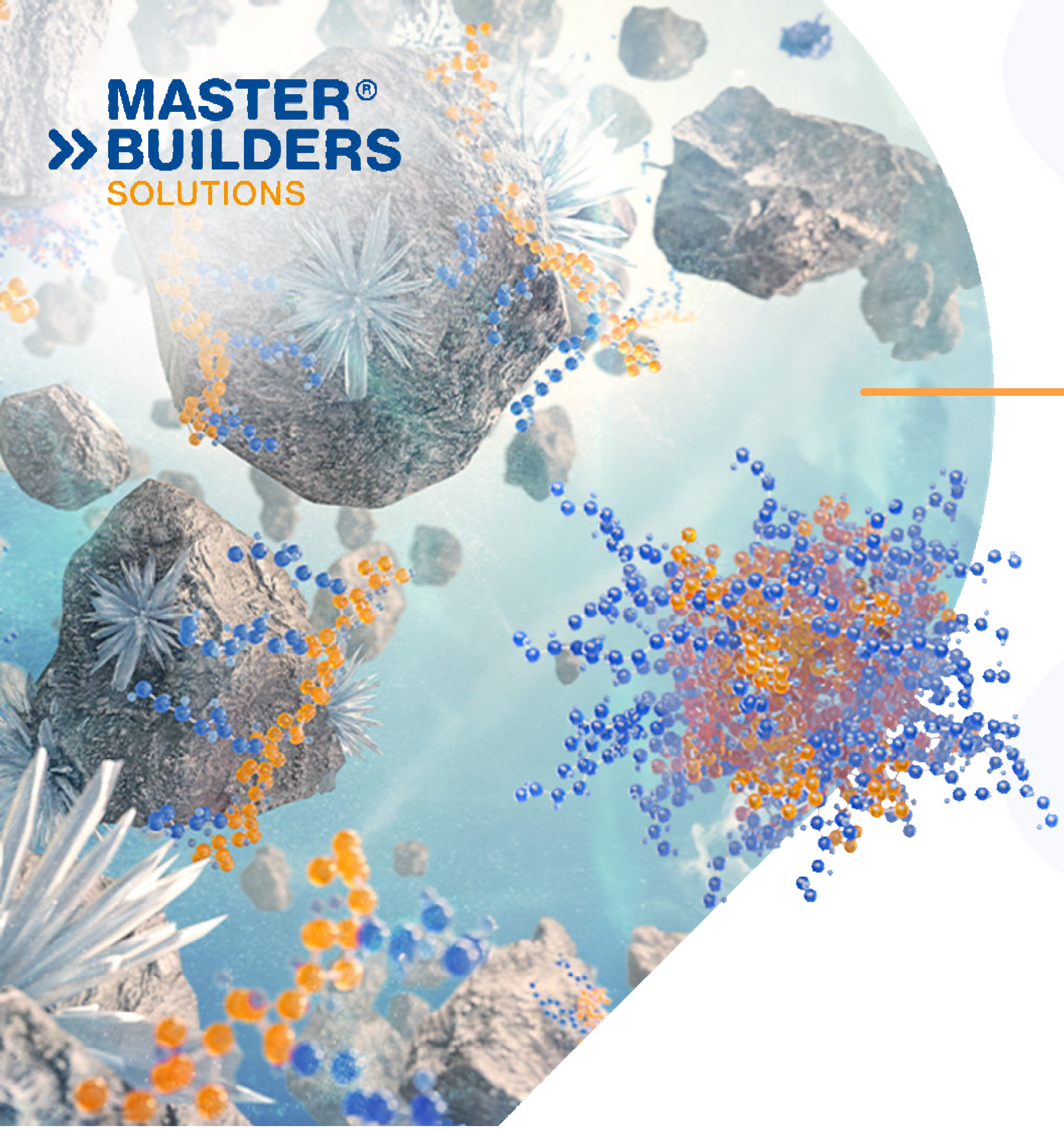
MASTER®
BUILDERS
SOLUTIONS



A new superplasticizer generation to improve the rheology and workability of Low Carbon Concrete

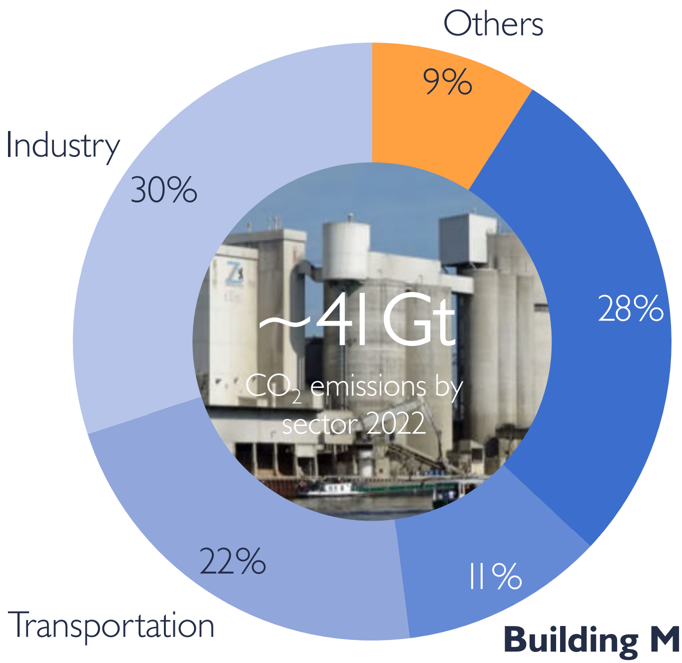
Oliver Mazanec

February 28th, 2024

CO_2 in concrete is a problem

Cement in concrete accounts for ~8% of the 41 Gt emitted worldwide

CO_2 emission in % by sector, 2022



Building Operations
CO_2 emissions are reduced significantly thanks to more efficient insulation and heating technology

Building Materials and Construction 1)
CO_2 emissions almost constant for many years

1 m^3 Concrete C25/30 =
~290kg Cement

290kg Cement =
~220kg of CO_2

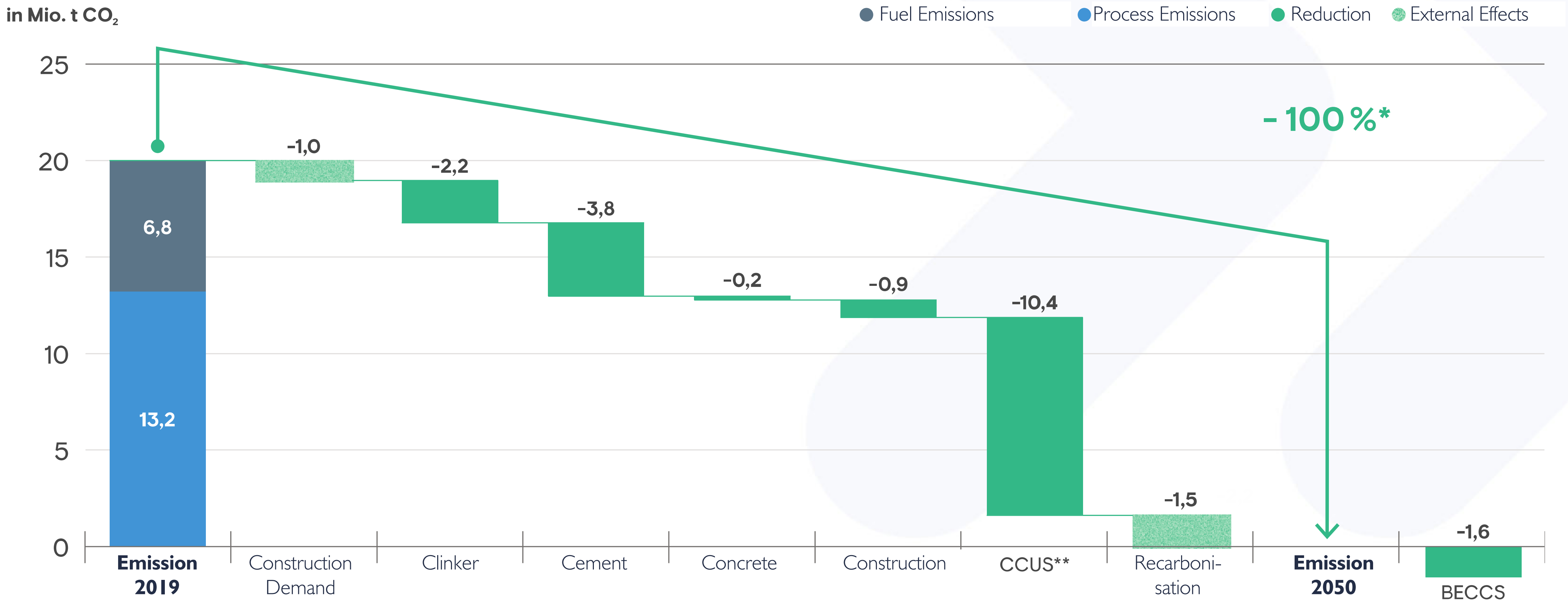
1 m^3 Concrete=
~240kg of CO_2 (t/o 90% cement)

1 m^3 Reinforced Concrete =
~290kg of CO_2

290kg/m^3 =
~2,600km by car

1) The cement clinker in concrete is responsible for ~90% of the CO_2 emissions of concrete

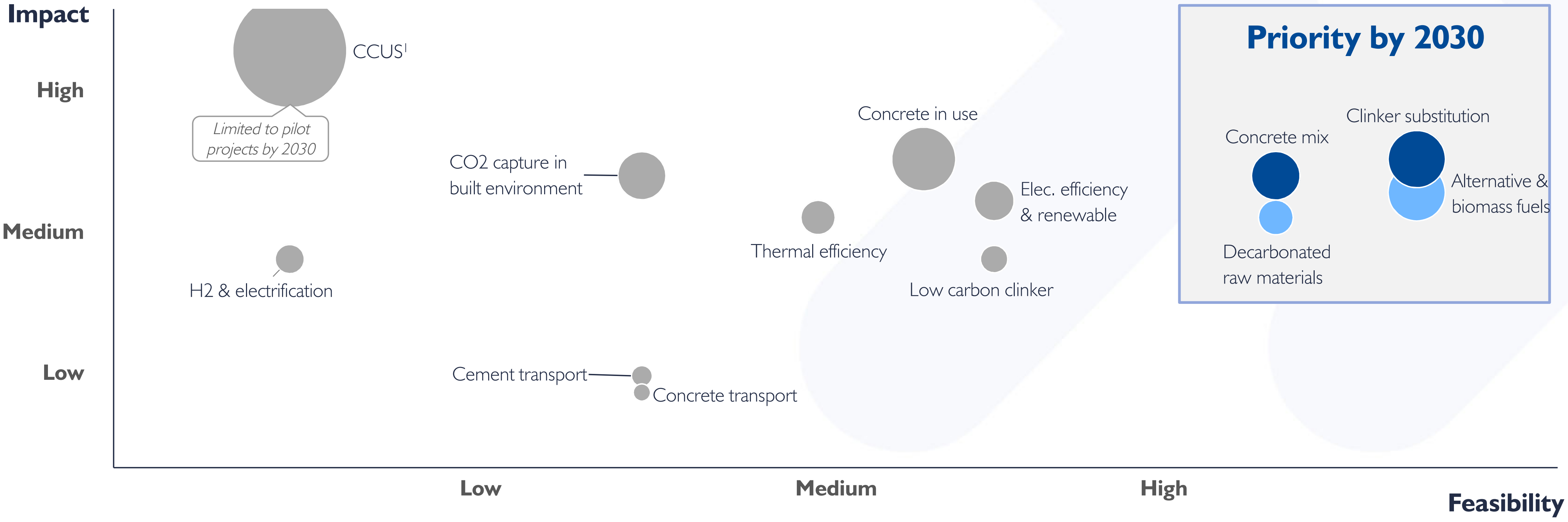
Roadmap for sustainable concrete construction in Germany CO_2 reduction in the climate-neutral scenario by 2045



Source: VDZ / Remarks: *Of which approx. 88% reduction is due to measures in the value chain. The remaining emissions will be reduced by the decline in construction demand as well as the contribution of recarbonation. ** Carbon capture technologies with the aim of avoiding CO2 emissions into the atmosphere through CO2 storage (CCS) and appropriate CO2 utilisation processes (CCU).

Clinker substitution & concrete mix as key priorities by 2030

Carbon neutrality roadmap of cement industry 2050



Note: Size of bubbles depicts 2050 emission reduction potential [1]. CCUS = Carbon Capture, Utilization and Storage
Source: Cembureau; BCG analysis

Pathways and challenges for low-carbon concrete

Low Carbon
Concrete (LoCC)

Use of cements with low clinker content

- Reducing of clinker is the key to achieving low CO_2 emissions
- At the same time, the amount of water or the **w/c value** is often **reduced** to compensate for the negative effects on strength and durability
- Low water amount often result in a **short slump retention** and **high viscosity**

Replacement of cements by SCMs

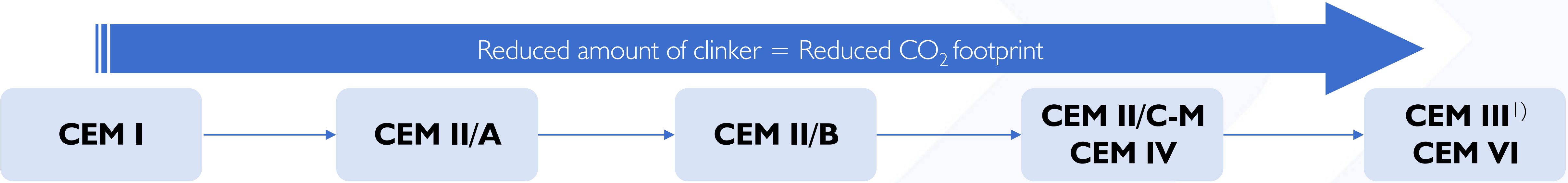
- Ensuring a minimum paste volume by using high SCM contents (≥260 l/m^3)
- Improving particle packing, rheology, strength and durability
- SCMs with high BET surface (e.g. fine LL or calcined clay) absorb quickly large amounts of polymer which lead to **short slump retention**

Use of recycled aggregates (RCA)

- Use of RCA to promote the circular economy
- High variety of raw materials
- Use of RCA with a porous structure absorb large amounts of water, which strongly **shortens the slump retention**

The path to the decarbonization of concrete structures starts by producing concrete with new cements with lower CO_2 footprint

The evolution of cement towards low clinker cements



Reduced amount of clinker = Reduced CO_2 footprint

CEM I → **CEM II/A** → **CEM II/B** → **CEM II/C-M CEM IV** → **CEM III**[1] **CEM VI**

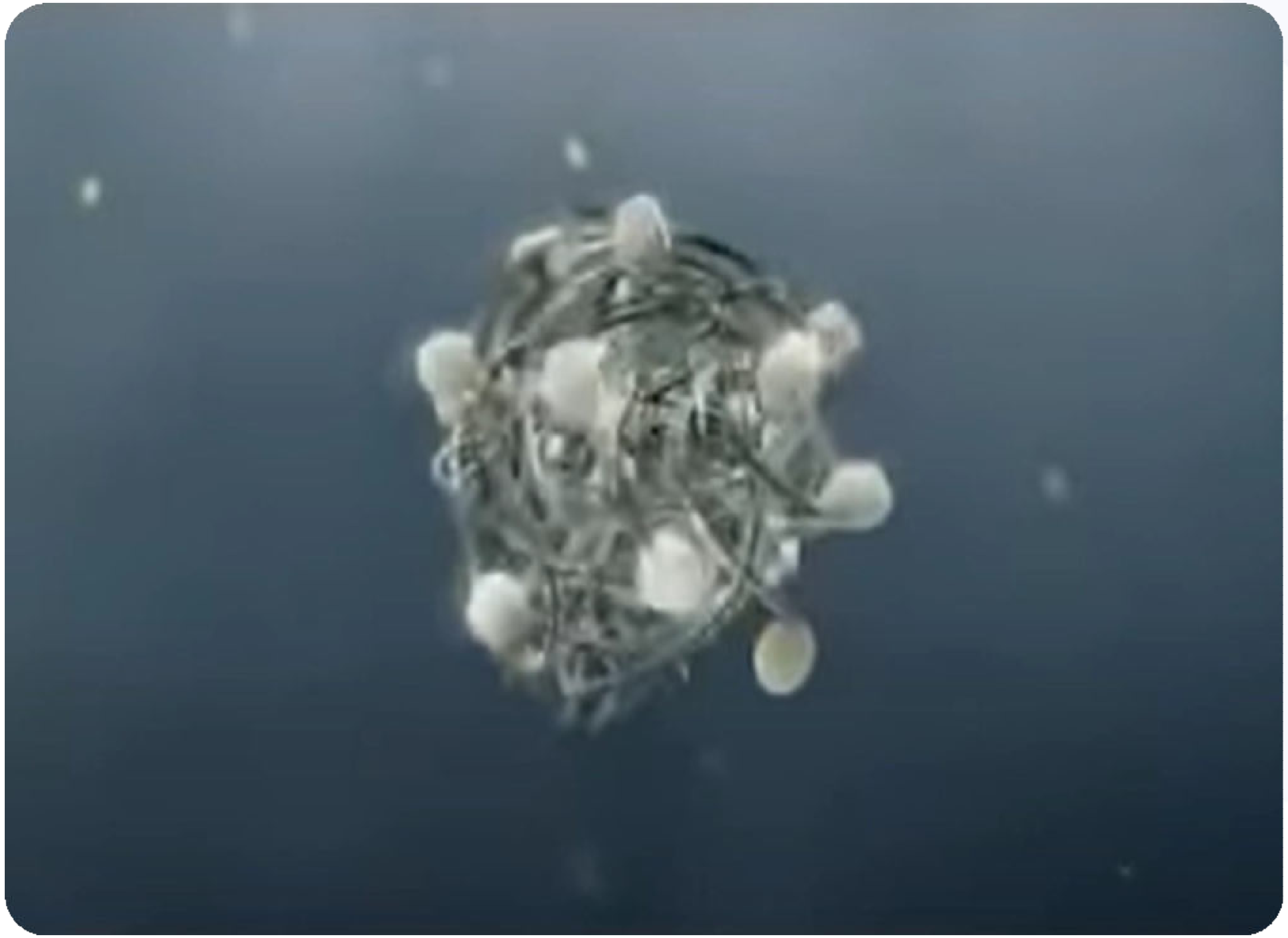
Technical challenges of Low Carbon Concrete

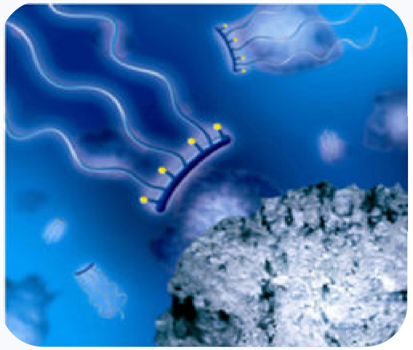
- **Water-demand** and **slump retention** over time
- **Rheology** control of fresh concrete (workability and pumping)
- **24-hours strength** (especially in winter)

---

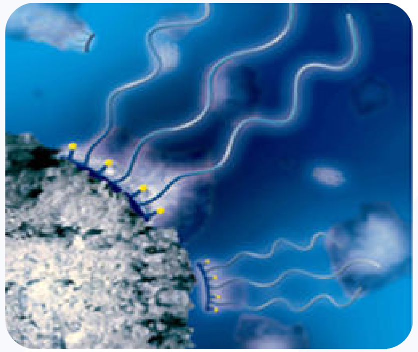
[1] CEM III with lowest CO_2 footprint, but limited availability

Mechanism of action of PCE polymers

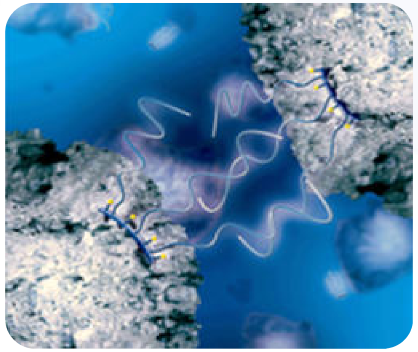




Orientation
of polymer in solution



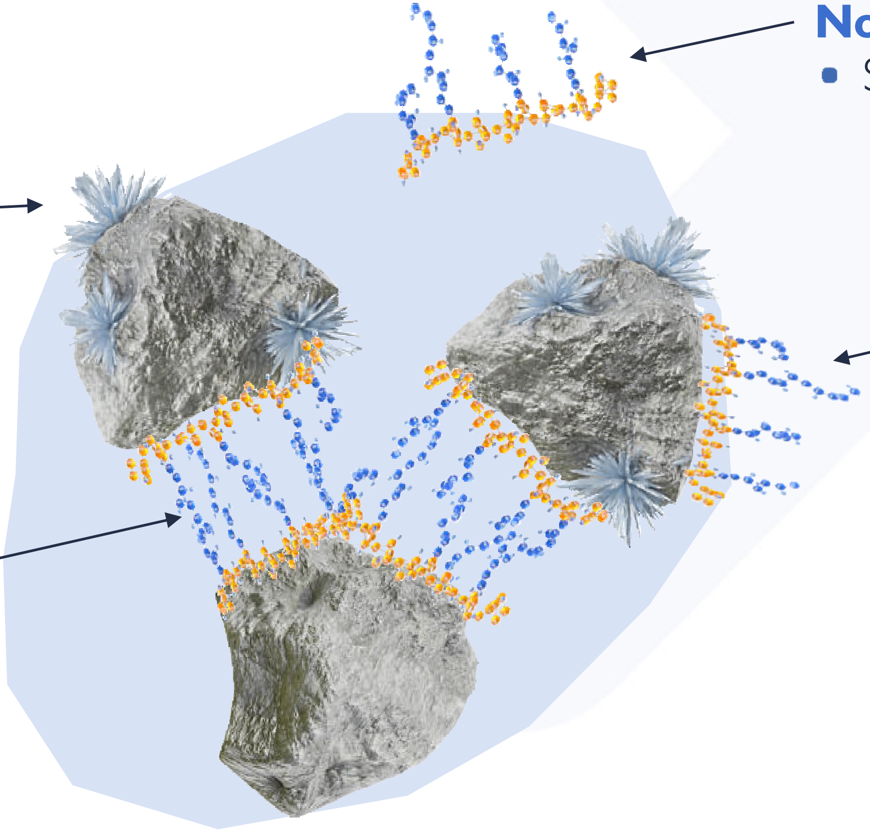
Adsorption
of polymer onto the cement surface (on the new-formed ettringite layer)



Dispersion
between particles generated by the side-chains of PCE polymers (steric hindrance)

Mechanism of action of PCE Polymers

Polycarboxylatether (PCE)



Non-adsorbed polymers

- Slump retention

Early cement hydration

Formation of ettringite negatively influences the polymer effect

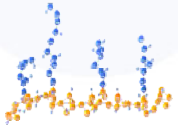
Adsorbed polymers

- Dispersion effect

Adsorbed polymer layer

(2 x polymer layer thickness)

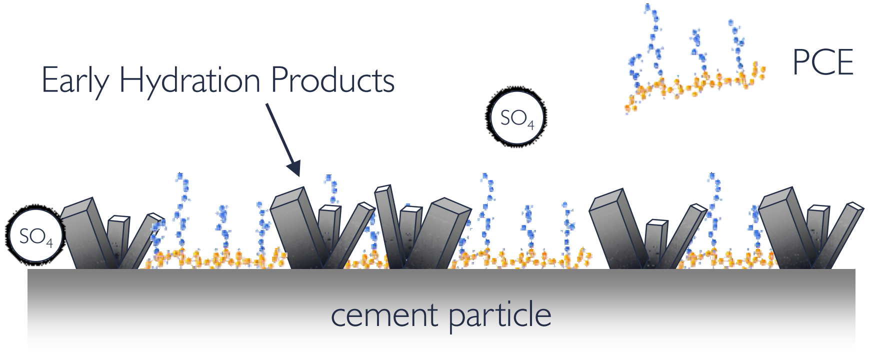
Steric particle repulsion


PCE

Influence of PCE adsorption on the workability retention

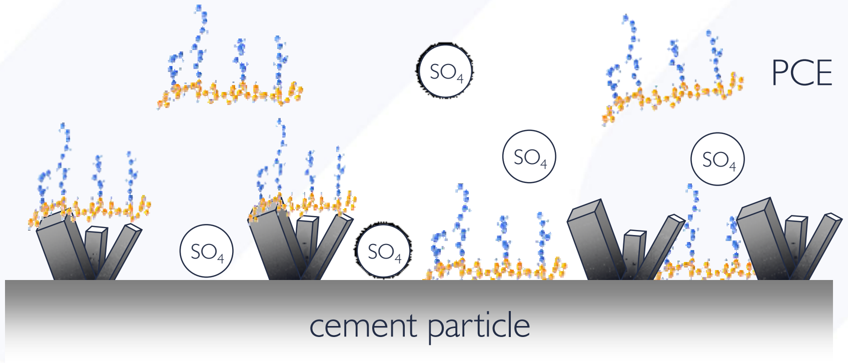
Negative impact

- Strong adsorptive cements (e.g. low Na_2O equivalent)
- High anionic charge density of PCE
- Low dosage of superplasticizer
- Intensive mixing
- High fresh concrete temperature



Positive impact

- Cements with good coordination of the reaction kinetics of sulphate on aluminate
- Low anionic charge density of PCE
- High dosage of superplasticizer
- Low fresh concrete temperature



Crutial for the optimal efficiency of PCE based superplasticizer is to **achieve the desired degree of adsorption** as accurately as possible after a certain time!

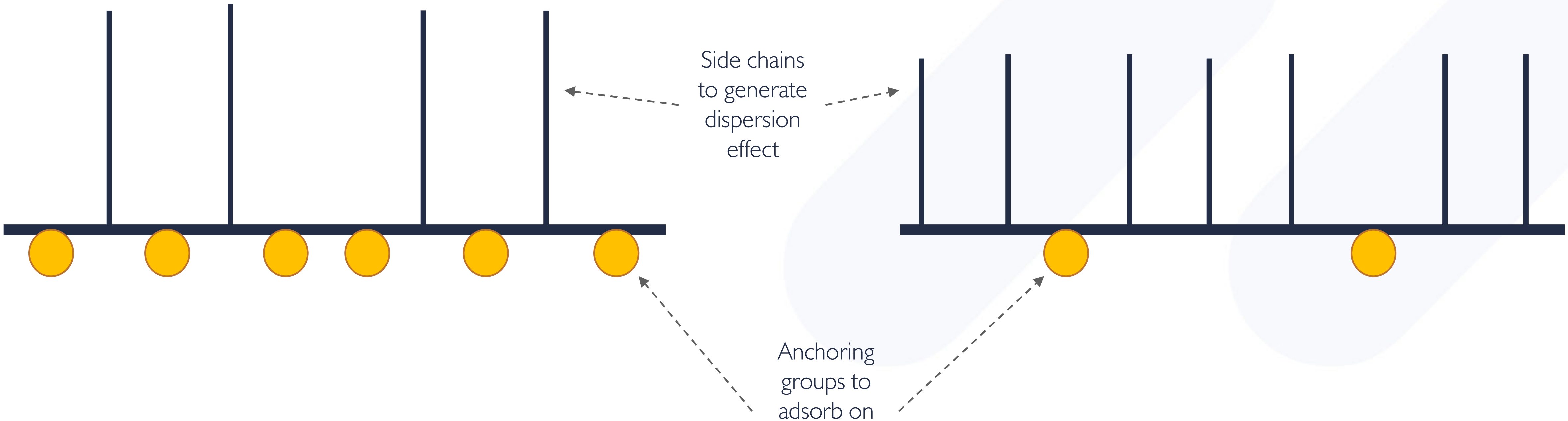
Controlling performance via the polymer structure

PCE polymer with high-water reduction capacity

Fast adsorption speed, low retardation

PCE polymer with slump retention properties

Slow adsorption speed, high retardation



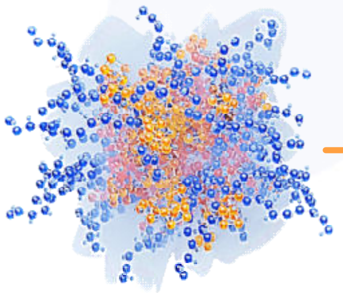
Side chains to generate dispersion effect

Anchoring groups to adsorb on cement surface

The new generation of superplasticizer is based on an Intelligent Cluster System Technology (ICS)

Conventional PCE superplasticizer

- Control of **adsorption rate** and dispersion effect via the **polymer structure**
- **Cement type**, crystallization process and temperature strongly **influence** the **dispersing effect**
- **The dilemma:** Well-dispersing PCEs have poor slump retention while PCEs with good slump retention are not particularly dosing efficient and delay strength development

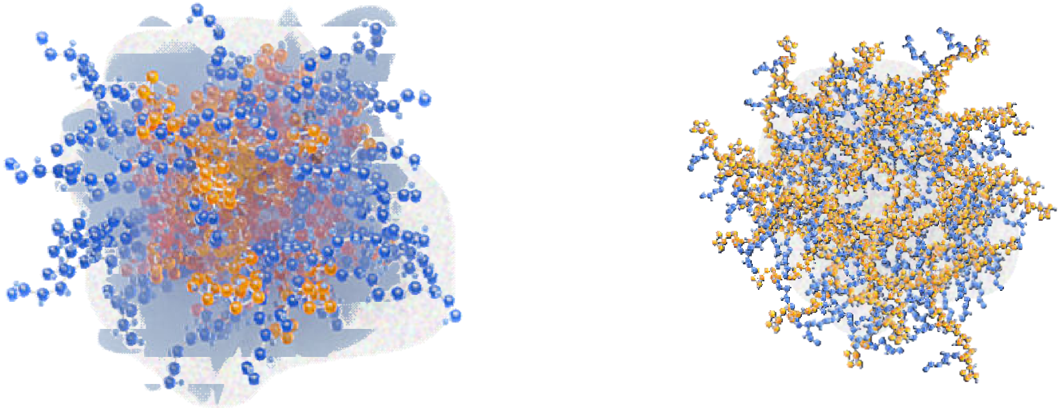


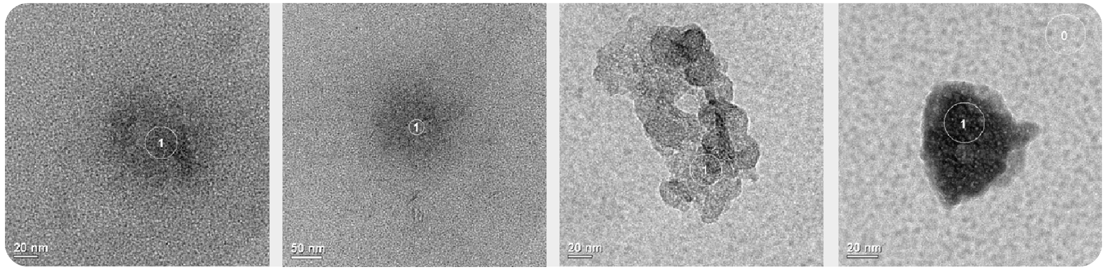
Intelligent Cluster System

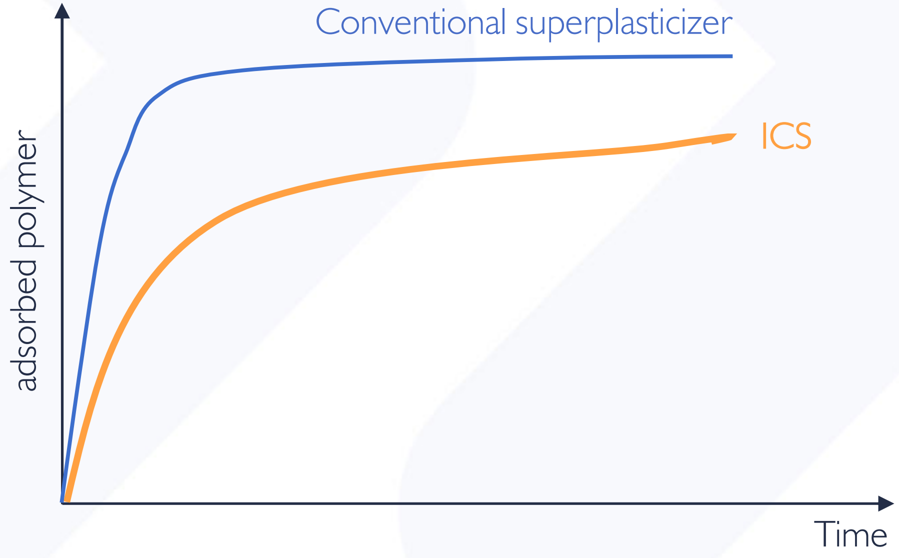
- The new generation of superplasticizers forms an **Intelligent Custer System (ICS)** that immediately releases some of its freely available polymers for initial dispersion
- The ICS then **releases** the remaining **polymers evenly**, controlling the **absorption rate** and ensuring constant workability during the ongoing cement crystallization process

Intelligent Cluster-System (ICS)

Mechanism of delayed release & adsorption



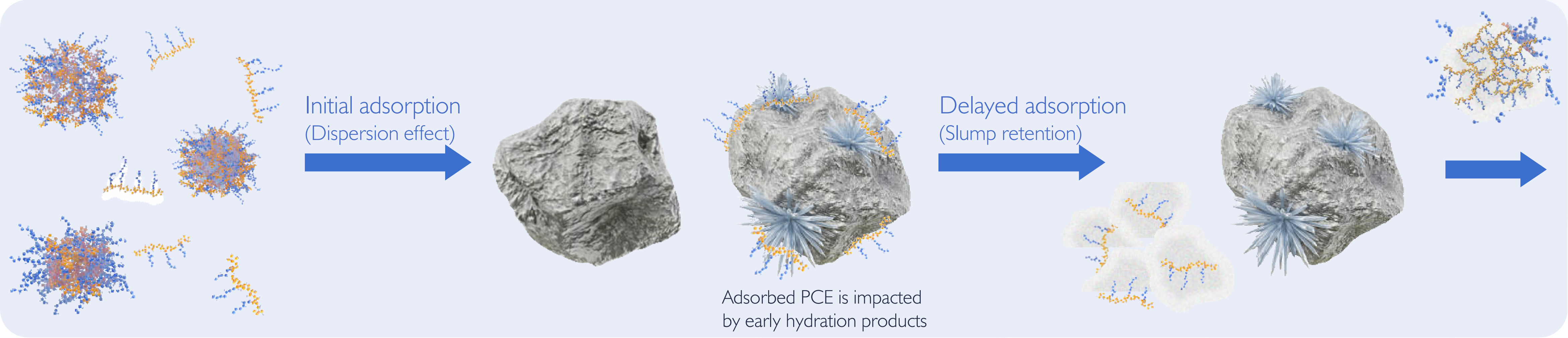




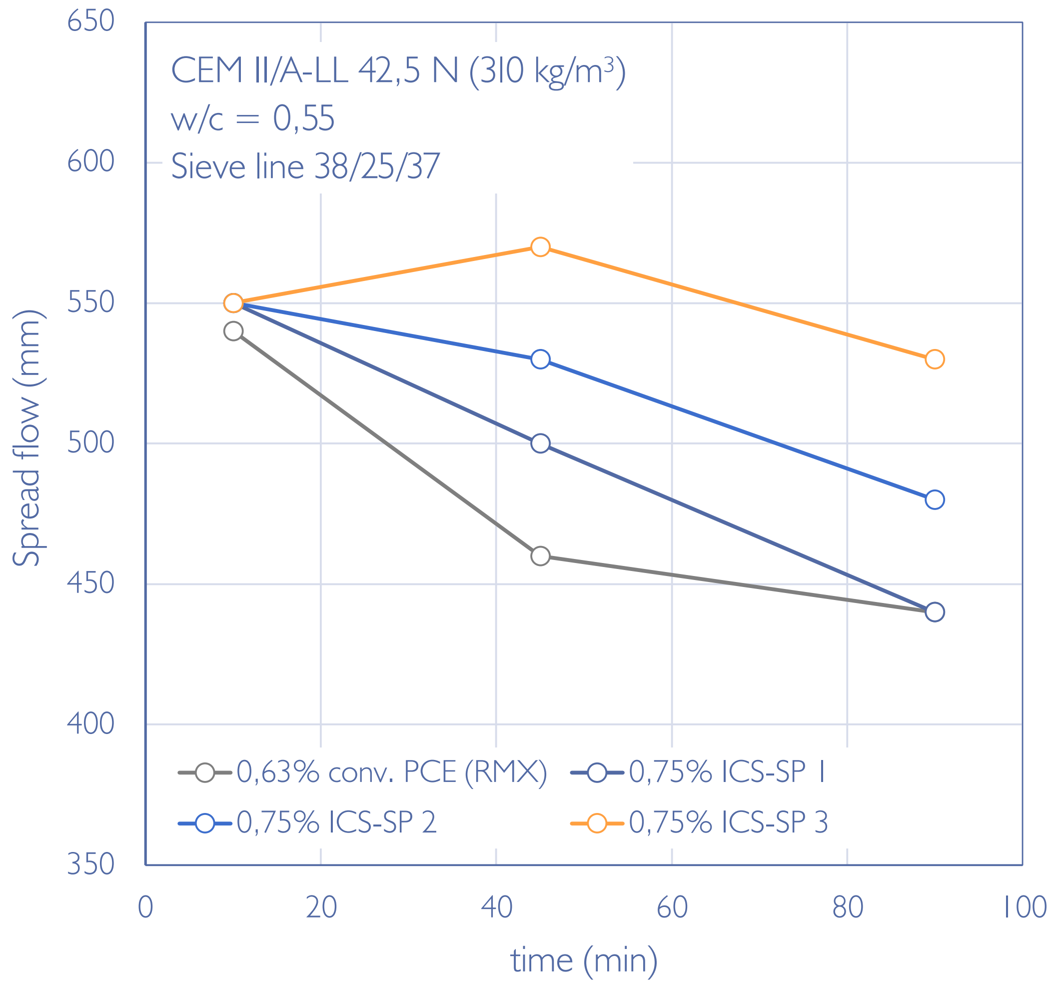
- In concrete, the polymers are **released** in a controlled manner by the ICS due to the increasing **pH value** and the **specific ionic strength** of the pore solution

Slump retention with Intelligent Cluster System Technology

Adsorption and early cement hydration



- In the case of ICS, some of the **polymers** are **freely available** and provide an **initial water reduction**
- By changing the pH value and the pore solution, the **polymers are released from the cluster matrix** in a controlled manner. They adsorb on the resulting hydration products and ensure good slump retention



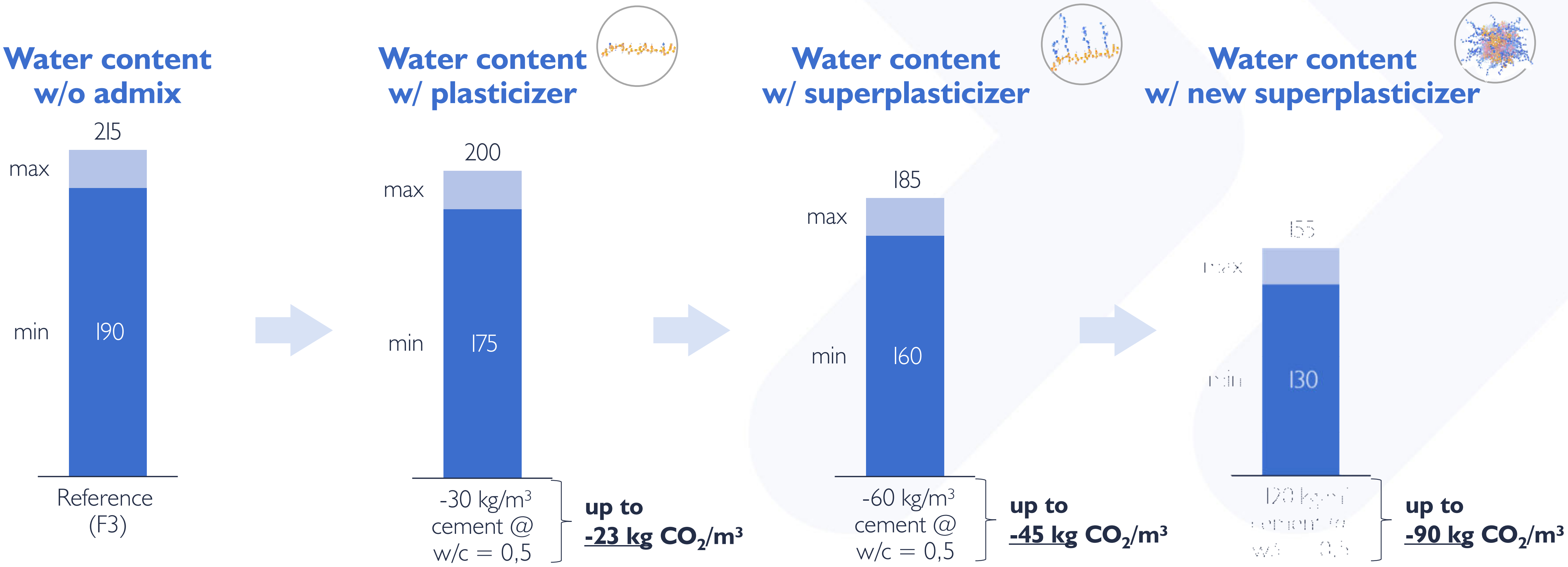
Consistency control combined with early strength

- **Slump retention** can be **individually adjusted** depending on the selected cluster system
- **High early strength** despite long slump retention

Time	0,63% conv. PCE (RMX)	0,75% ICS-SP 2	0,75% ICS-SP 3
24 h	**6,9**	**9,0** (+30%)	**8,0** (+16%)
28 d	**42,3**	**42,5** (0%)	**41,7** (-1%)

*ICS-SP are commercially available superplasticizer from the MasterCO$_2$re product group

Clinker reduction often comes along with a reduction of water to compensate negative impact on strength and durability



-30 kg/m³ cement @ w/c = 0,5

up to
<u>-23 kg</u> CO_2/m³

-60 kg/m³ cement @ w/c = 0,5

up to
<u>-45 kg</u> CO_2/m³

120 kg/m³ cement @ w/c = 0,5

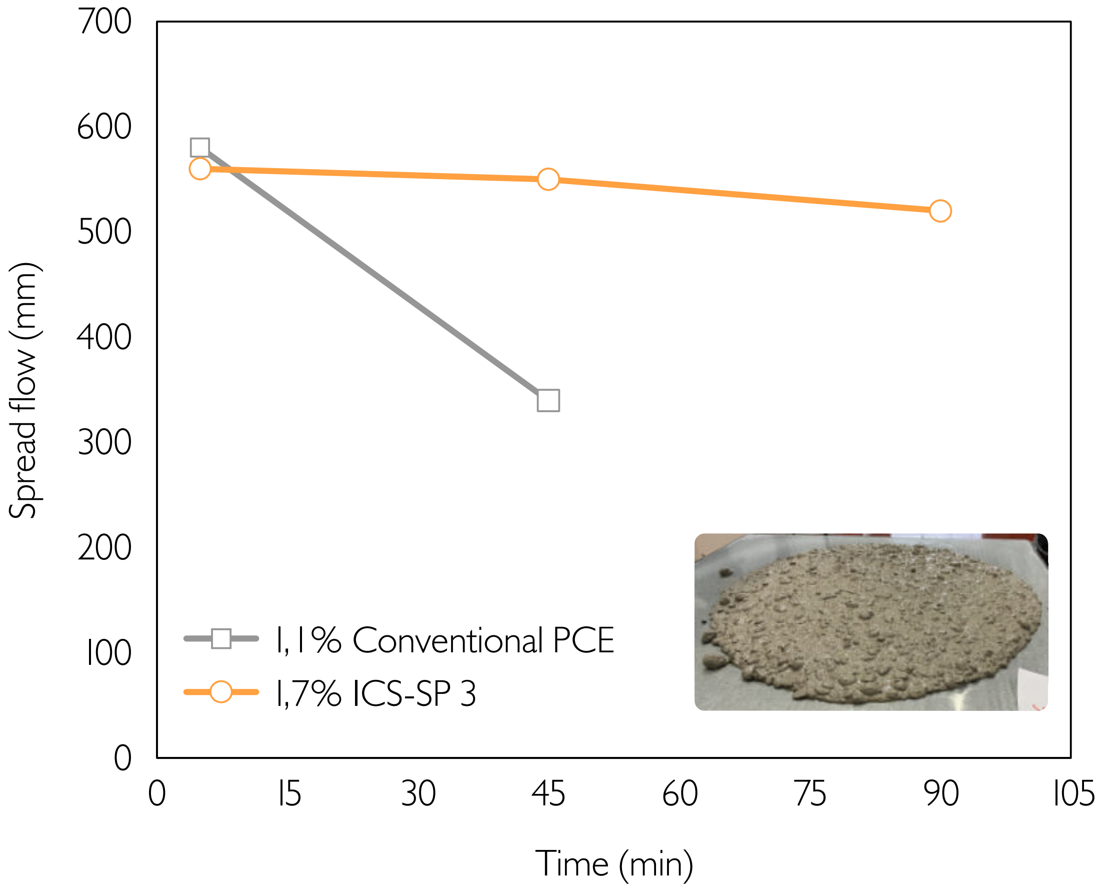
up to
<u>-90 kg</u> CO_2/m³

Status Quo

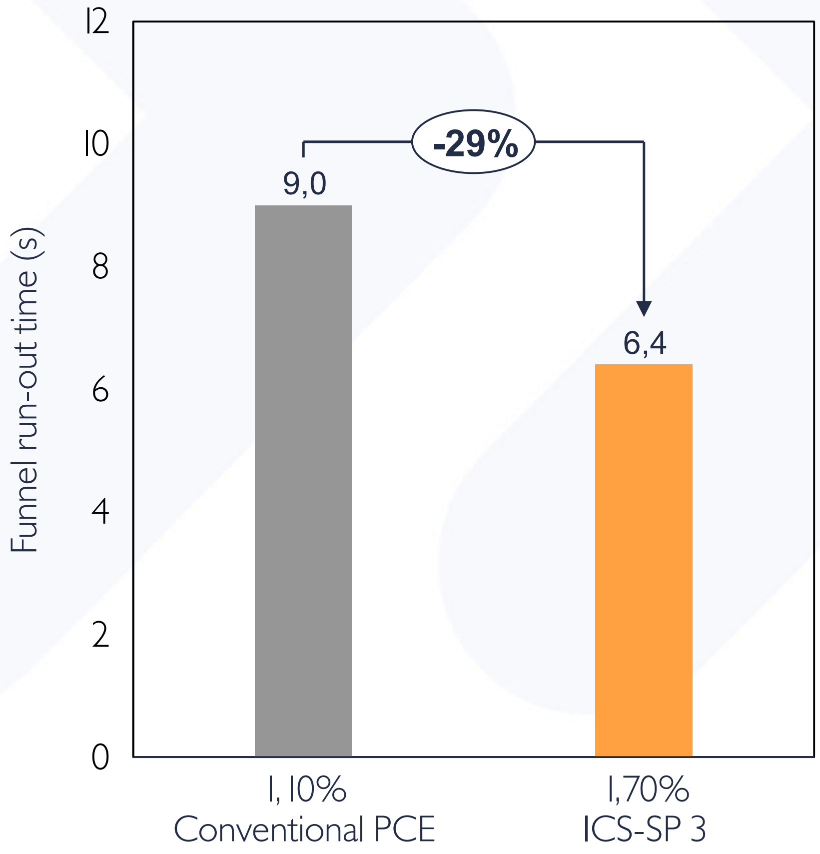
LoCC

Performance in CO_2-optimized concrete with 130 l/m^3 water

Consistency



Rheology



*CO_2-optimized concrete with 280 kg/m^3 CEM II/C-M (S-LL), 100 kg/m^3 Limestone powder and 130 l/m^3 water

Improve slump retention of Limestone calcined clay cement (LC^3)

Slump retention of LC^3 with conventional SP and ICS Technology

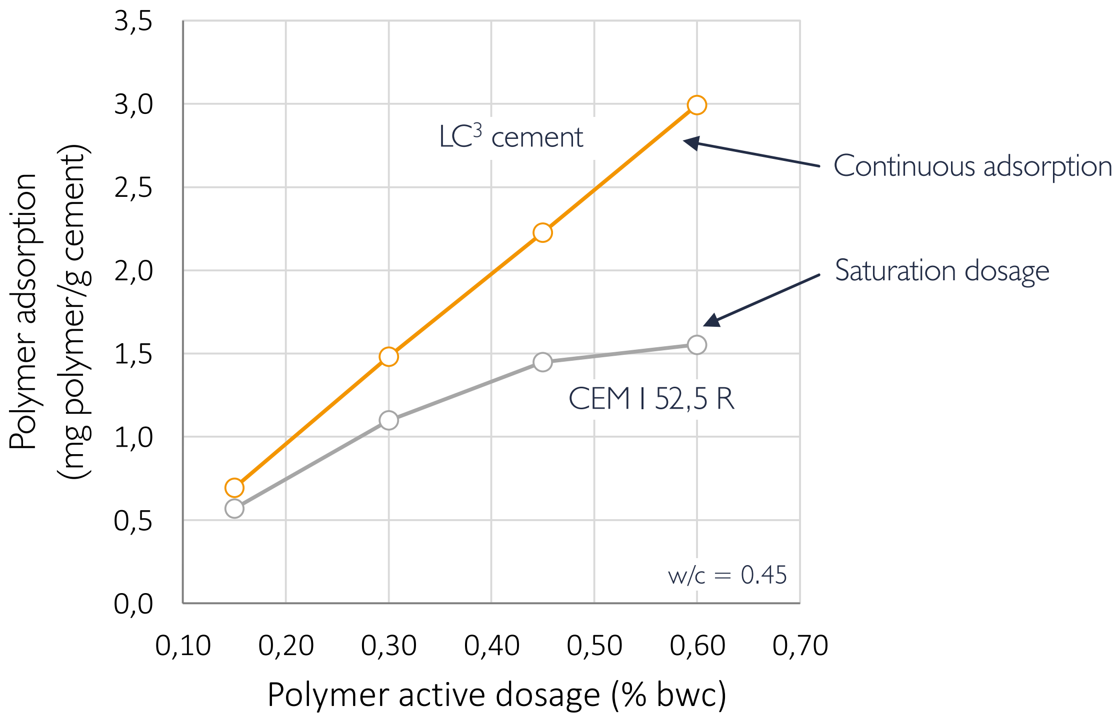
Mortars	**SP** (wt%)	**ICS-SP 3** (wt%)	**Slump (mm)** t_0	**Slump (mm)** t_{30min}	**Slump (mm)** t_{60min}
PC	0.34	-	183	156	143
LC^3-CC1	1.00	-	**196**	**106**	**100**
PC	-	1.20	190	264	288
LC^3-CC1	-	1.20	**186**	**210**	**196**
LC^3-CC2	-	1.00	**214**	**271**	**284**
LC^3-CC3	-	0.50	**210**	**267**	**276**

- The SP content was optimized for an initial slump of 200±20mm, w/c = 0,40
- The amount of required SP depends on the kaolinite content in the raw clay which usually correlates with surface areas

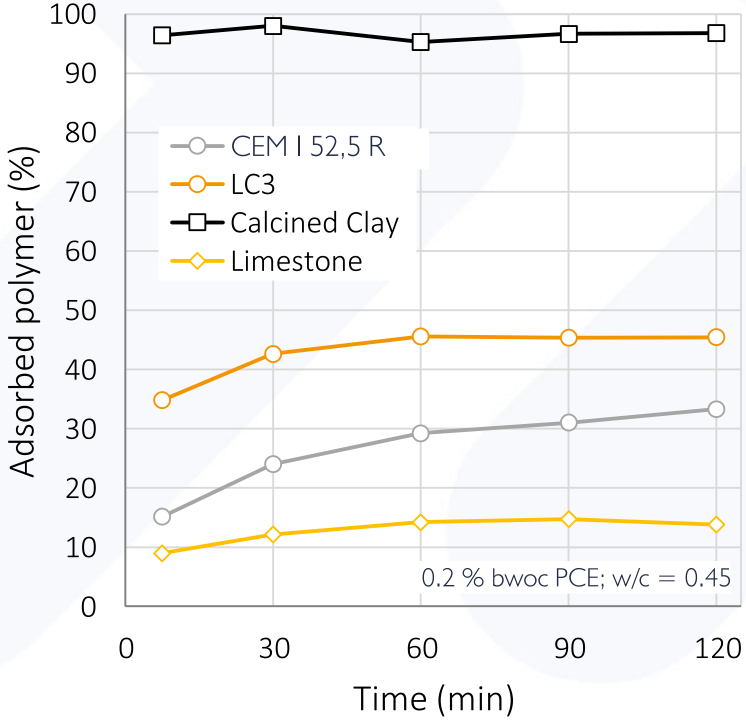
Source: A. Morales-Cantero et al.: Activation of LC3 low-carbon cements by C-S-H seeding. 2023, DOI: 10.13140/RG.2.2.26594.09920

LC^3 with high BET surface absorb quickly large amounts of polymer which lead to fast stiffening and short slump retention of concrete

Adsorption of PCE onto LC^3 vs. Portland cement



Adsorption of PCE onto single components of LC^3

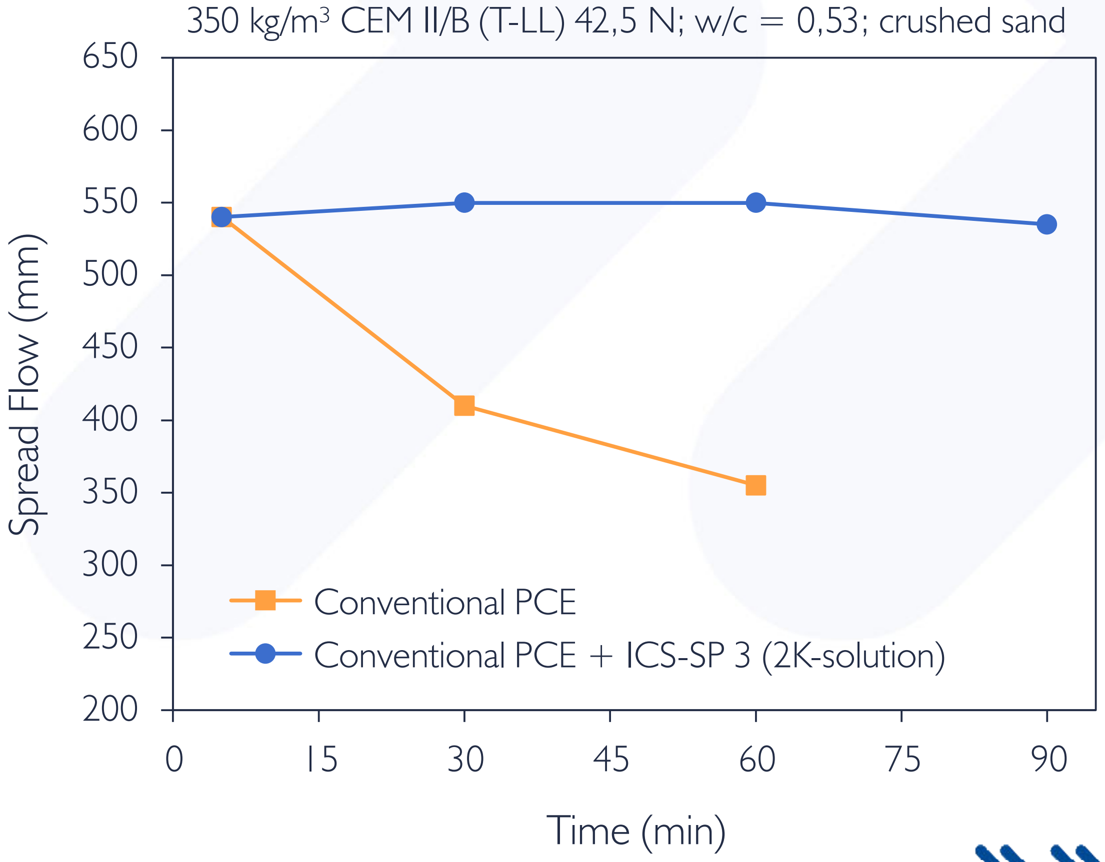


- The controlled release mechanism of the new superplasticizer generation (ICS) avoid that all polymer is adsorbed immediately which strongly **improves the slump retention** of LC3 binder

Improved circular economy through the use of recycled concrete aggregates and crushed sand

Impact of RCA and crushed sand on slump retention

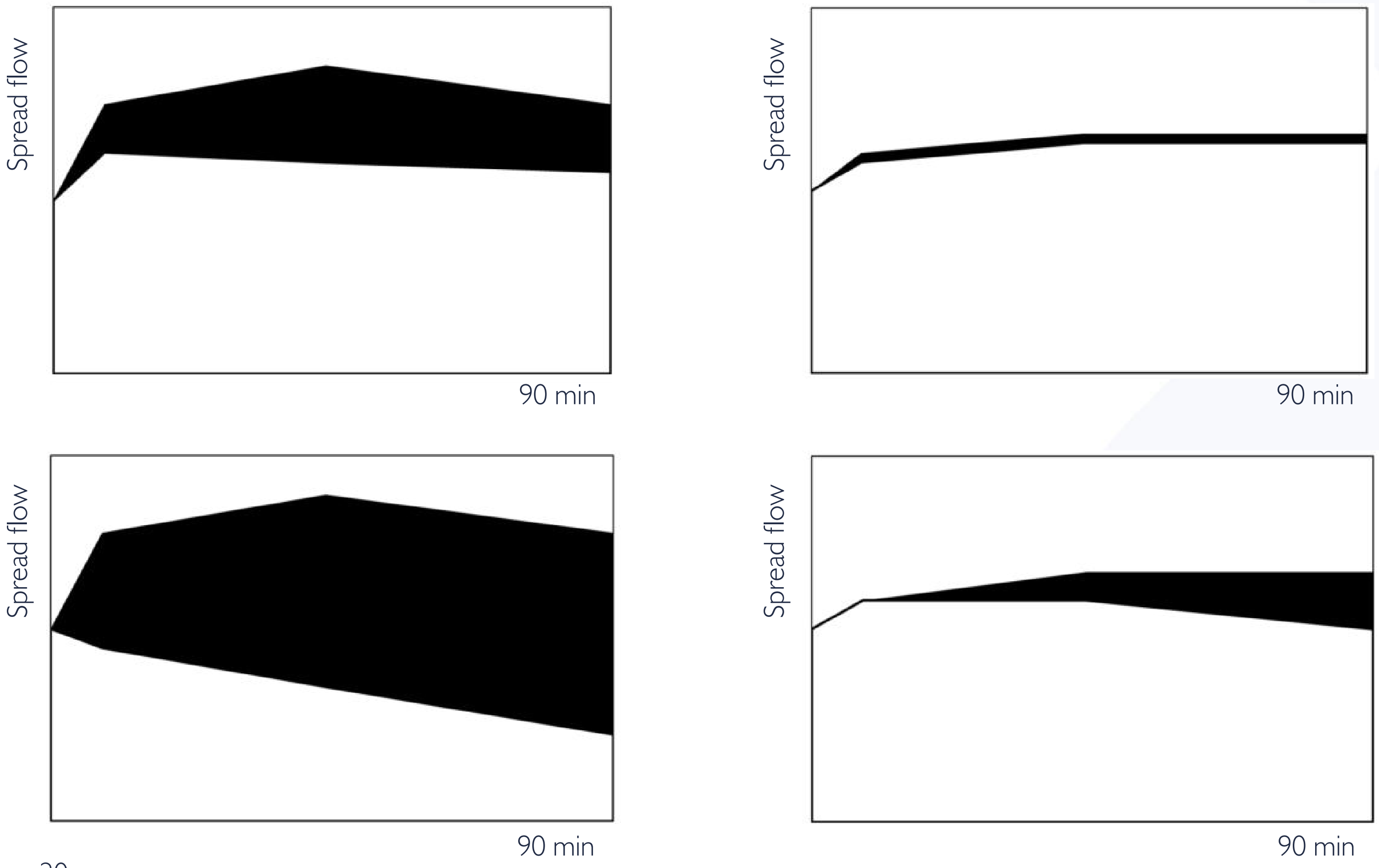
- Recycled concrete aggregates (RCA) and crushed sand have a high surface area and a **porous structure**
- They **absorb large amounts** of **water**, which shortens the workability time of the concrete



High robustness even in changing conditions

PCE slump retainer

ICS-Technology



- Variation of the spread flow for **3 cements**

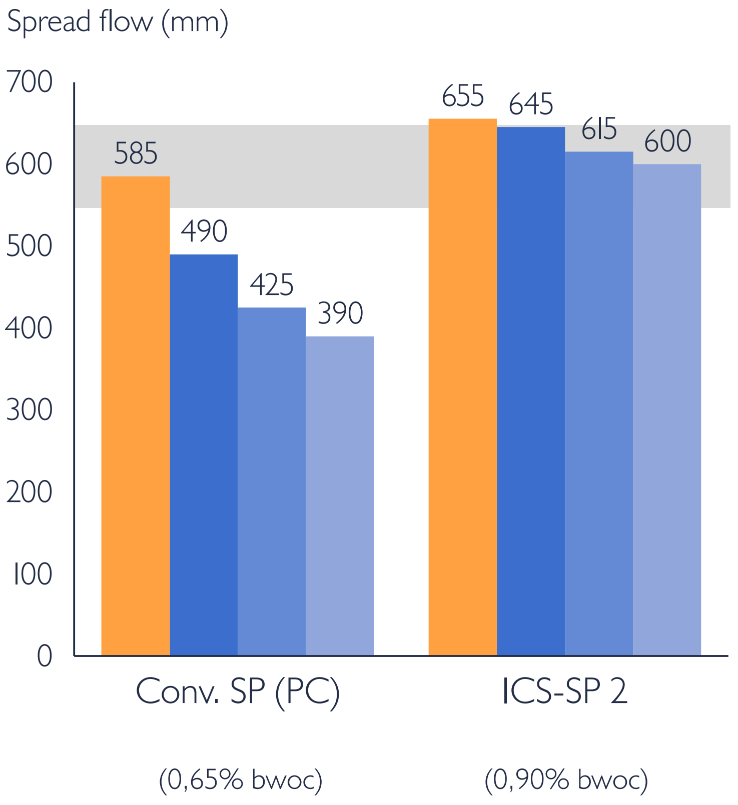
- Variation of the spread flow at **10 °C** and **30 °C***

*CEM II/A-LL 32,5 R

Robustness when changing cement

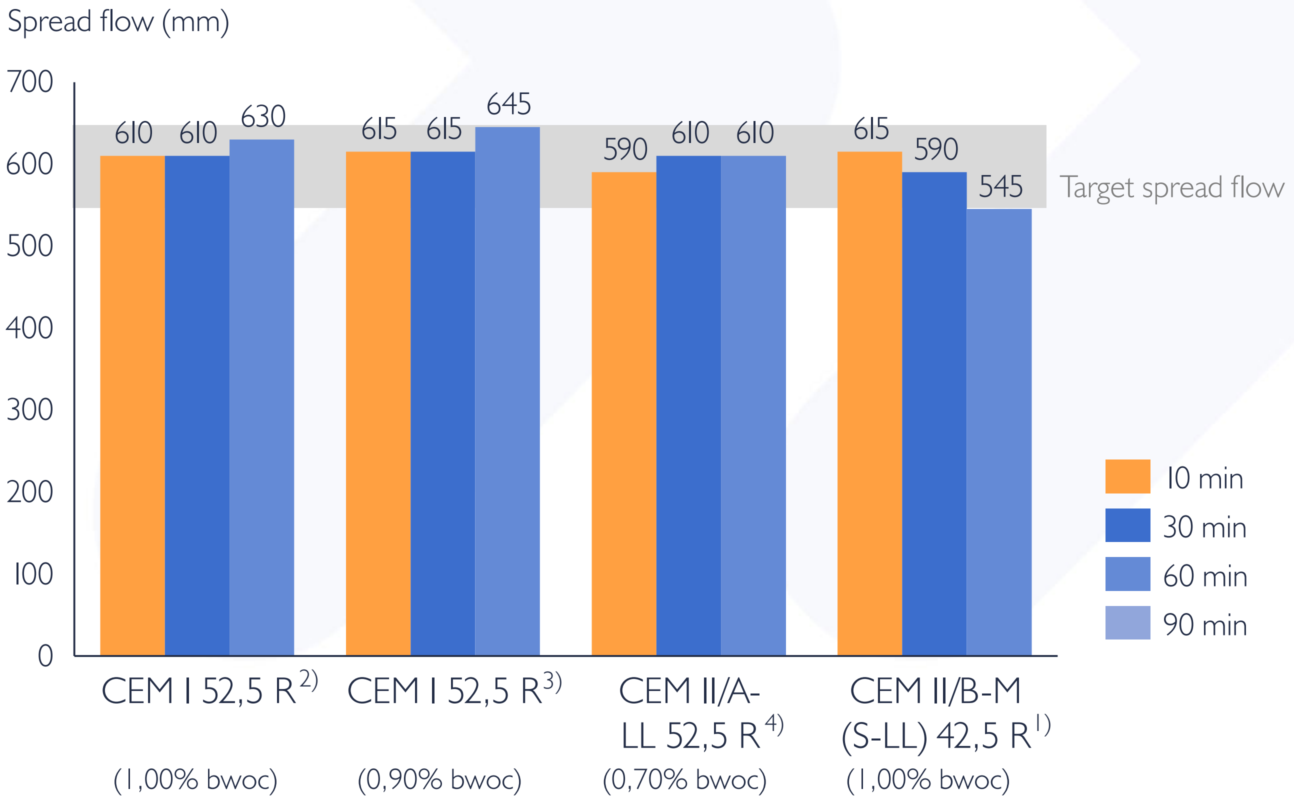
Various SP technologies

350 kg/m^3 CEM I 42,5 R1), w/c = 0,47



5 cements from 4 plants with ICS-SP 2

350 kg/m^3 CEM, w/c = 0,47



---

1) Cement plant A, 2) Cement plant B; 3) Cement plant C; 4) Cement plant D

Lighthouse project

EDGE East Side Berlin Tower, 2022

spenner zementwerk berlin

EDGE

ZÜBLIN

acemy CONCRETE, CALCULATED

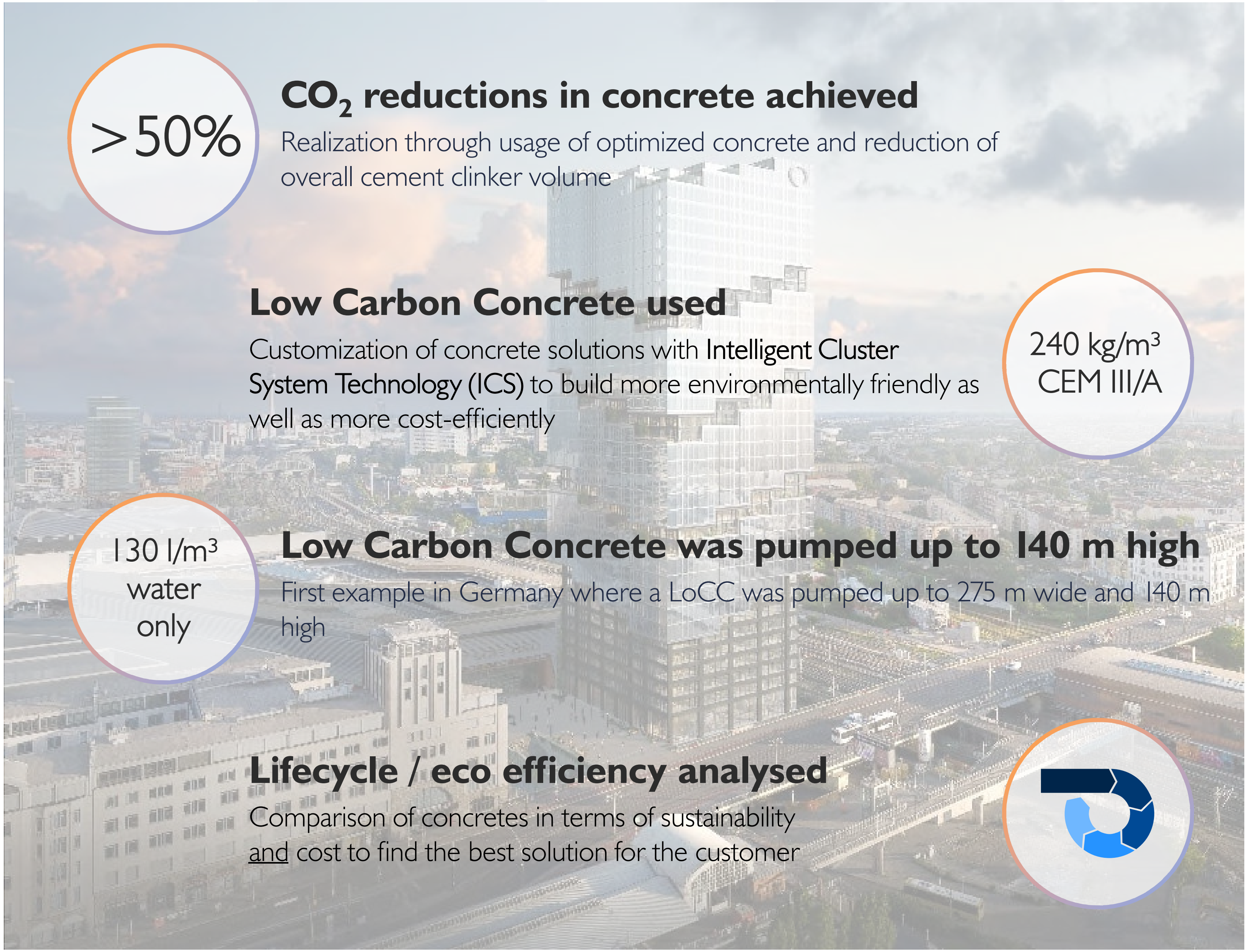
LOWKE · SCHIESSL Ingenieure

The solution

MASTER® BUILDERS SOLUTIONS

Low Carbon Concrete

Optimized concrete with 144 kg CO_2/m^3 and 130 l/m^3 water possible thanks to ICS technology



>50%

CO_2 reductions in concrete achieved

Realization through usage of optimized concrete and reduction of overall cement clinker volume

Low Carbon Concrete used

Customization of concrete solutions with Intelligent Cluster System Technology (ICS) to build more environmentally friendly as well as more cost-efficiently

240 kg/m^3 CEM III/A

130 l/m^3 water only

Low Carbon Concrete was pumped up to 140 m high

First example in Germany where a LoCC was pumped up to 275 m wide and 140 m high

Lifecycle / eco efficiency analysed

Comparison of concretes in terms of sustainability and cost to find the best solution for the customer

Conclusions

Low Carbon Concrete

- Use of **cements** with **low clinker content**, replacement of cements by **SCMs** and the use of **recycled concrete aggregates** (RCA) often lead to **short slump retention** and **low early strength** when conventional PCE based superplasticizer are used
- This currently makes the use of LoCC difficult
- The new generation of superplasticizer for LoCC is based on an **Intelligent Cluster System (ICS)**
- The polymers are held together in clusters of different sizes, which allows a achieve the **desired degree of adsorption** as accurately as possible after a certain time to **control slump retention** and **rheology**

*Superplasticizer based on ICS technology are commercially available from the MasterCO$_2$re product group

MASTER®
BUILDERS
SOLUTIONS