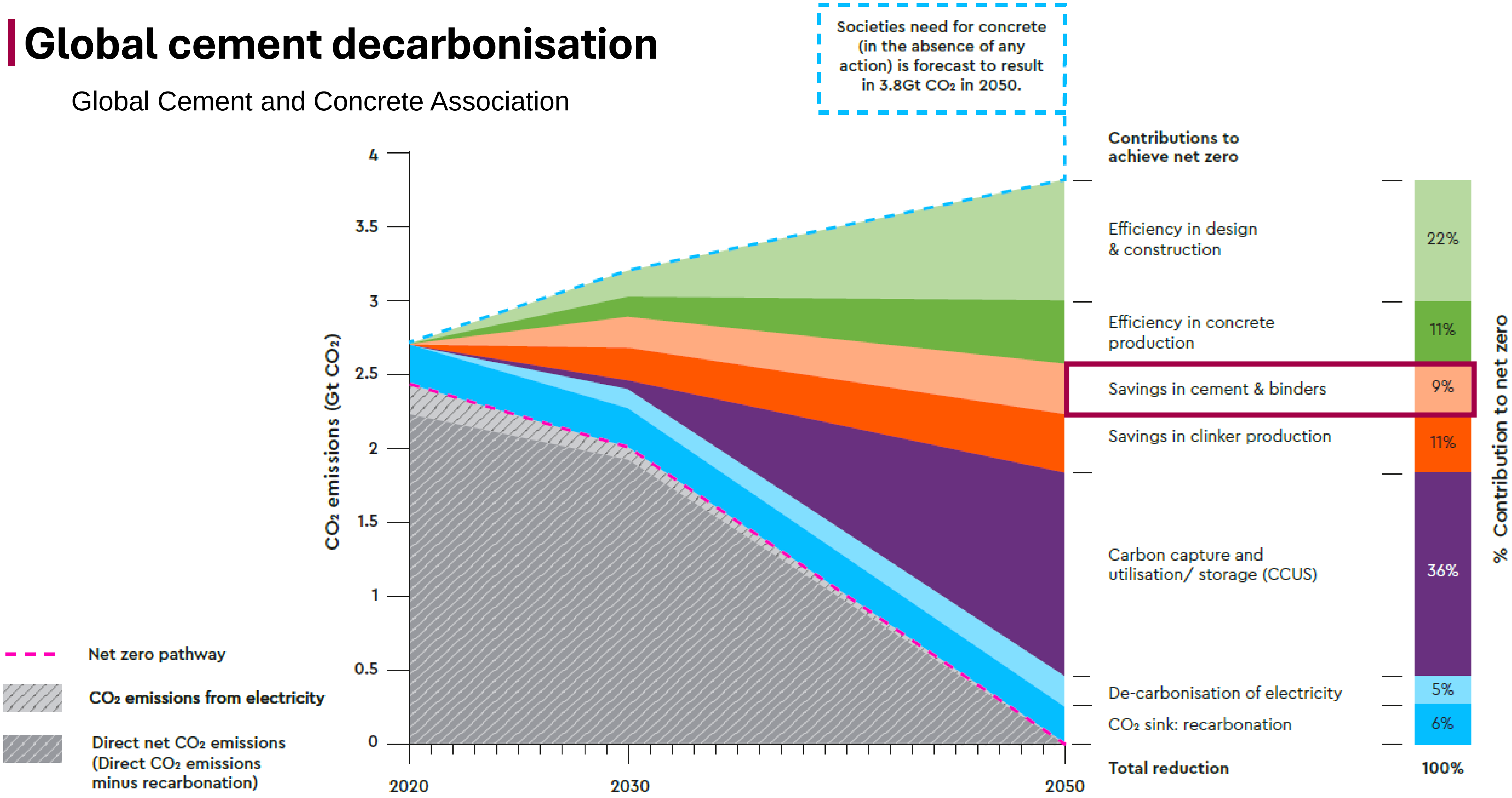
Does the development in the cement industry follow legislative and developer requirements?

Jesper Sand Damtoft

Global cement decarbonisation

Global Cement and Concrete Association



What is FUTURECEM®?

- **FUTURECEM®** is a cement with reduced clinker content, but similar performance as conventional cement.
- Based on the fact that a mixture of **fine-grained limestone** and **calcined clay** develops higher strength when mixed with Portland clinker than used separately
- **35% clinker replacement** enables up to 25% reduced CO_2 footprint of concrete

Calcined clay

Burned at much lower temperature than clinker and small process emissions

Limestone

Non-harmonized cement standard EN 197-5 is now valid

- Up to **50% clinker replacement** by limestone and calcined clay
- Max. **20%** limestone

Main types	Notation of the products (types of cement)		Composition (percentage by mass [a])										
			Main constituents										Minor additional constituents
			Clinker	Blast-furnace slag	Silica fume	Pozzolana		Fly ash		Burnt shale	Limestone		
						natural	natural calcined	siliceous	calcareous				
	Type name	Type notation	K	S	D [b]	P	Q	V	W	T	L [c]	LL [c]	
CEM II	Portland-composite cement [d]	CEM II/C-M	50-64	‹---- 36-50 ----›									0-5
CEM VI	Composite cement	CEM VI (S-P)	35-49	31-59	–	6-20	–	–	–	–	–	–	0-5
		CEM VI (S-V)	35-49	31-59	–	–	–	6-20	–	–	–	–	0-5
		CEM VI (S-L)	35-49	31-59	–	–	–	–	–	–	6-20	–	0-5
		CEM VI (S-LL)	35-49	31-59	–	–	–	–	–	–	–	6-20	0-5

a The values in the table refer to the sum of the main and minor additional constituents.

b In case of the use of silica fume, the proportion of silica fume is limited to 6-10 % by mass.

c In case of the use of limestone, the proportion of limestone (sum of L, LL) is limited to 6-20 % by mass.

d The number of main constituents other than clinker is limited to two and these main constituents shall be declared by designation of the cement (for examples, see Clause 6).

CALLISTE: CALcined clay LImeStone cement Technology Extension

Builds on FUTURECEM®

Two versions to be investigated

- CEM II/B-M (Q, LL)
  - Enhancing early strength to optimise use in pre-cast concrete
- CEM II/C-M (Q,LL)
  - Up to 50% clinker replacement to further reduce CO_2 footprint

Project basics

- Budget: 33 million Danish kroner
- Grant from Innovation Fund Denmark: 22 million Danish kroner
- Project duration: 4 years, 3 months, starting October 2020

Innovationsfonden

Partners in CALLISTE

- Aalborg Portland A/S
- Danish Technological Institute
- Technical University of Munich
- Aarhus University
- Technical University of Denmark
- Unicon
- CRH Concrete A/S
- IBF
- Danish Road Directorate
- FB Gruppen
- Femern A/S
- Danish Concrete Association (Dansk Beton)

Research approach

Reactivity of clay

Admixtures

Durability

Cement for precast concrete

Cement with high clinker substitution

Testing and documentation in full scale

Basic research

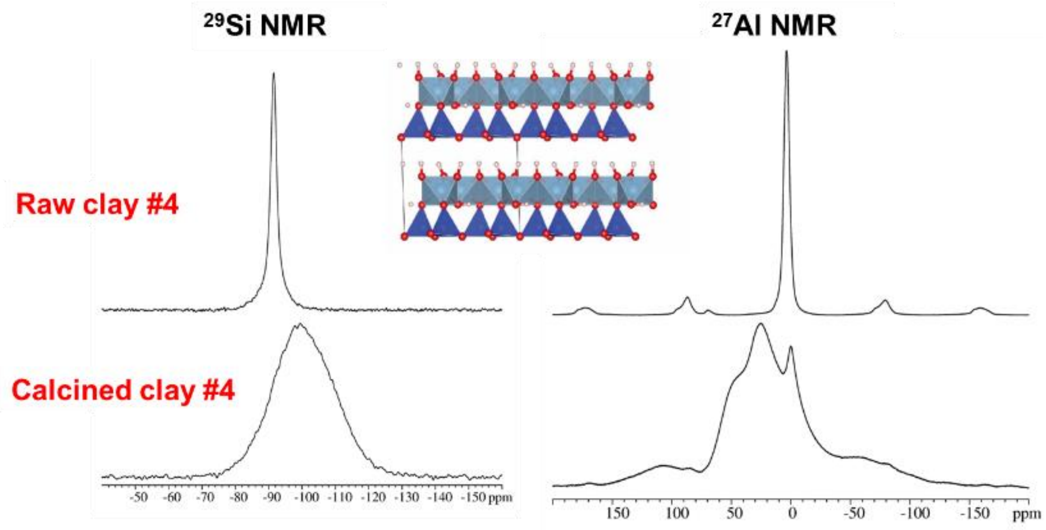
Applied research

Demonstration

Activation of calcined clay

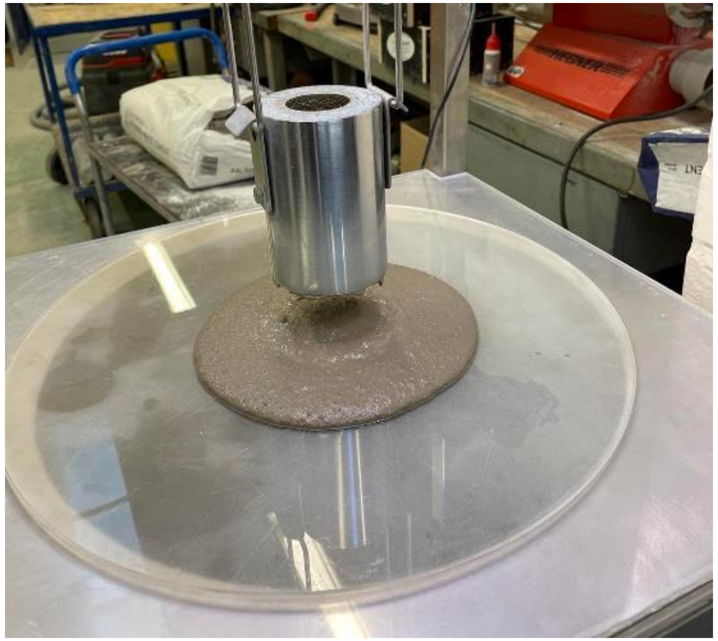
The effect on **reactivity of clays** that can be obtained from co-calcination of clays with chalk has been investigated.

- Methods include: ^{27}Al, ^{29}Si and ^{23}Na NMR spectroscopy, thermogravimetric analysis
- Results: Increased reactivity can be achieved from co-calcination of the clay with chalk
  - An increase in early reactivity has been demonstrated for 1:1 kaolinitic clay and confirmed by mortar tests.
  - The optimized co-calcined content and temperature for limestone are 20 wt.% and 800℃, resulting in a degree of reaction at 1 day for co-calcined clay that is more than **50% higher** than that of pure calcined clay
  - Tests with Danish clays (2:1 smectitic clay) currently on-going



Studies of the interaction between calcined clay and additives

- Investigations to identify PCE-structures (superplasticizers) optimized for calcined clay-limestone cement
- Wide range of PCE-structures have been synthesized and tested in lab:
  - Potential input for development of new industrial products.
- It has been confirmed that industrial PCE products are available, which enable to produce concrete of high quality with calcined clay-limestone cement
- Basic research on interaction between PCE sidechains and clay particles:
  - Indicates why higher dosages of PCEs are needed for cements with calcined clay → Potential input for design of more efficient PCE for such cements.



Durability

Frost resistance

Carbonation

Durability **80% clinker > 65% clinker > 50% clinker**

Nordic workshop on frost testing of concrete

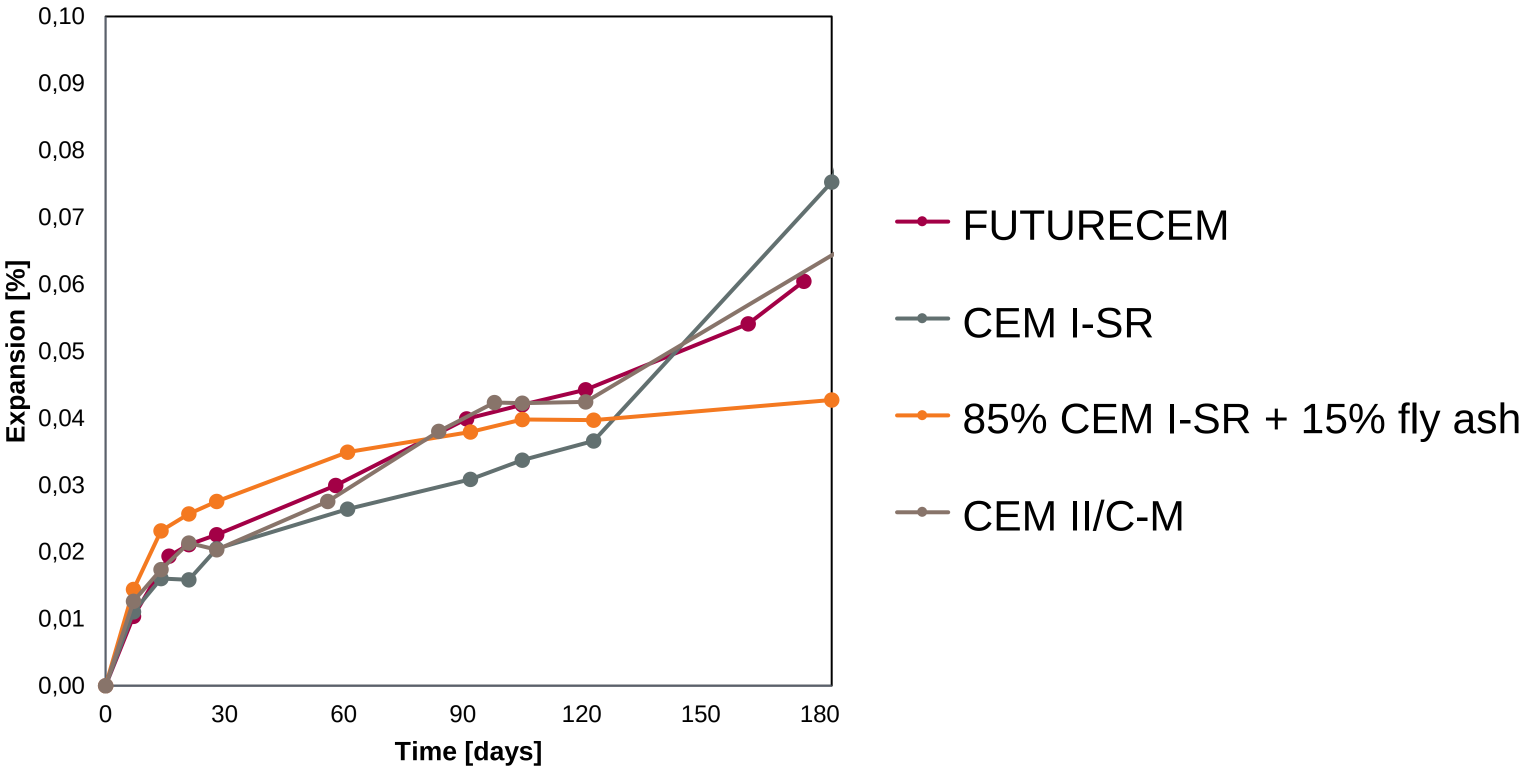
As part of CALLISTE a "**Nordic Concrete Research**" workshop was arranged to address various topics related to frost testing of concrete

- Title: **"Accelerated freeze-thaw testing of concrete"**
- Held at DTU, April 20, 2022, with 30 participants.
- 9 presentations on various topics related frost testing of concrete
- The **influence of test conditions** (e.g., the temperature curve) was heavily discussed during the workshop.

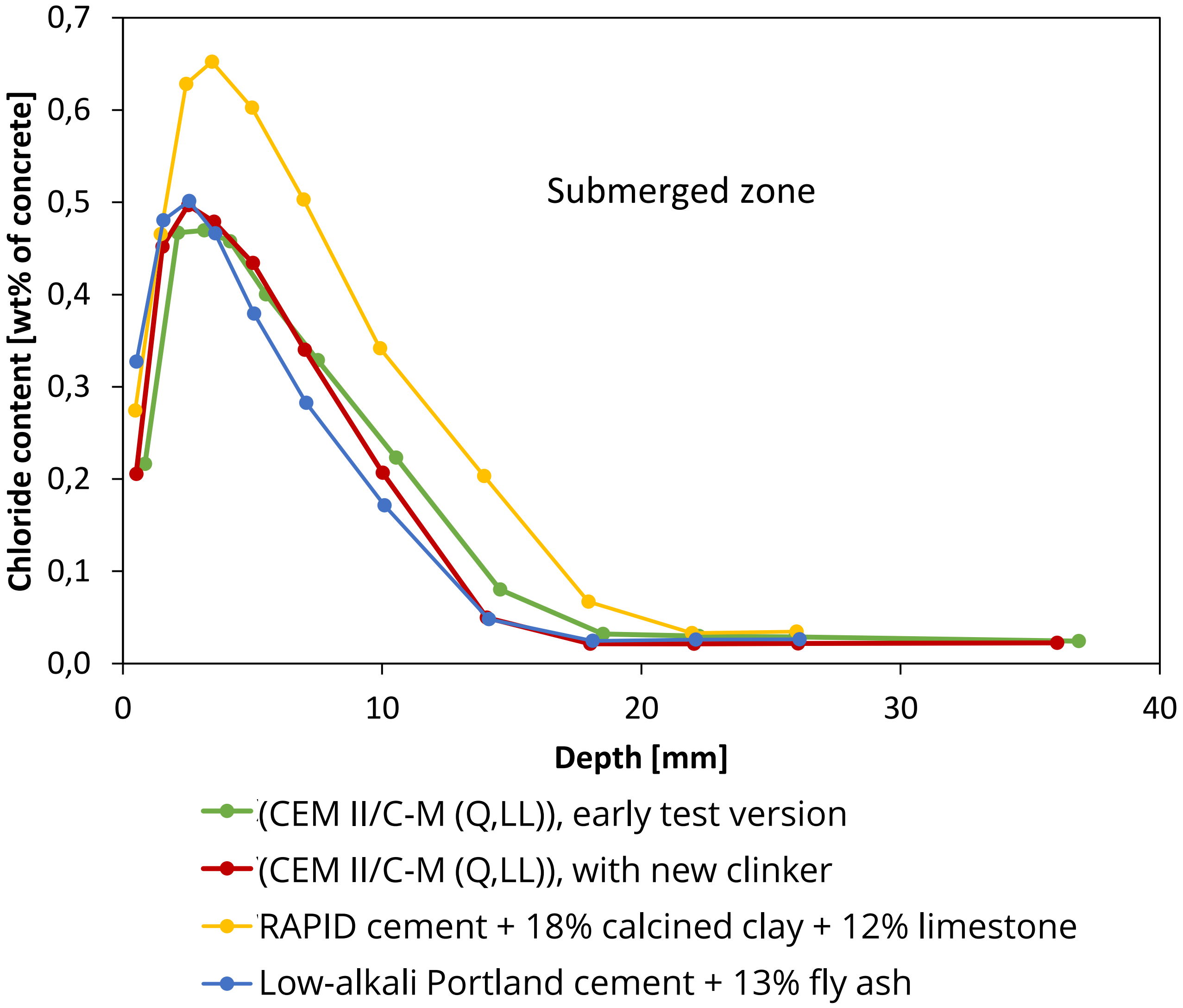
More research is needed about the actual frost damage mechanisms and relevant combined action (e.g., carbonation and freeze-thaw)

Presenters at the Nordic Concrete Research workshop. From left to right: Matthias Müller, Katja Frid, Frank Spörel, Elisabeth Helsing, Jukka Lahdensivu, Sara Al Haj Sleiman (screen), Marianne Tange Hasholt (front), Abdul Faheem and Stefan Jacobsen.

Parametric studies: Sulphate resistance



Chloride ingress, Port of Hirtshals exposure site



Industrial trials at Aalborg Portland to produce experimental cements

New clinker optimized for high early strength

Production of experimental clinker

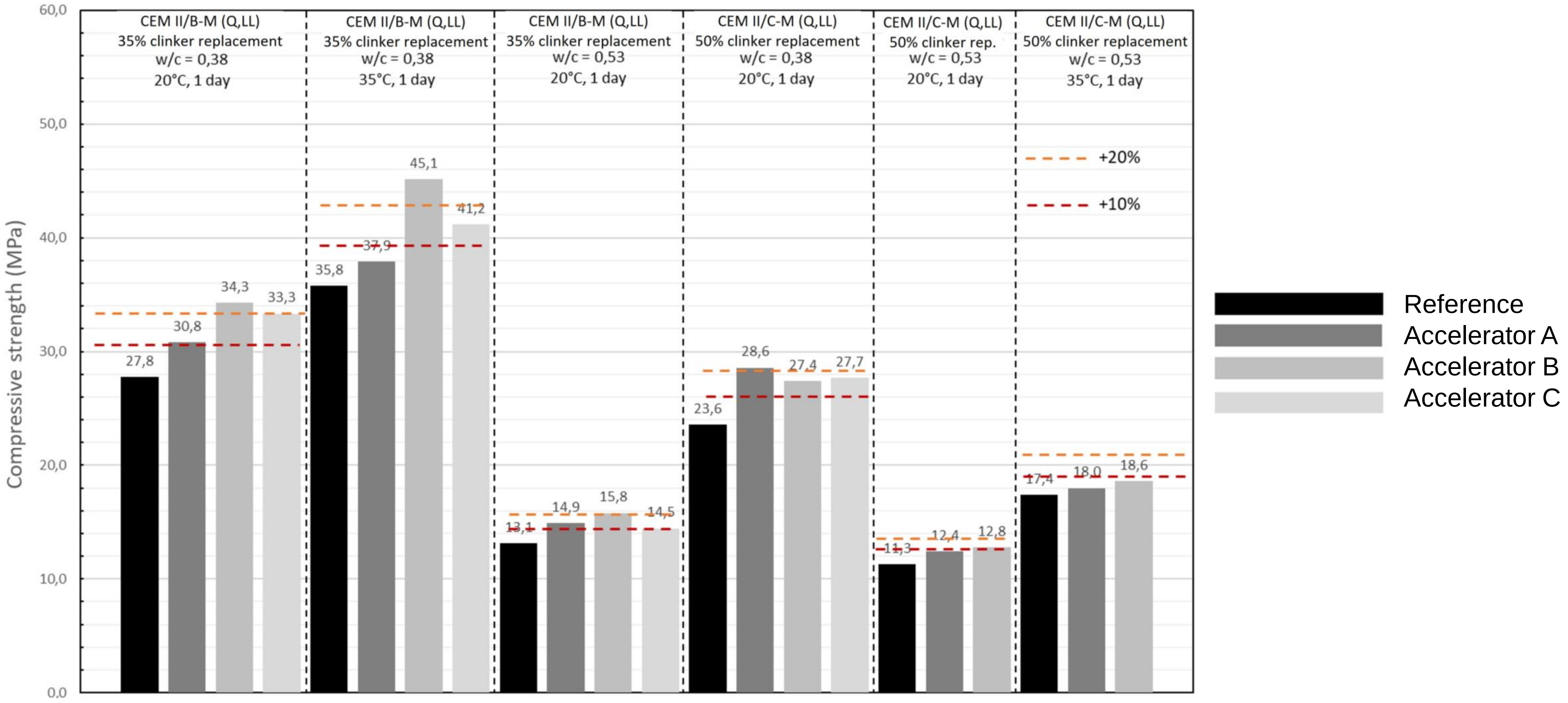
- 1500 tons of the new clinker at Aalborg Portland factory

Full-scale milling trials

- 130 tons CEM II/B-M (Q,LL)
- 200 tons CEM II/C-M (Q,LL)

	CEM II/B-M	CEM II/C-M
Clinker content (%)	66	53
1 day strength (MPa)	17	14
2 days strength (MPa)	29	25
28 days strength (MPa)	63	58

Use of accelerators to increase early concrete strength



DS/EN 206 documentation of CEM II/C-M (Q,LL) cement

- Concrete mix designs with CEM II/C-M (Q,LL) for moderate, aggressive and extra aggressive environmental impact developed for DS/EN 206, Annex N documentation

- Program carried out with testing of concrete properties
  - Fresh concrete properties (slump, air content, density)
  - Strength development
  - Heat development
  - Shrinkage
  - E-modulus
  - Frost resistance/air void structure
  - Chloride migration
  - Carbonation (natural + accelerated)
  - Sulphate resistance

- Generally, promising results
  - Challenges regarding frost resistance and carbonation

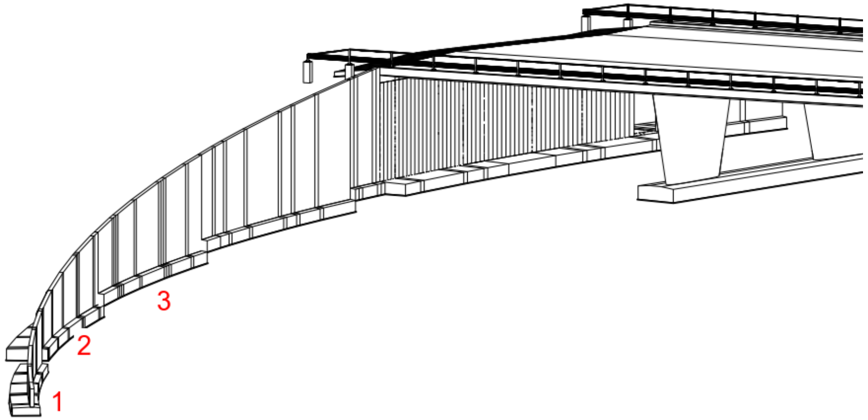
Demonstration projects

	Cement type	Building owner	Concrete producer
250 m^2 pavers in “Nærheden”, Hedehusene. Spring/summer 2023.	CEM II/C-M (Q,LL)	FB Gruppen	IBF
Prefabricated concrete elements for building in “Nærheden”, Hedehusene. Autumn 2023.	CEM II/B-M (Q,LL)	FB Gruppen	CRH Concrete
In-situ casting of retaining wall for road bridge near Aarhus. Sept. 2024 – Jan. 2025	CEM II/C-M (Q,LL)	Danish Road Directorate	IBF
In-situ casting of concrete wall near service road at Femern Link Contractors prefab yard. October 2024.	CEM II/C-M (Q,LL)	Femern A/S	Unicon

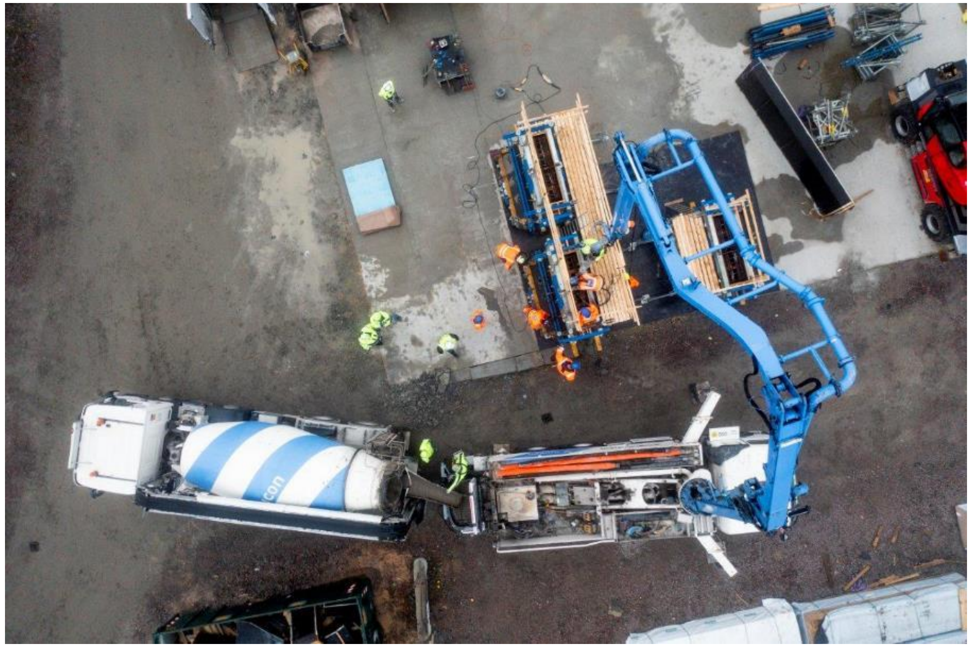
Demo project in Hedehusene: Nærheden (IBF/FB Gruppen)

Demo project in Hedehusene: Nærheden (CRH/FB Gruppen)

Demo project with retaining wall near Aarhus (IBF/Danish Road Directorate)



Demo project in Rødbyhavn (Unicon/Femern A/S)



Estimation of CO_2 reductions for concretes used in demo projects

(preliminary results)

Demo project	Concrete type	GWP, concrete with cement from CALLISTE	GWP, concrete with reference cement	Reduction
Rødbyhavn	Ready-mixed concrete	CEM II/C: 255 kg/m³	FUTURECEM: 294 kg/m³	**13.3%**
Retaining wall	Ready-mixed concrete	CEM II/C: 241 kg/m³	FUTURECEM: 255 kg/m³	**5.5%**
Hedehusene	Concrete wall element	CEM II/B: 135 kg/ton	Basis cement: 138 kg/ton	**2.0%**
	Hollow core slab	CEM II/B: 112 kg/ton	Basis cement: 126 kg/ton	**11.4%**
	Lightweight concrete wall element (LAC15/1850)	CEM II/B: 113 kg/ton	Basis cement: 117 kg/ton	**3.7%**
	Lightweight concrete wall element (LAC10/2000)	CEM II/B: 98 kg/ton	Basis cement: 101 kg/ton	**3.0%**

CEM II/B: 35% clinker substitution
CEM II/C: 50% clinker substitution

Some achievements

- Basic research has provided new knowledge of clay activation and interactions between calcined clay and superplasticisers

- Valuable knowledge of durability of calcined clay-limestone cement has been gained and will be used in the continued development of cement and concrete.

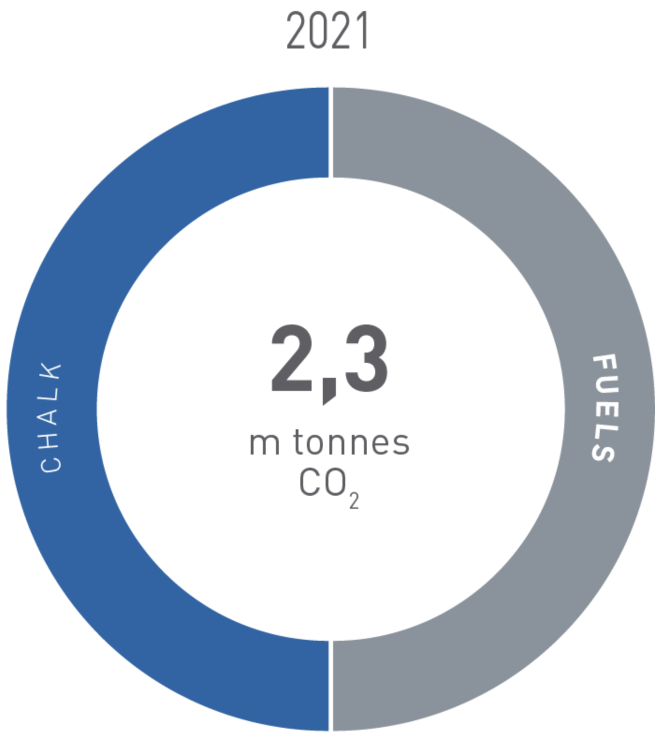
- Lessons learned from the industrial trials in the cement production has been implemented and is used today

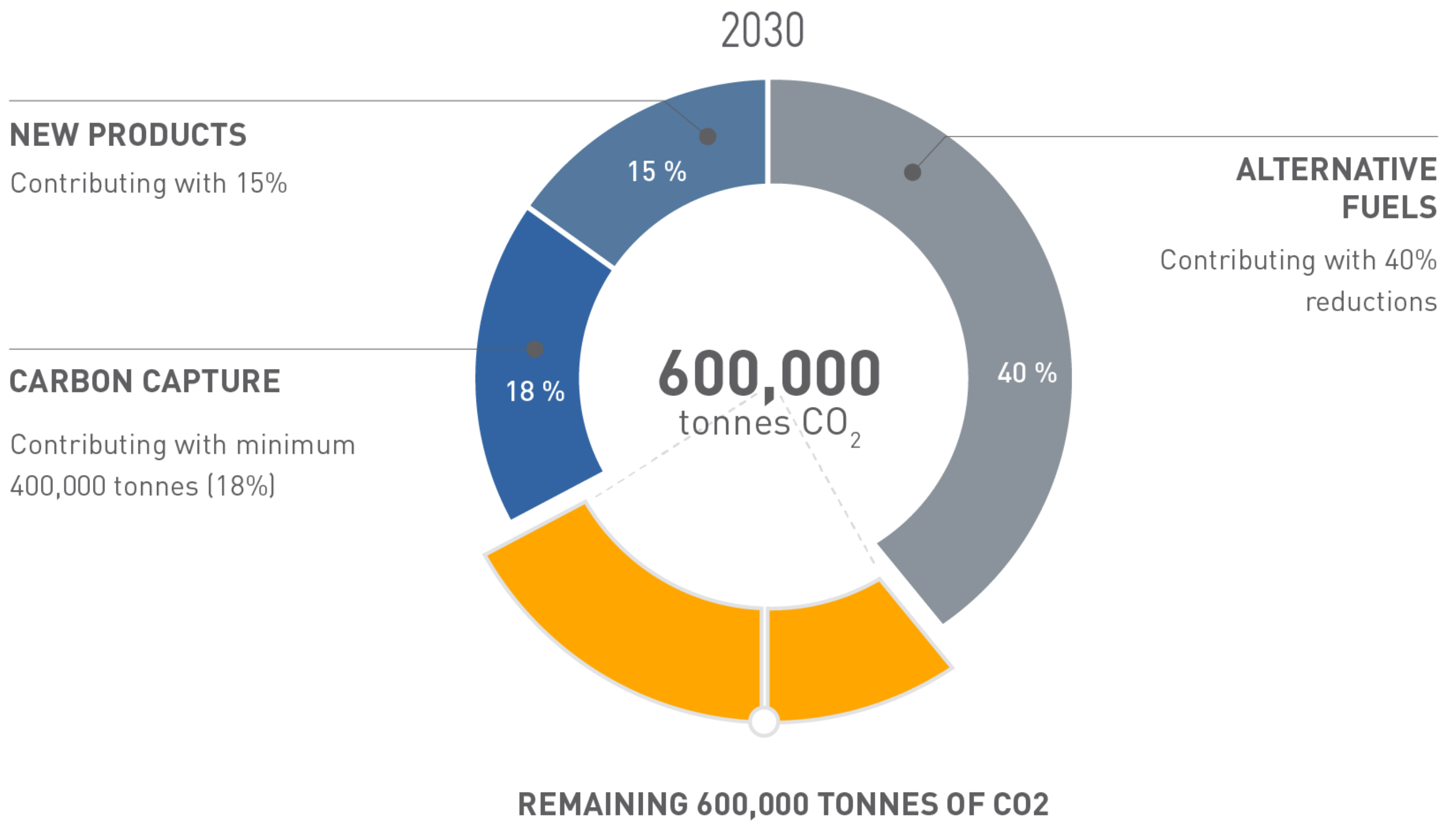
- Methods to improve the early strength of CEM II/B-M has been developed

- CEM II/C-M has been tested in full scale with a pilot cement production. DS/EN 206, Annex N documentation will be evaluated.

- Full-scale demonstration structures has demonstrated that the experimental cements can be used in real constructions

Aalborg Portland's 2023 CO_2 reduction roadmap (Scope 1)





Emissions

2021: **2.3 million tons CO_2**

2023: **1.7 million tons CO_2**

2030: **0.6 million tons CO_2 by 400,000 tons captured**

ACCSION → **1.4 million tons captured**

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