



Concrete – the carbon sink for a climate neutral Switzerland?

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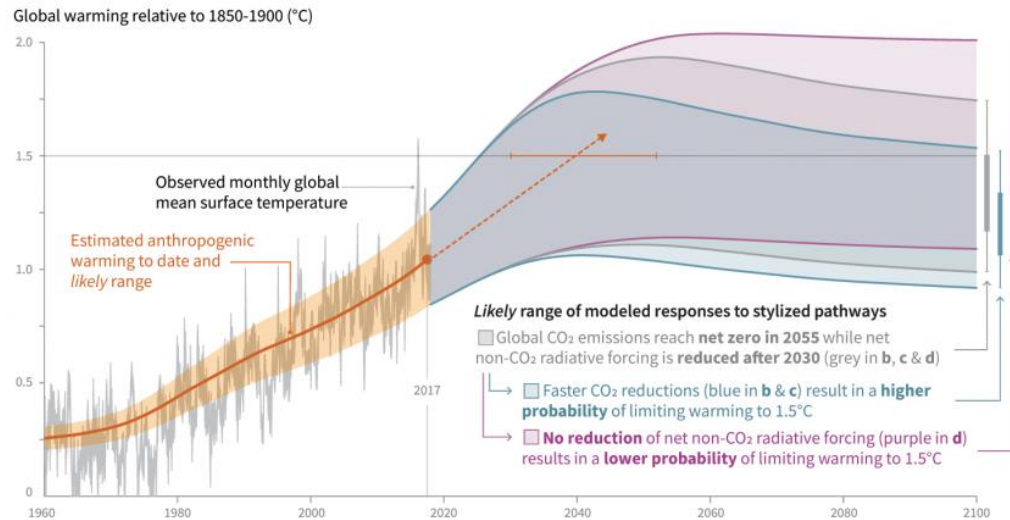
Outline

1. The emission problem of the cement & concrete industry
2. The physics of concrete carbonation
3. Piloting concrete as a carbon sink in Bern
4. Pathways towards a net-zero CO₂ concrete

The Net-Zero GHG challenge

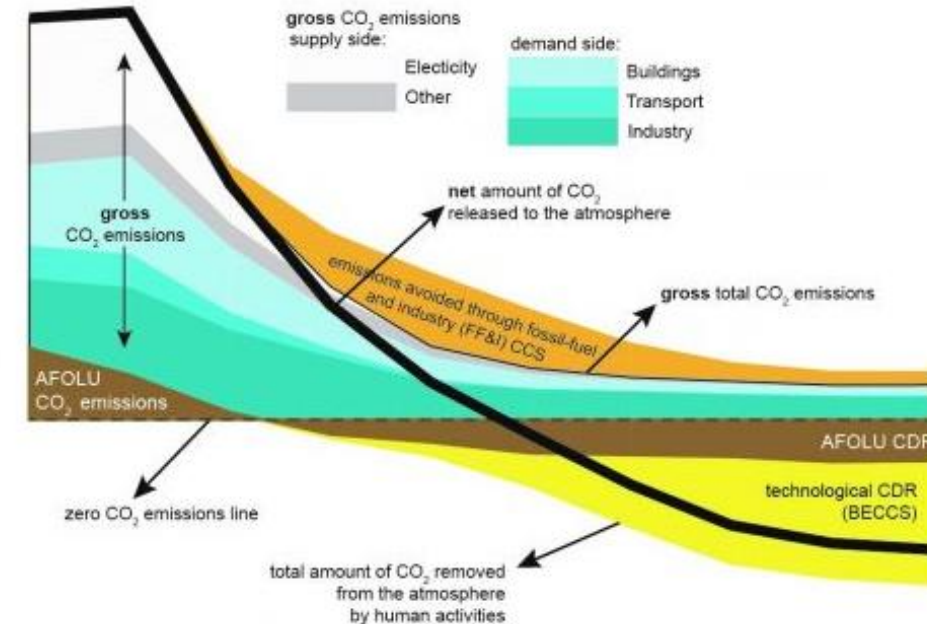
Cumulative emissions of CO₂ and future non-CO₂ radiative forcing determine the probability of limiting warming to 1.5°C

a) Observed global temperature change and modeled responses to stylized anthropogenic emission and forcing pathways



- Current rate of global warming due to human activities
- Paris agreement → 2°C is an acceptable level of global warming
- Temperature goal is equivalent to a limited carbon budget

LEGEND: EMISSION CONTRIBUTIONS



- From 40Gt CO₂ to Net Zero in 30 years
- CCS a key technology to decarbonize the industrial sector and to create negative emissions

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The global cement industry – some key numbers

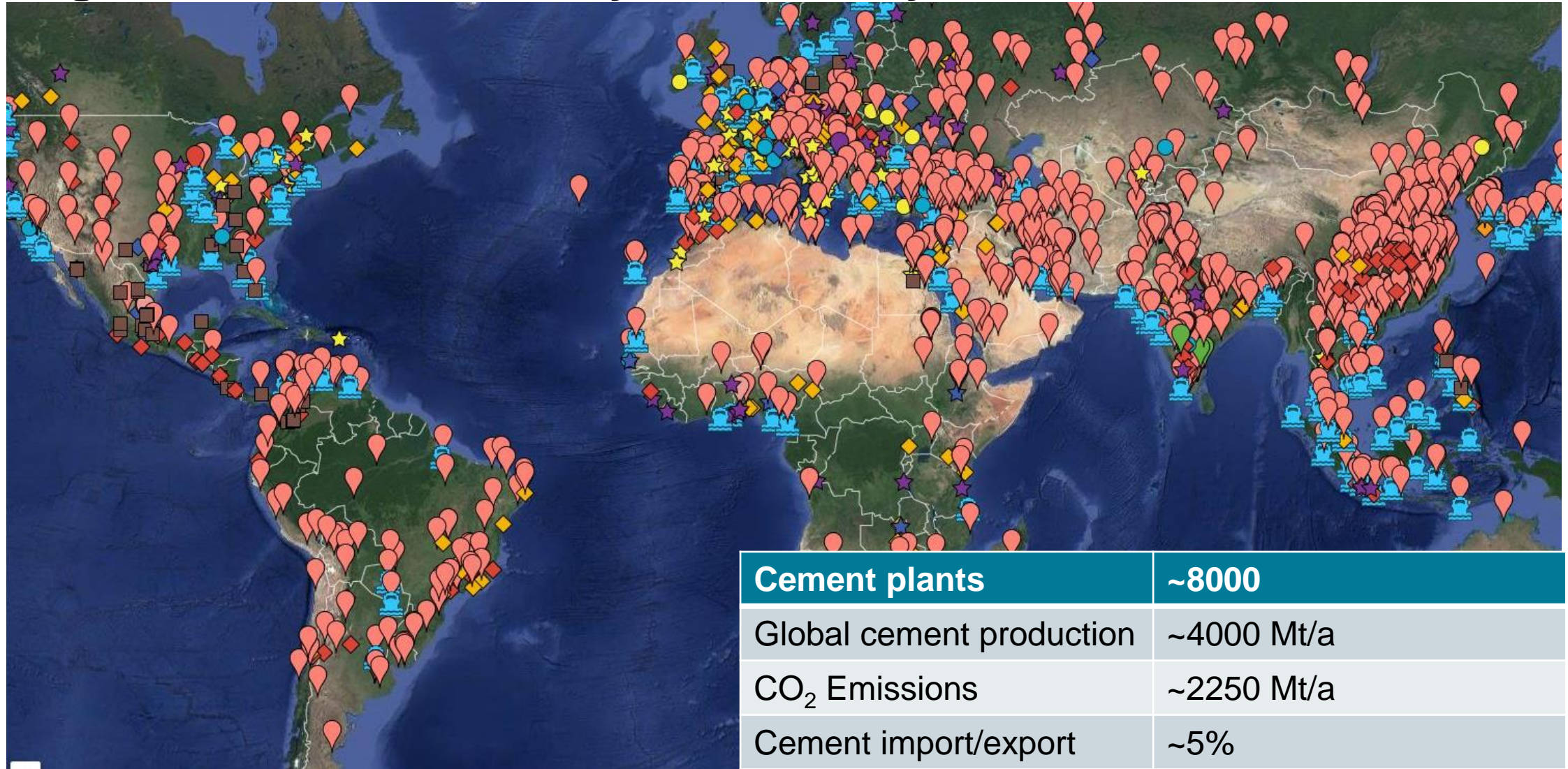
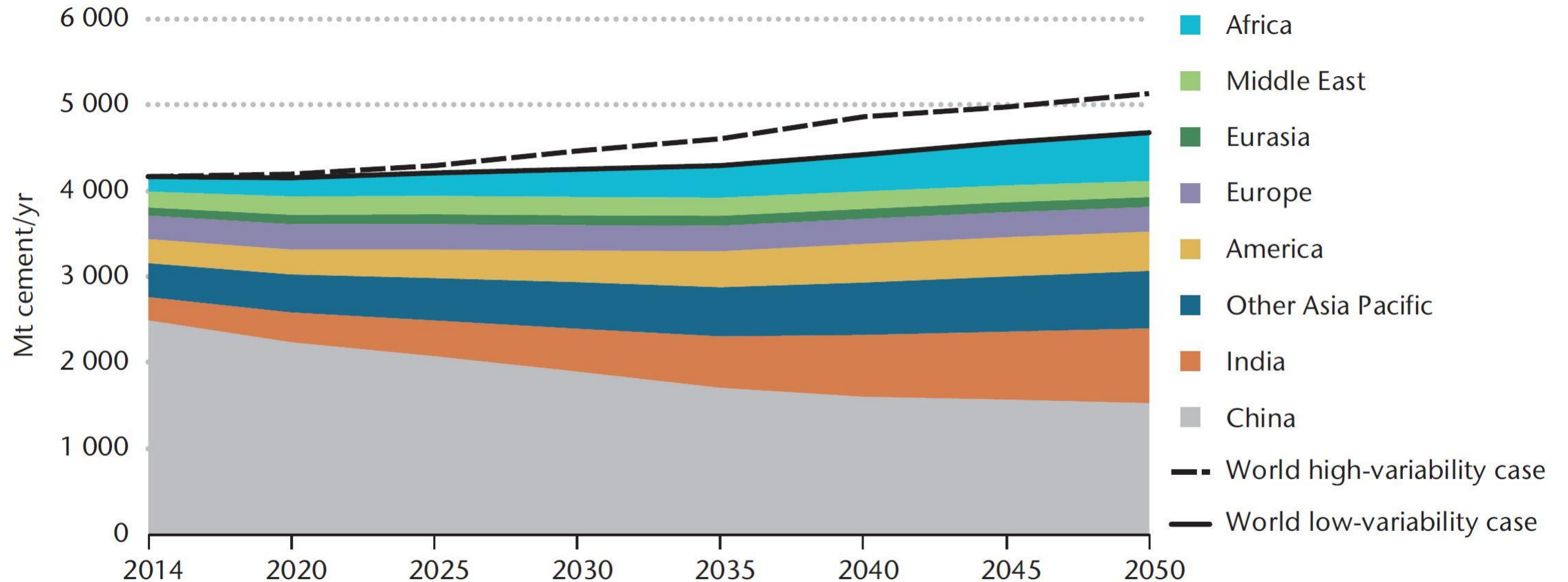


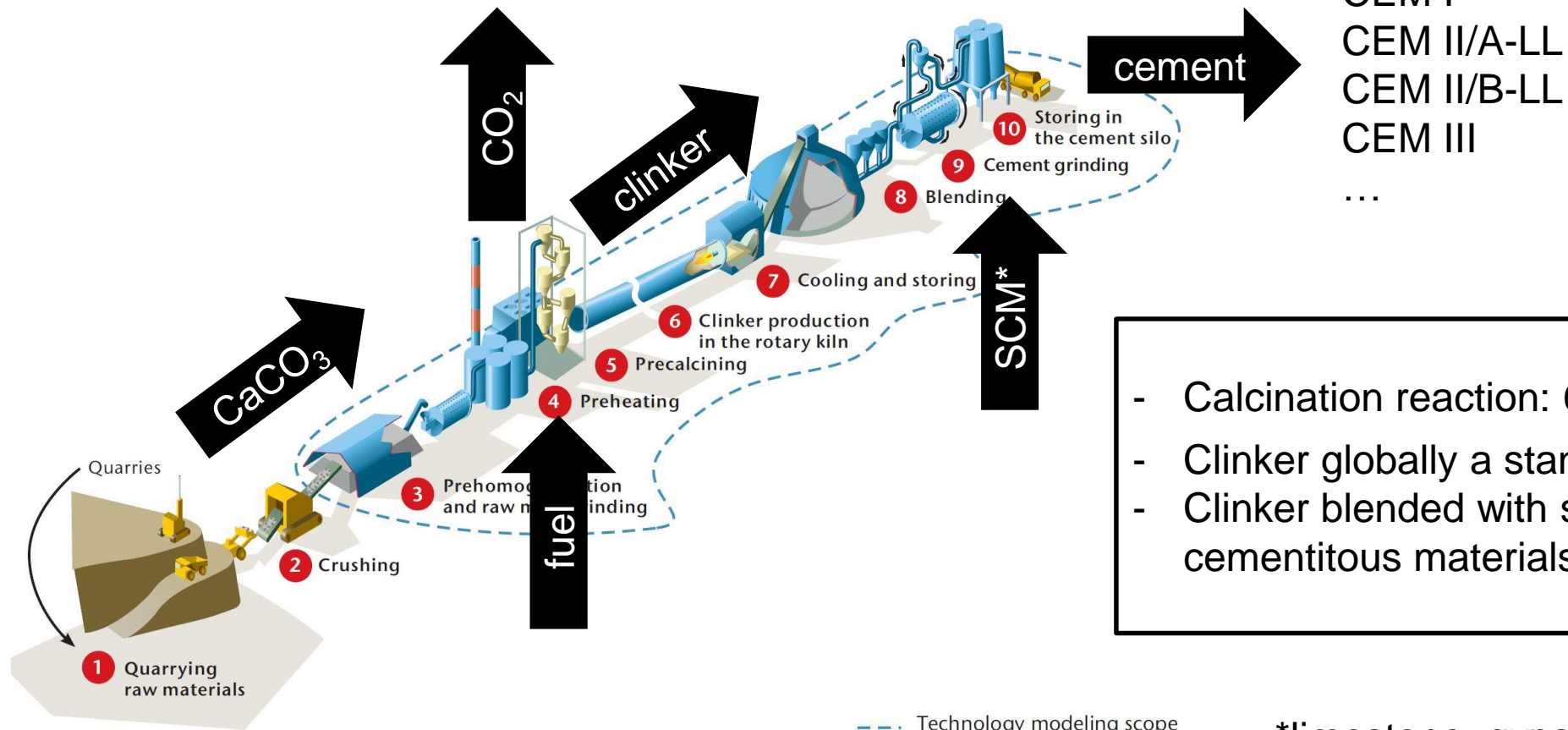
Figure 4: Cement production by region



Note: See Annex for regional definitions.

Sources: Base year cement production data from van Oss, H. G. (2016), *2014 Minerals Yearbook: Cement*, United States Geological Survey data release, <https://minerals.usgs.gov/minerals/pubs/commodity/cement/myb1-2014-cemen.pdf>.

The cement manufacturing process



- Calcination reaction: $\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$
- Clinker globally a standard product
- Clinker blended with supplementary cementitious materials → cement

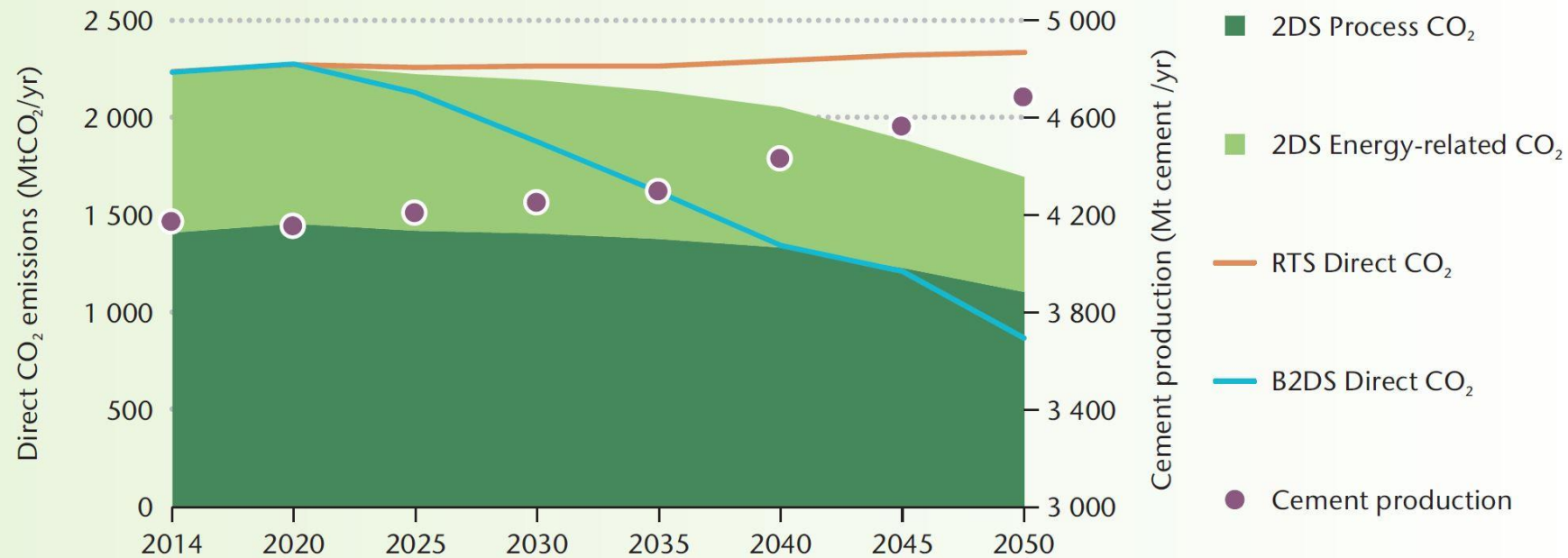
Note: A dry-process kiln is shown with a precalciner and multistage cyclone preheater, which is considered state-of-the-art technology. The modelling results used for the analysis in this roadmap include steps 3-10 of the above figure.

Source: IEA and WBCSD (2009), *Cement Technology Roadmap 2009: Carbon Emissions Reductions up to 2050*, www.iea.org/publications/freepublications/publication/Cement.pdf.

*limestone, gypsum, fly ash, clays, blast furnace slag

Cement sustainability initiative – climate strategy I

Figure 5: Global direct CO₂ emissions in cement production by scenario



KEY MESSAGE: The B2DS would require the cement industry to increase by about 45% the cumulative carbon emissions reductions effort compared to the 2DS, which is the reference carbon emissions reduction scenario for this roadmap's vision.

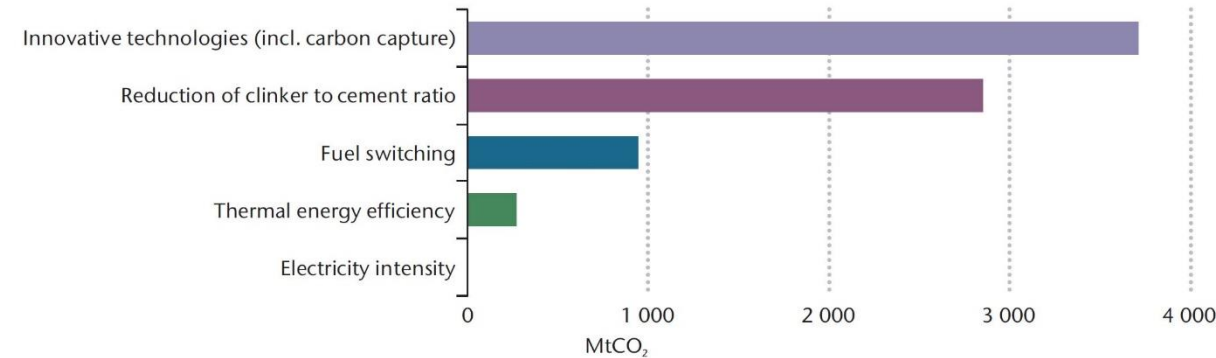
Cement sustainability initiative – climate strategy II

Table 2: Key indicators for the global cement industry in the RTS and the roadmap vision (2DS)

	2014	RTS Low-variability case			Roadmap vision (2DS) Low-variability case		
		2030	2040	2050	2030	2040	2050
Cement production (Mt/yr)	4 171	4 250	4 429	4 682	4 250	4 429	4 682
Clinker to cement ratio	0.65	0.66	0.67	0.66	0.64	0.63	0.60
Thermal energy intensity of clinker (GJ/t clinker)	3.5	3.4	3.3	3.2	3.3	3.2	3.1
Electricity intensity of cement (kWh/t cement)	91	89	86	82	87	83	79
Alternative fuel use (percentage of thermal energy consumption)	5.6	10.9	14.4	17.5	17.5	25.1	30.0
CO ₂ captured and stored (MtCO ₂ /yr)	-	7	65	83	14	173	552
Direct process CO ₂ intensity of cement (tCO ₂ /t cement)	0.34	0.34	0.34	0.33	0.33	0.30	0.24
Direct energy-related CO ₂ intensity of cement (tCO ₂ /t cement)	0.20	0.19	0.18	0.17	0.19	0.16	0.13

Notes: Thermal energy intensity of clinker does not include any impact related to other carbon mitigation levers beyond improving energy efficiency (e.g. carbon capture). Electricity intensity of cement production does not include reduction in purchased electricity demand from the use of waste heat recovery equipment or any impact related to other carbon mitigation levers beyond improving energy efficiency (e.g. carbon capture). Alternative fuel use includes biomass, and biogenic and non-biogenic waste. Direct CO₂ intensity refers to net CO₂ emissions, after carbon capture.

Figure 7: Global cumulative CO₂ emissions reductions by applying the roadmap vision (2DS) compared to the RTS



Note: Cumulative CO₂ emissions reductions refer to the period from 2020 to 2050 and are based on the low-variability case of the scenarios.

2020-2050: The cement sector forecasts cumulative savings of 7.5 Gt CO₂ while they emit about 70 Gt CO₂. Investments in CCS are delayed

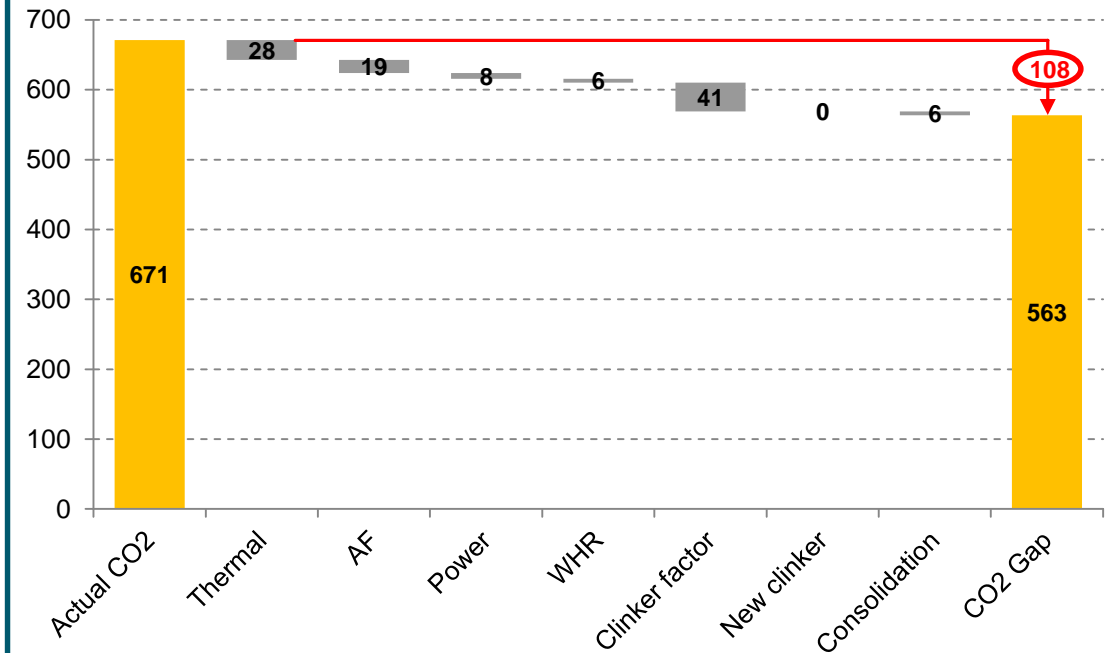
Emission reduction potential along the cement manufacturing value chain

Performance improvement potential

Lever	Measure	Performance		
		Unit	Current	Potential
Thermal efficiency	Upgrade to modern dry precalciner preheater kilns	MJ/t clinker	3'690	3'200
Alternative fuels	Increase the thermal substitution rate	%	43	60
Electrical efficiency	Replace ball mills with vertical roller mills...	kWh/t cement	116	100
Waste heat recovery	Install in all plants	kWh/t cement	0	15
Clinker substitution	Reduce the clinker-to-cement ratio with SCMs	Clinker content in %	74	69
Low carbon cement	Product innovation	Market share of low carbon cements %	0	0

CSI/GNR database (values for EU28), ECRA Technology papers (2017)

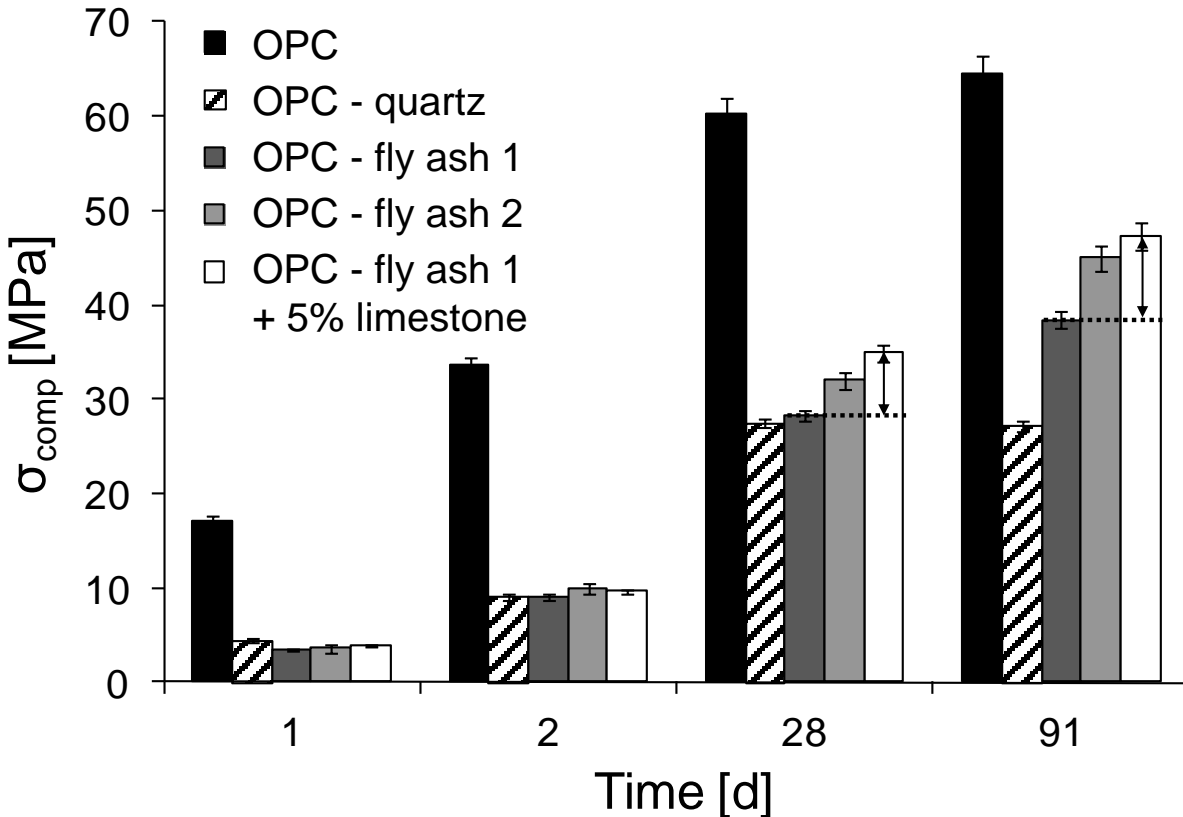
CO₂ reduction potential



Estimates D. Włodarczak

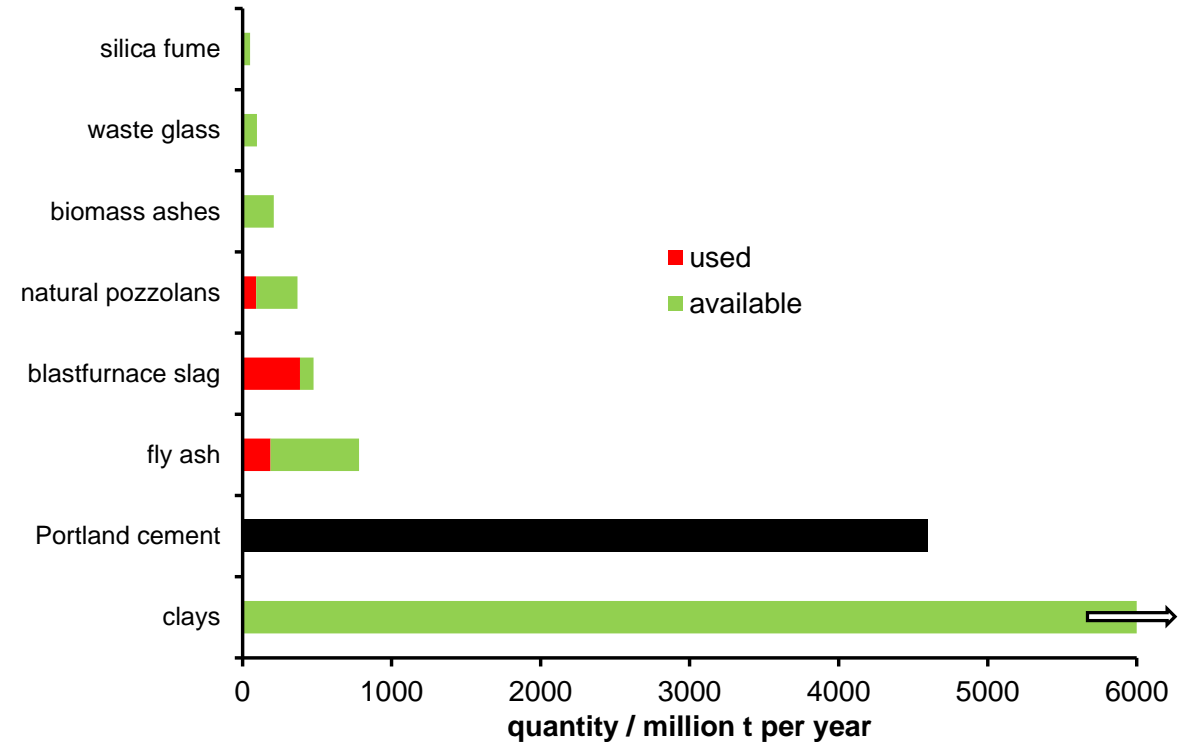
Alternative binders

Material properties



[1] Deschner, Winnefeld, Lothenbach, Seufert, Schwesig, Dittrich, Götz-Neunhoeffler, Neubauer: Cem. Concr. Res. 42 (2012), 1389.

Resources for alternative binders



[2] Scrivener, John, Gartner: Eco-efficient cements: Potential, economically viable solutions for a low-CO₂, cement-based materials industry, Report of the United Nations Environment Programme, 2016.

Summary

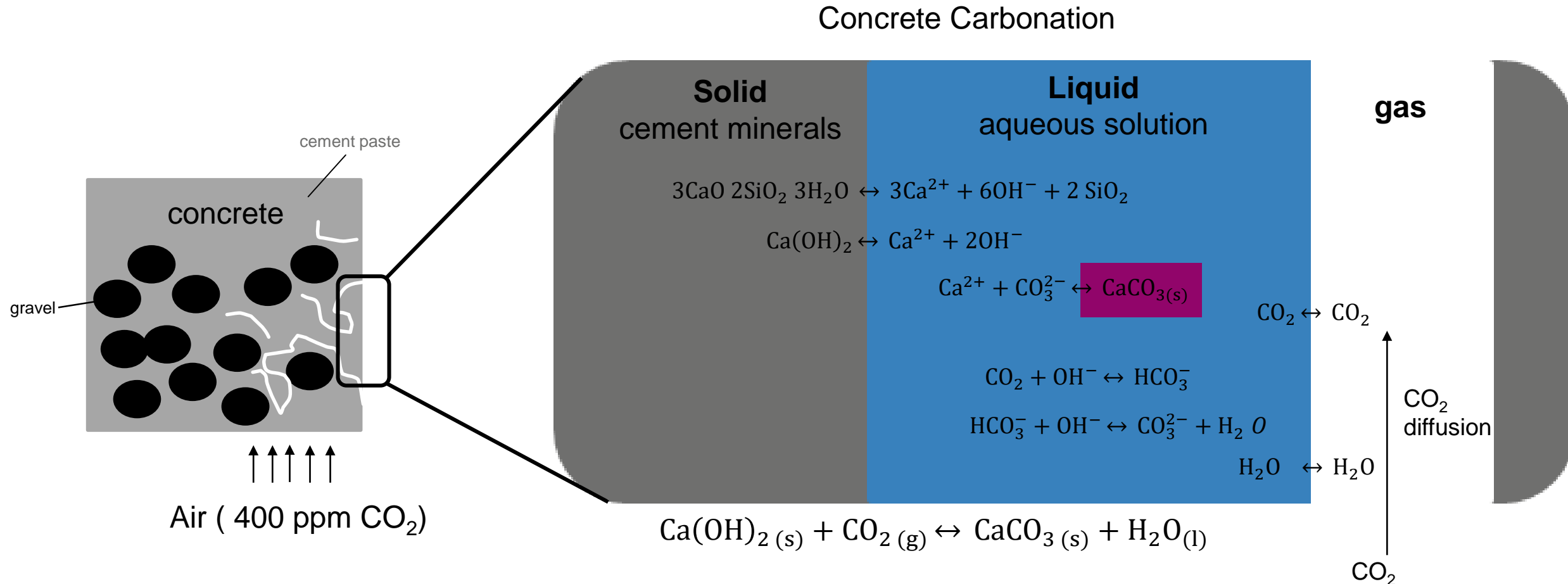
- Annual GHG emissions have to go to net-zero until 2050 – and cumulative emissions should be minimized
- There is very limited potential to save GHG emissions along the cement manufacturing process
- There are no alternatives to Portland cement
- CCS still needs 1) a business case 2) transport and storage infrastructure

→ What can be done right now to reduce emissions?

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Physics behind carbonation of concrete



Carbonation of concrete – state of the art

Modelling



Figure 4. Slab and control volume geometry.

Diffusion with reaction

$$\frac{\partial c_{\text{CO}_2}}{\partial t} = \frac{\partial}{\partial x} \left(D_{\text{CO}_2} \frac{\partial c_{\text{CO}_2}}{\partial x} \right) - r_{\text{CaCO}_3}$$

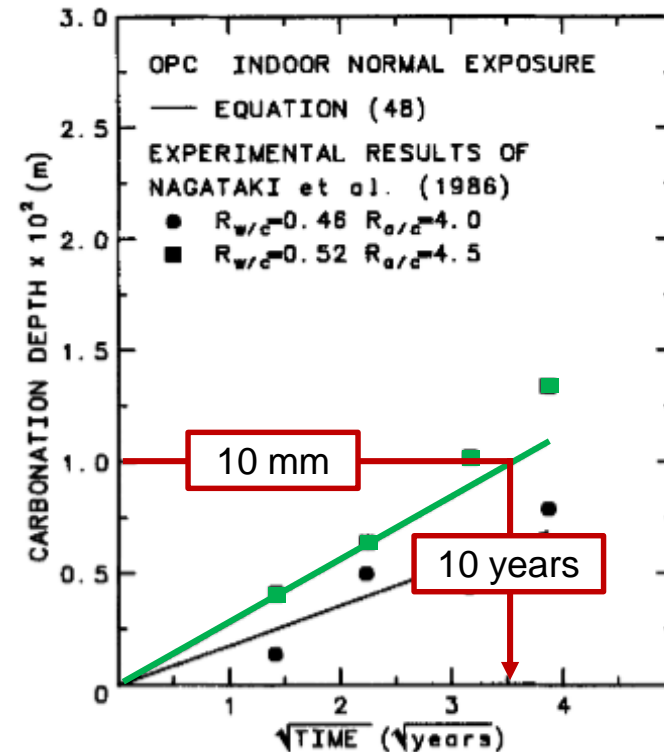
Carbonation depth

$$x_c = \sqrt{\frac{2p_{\text{CO}_2} D_{\text{CO}_2} t}{c_{\text{Ca}(\text{OH})_2}^0 + c_{\text{CSH}}^0}}$$

Model validation

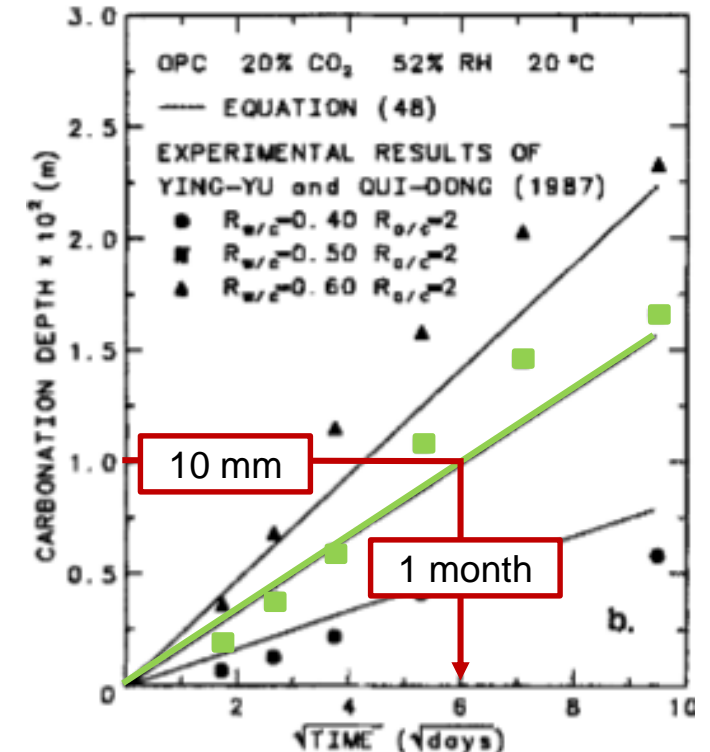
Natural carbonation

indoor exposure



Accelerated carbonation

20% CO₂ / 52% RH / 20°C / W/C 0.4 -0.6



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ara region bern ag




neustark™

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 Bundesrat will bis 2050 eine klimaneutrale Schweiz

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Bundesrat will bis 2050 eine klimaneutrale Schweiz

Bern, 28.08.2019 - Die Schweiz hat sich im Rahmen des Pariser Klimaübereinkommens verpflichtet, bis 2030 ihren Treibhausgasausstoss gegenüber dem Stand von 1990 zu halbieren. Aufgrund der neuen wissenschaftlichen Erkenntnisse des Weltklimarates hat der Bundesrat an seiner Sitzung vom 28. August 2019 entschieden, dieses Ziel zu verschärfen: Ab dem Jahr 2050 soll die Schweiz unter dem Strich keine Treibhausgasemissionen mehr ausstossen. Damit entspricht die Schweiz dem international vereinbarten Ziel, die globale Klimaerwärmung auf maximal 1,5°C gegenüber der vorindustriellen Zeit zu begrenzen.

Mit der Unterzeichnung des Klimaübereinkommens von Paris hatte der Bundesrat das langfristige Ziel angekündigt, die Emissionen der Schweiz bis 2050 um 70–85 Prozent zu vermindern. Dieses Ziel basierte auf Erkenntnissen des Weltklimarates (IPCC), wonach die Klimaerwärmung bis zum Jahr 2100 auf unter 2 Grad zu begrenzen ist, um gravierende Folgen für Mensch und Artenvielfalt zu verhindern. 2018 hat der IPCC aufgezeigt, dass bereits ab einer globalen Erwärmung um 1,5 Grad mit gravierenden Veränderungen der Ökosysteme gerechnet werden muss und eine ausgeglichene Emissionsbilanz von Netto-Null bereits wesentlich früher erreicht werden muss. Der Bundesrat hat daraufhin das Bundesamt für Umwelt (BAFU) beauftragt, die langfristigen Klimaziele neu zu prüfen und Handlungsmöglichkeiten auszuarbeiten. Zudem hatte der Bundesrat am 26.

5%

of CH CO₂ emissions
have to be addressed by
sinks.

CO₂ SINK CONCRETE

CO₂ SINK DEMOLITION CONCRETE

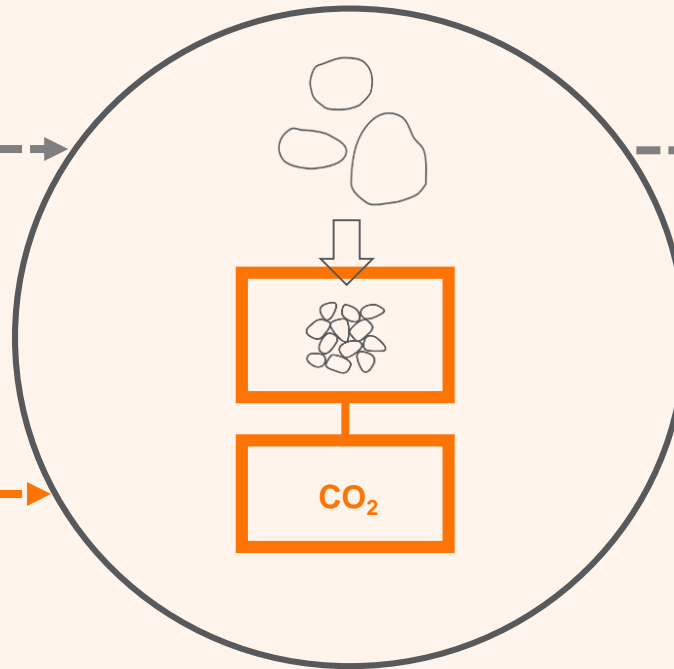
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Demolition
concrete



CO₂



Concrete recycling
plant



Concrete
batching



Recycling
concrete

- cement
+ RC-fraction



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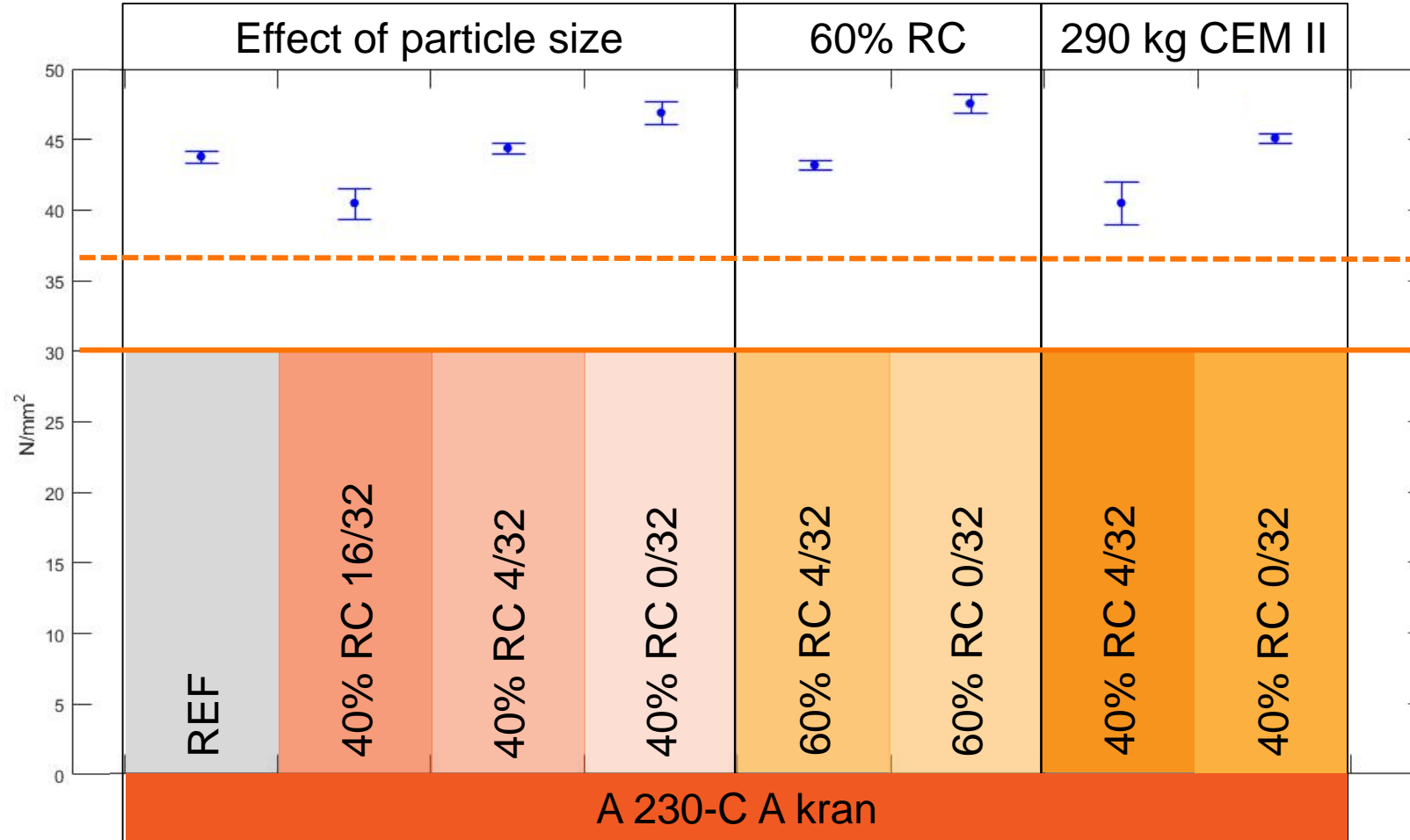


Compressive strength after 28 days

RECARB



Beton SN EN 206; C 25/30; XC2; CI 0.1; 0/32; F3; Kran



Carb. Resistance, spreading properties & E-Module

RECARB






Carbonation resistance



Prüfkörperart Prisma 120x120x360 mm Probeneingang 21.11.2019
Prüfungsbeginn 17.12.2019 (Nullmessung) Betonalter 28 Tage bei Nullmessung

Prüfkörper		Karbonatisierungstiefe				Karbonatisierungstiefe vs. Versuchsdauer	
Seite		[mm]					
Nr.		d_{KE1}	d_{KE2}	d_{KE3}	d_{KE4}	Karbonatisierungstiefe d_{KM} [mm]	
1		3.0	9.5	13.0	16.8		
2		2.0	9.8	11.8	15.0		
3		1.8	9.0	13.5	14.8		
4		2.0	9.0	13.0	16.5		
Mittelwert d_{KM}		2.2	9.3	12.8	15.8		
Zeit t	[Tage]	0	7	28	63		
Zeit $t^{0.5}$	[Tage] ^{0.5}	0.0	2.6	5.3	7.9		
Koeffizient K_S	[mm/Tag] ^{0.5}			1.67			
Koeffizient K_N	[mm/Jahr] ^{0.5}			4.3			

	Messresultate		Lineare Regression
			R = Regressionskoeffizient

Anmerkung: Probekörperlagerung (Herstellung bis Laboreingang) durch Auftraggeber.

Increasing from 4.9 to 4.3 mm/y^{0.5}

E-Module

Festbetoneigenschaften					
Probeneingang	21.11.2019	Festbetonprobe		Bohrkerne aus Würfel	
Prüfungsdatum	17.12.2019	Prüfkörper		Bohrkern Ø = 50 mm	
Prüfalter	28 Tage				
PK Nr.	Länge	Durchmesser	Unterspannung σ_s	Oberspannung σ_s	Stabilisierter E-Modul $E_{c,s}$
[:]	[mm]	[mm]	[N/mm ²]	[N/mm ²]	[N/mm ²]
1	148,1	49,4	2,5	7,0	34'336
2	148,1	49,4	2,5	7,0	38'020
3	148,0	49,4	2,5	7,0	30'855
4	148,0	49,4	2,5	7,0	37'235
5	148,4	49,4	2,5	7,0	32'526
Belastungsflächen der Prüfkörper planparallel geschliffen; Messeinrichtung: 2 Dehnungsaufnehmer auf gegenüberliegenden Mantellinien / Messlinie $L_0 = 100$ mm				Mittelwert	34'594
				Standardabw.	3'043

Lagerung des Probekörpers (Würfel) gem. SN EN 12390-2 (Wasserlagerung 20 ± 2°)
Feuchtigkeitszustand der Prüfkörper zum Zeitpunkt der Prüfung: wassergesättigt und oberflächentrocken
Auftragsgemäss wurde die Druckfestigkeit f_c an Begleitprobekörpern nicht bestimmt (SN EN 12390-13:2013, Ziff. NA.7.2). Aus diesem Grund wurde auch die Druckfestigkeit der verwendeten Prüfkörper nach Abschluss der E-Modul-Messungen nicht ermittelt (Vergleichsmessung zu f_c).

Berichtsdatum 19.12.2019

Remained at about 35 MPa

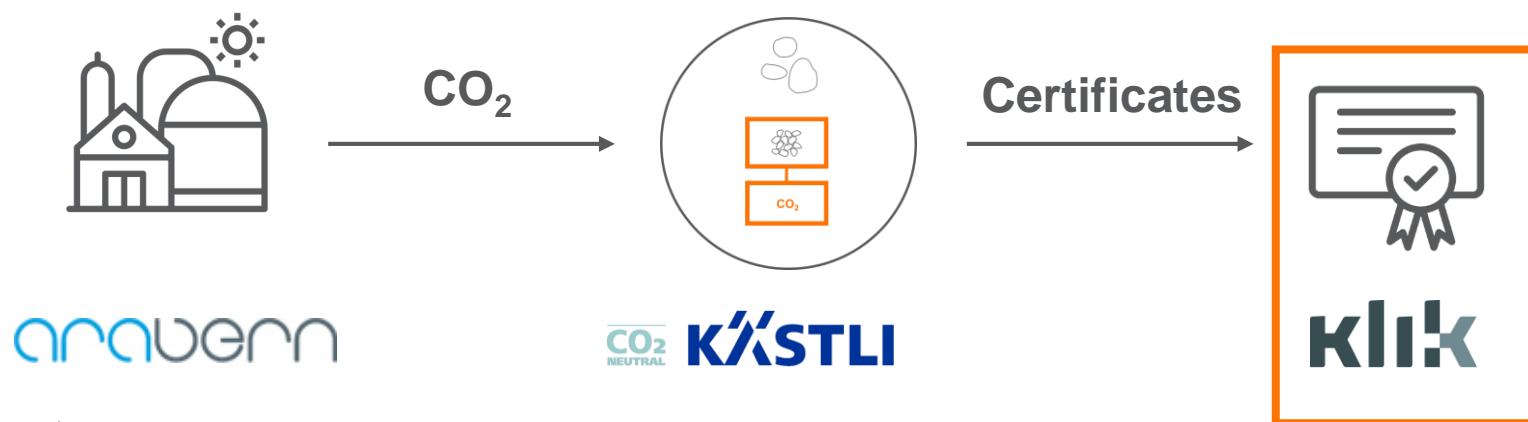
Fresh properties of concrete

Frischbetoneigenschaften					
Betonherstellung	19.11.2019	10:00 Uhr	Wassergehalt	8.9 Masse-%	SIA 262/1 Anhang H
Prüfung durch	Betonwerk		Probenmasse		(Einwaage)
Ort	Betonwerk		w _{tot}	211 kg/m³	(Gesamtwasser)
Temperatur	Beton: 14 °C	Luft: 6 °C	w	191 kg/m³	(w _g berücksichtigt)
Konsistenz			w _u /z	0.67	
Verdichtungsmass		SN EN 12350-4	w / z	0.60	
Ausbreitmass	48 cm	SN EN 12350-5	w _u /z _{eq}		
Setzmass		SN EN 12350-2	w / z _{eq}		
Luftporengehalt	1.2 Vol.-%	SN EN 12350-7 (Kap. 5)			
Rohdichte	2357 kg/m³	SN EN 12350-6			

Spreading properties, entrained air, density remained within norm

PROJECT OUTLINE

RECARB



CO₂ infrastructure:

- CO₂ liquefaction installed (until 5.2021)
- CO₂ transport organized (until 5.2021)

Engineering, construction and testing of pilot

- Pilot plant installed (until 8.2020)
- Pilot plant tested in operation at the Kästli concrete plant

Material handling and material tests

- Material will be filled into conventional silos
- Kästli will mix concrete with their large scale concrete mixer
- Fresh properties of concrete as well as properties of hardened concrete will be analyzed

CO₂ accounting program

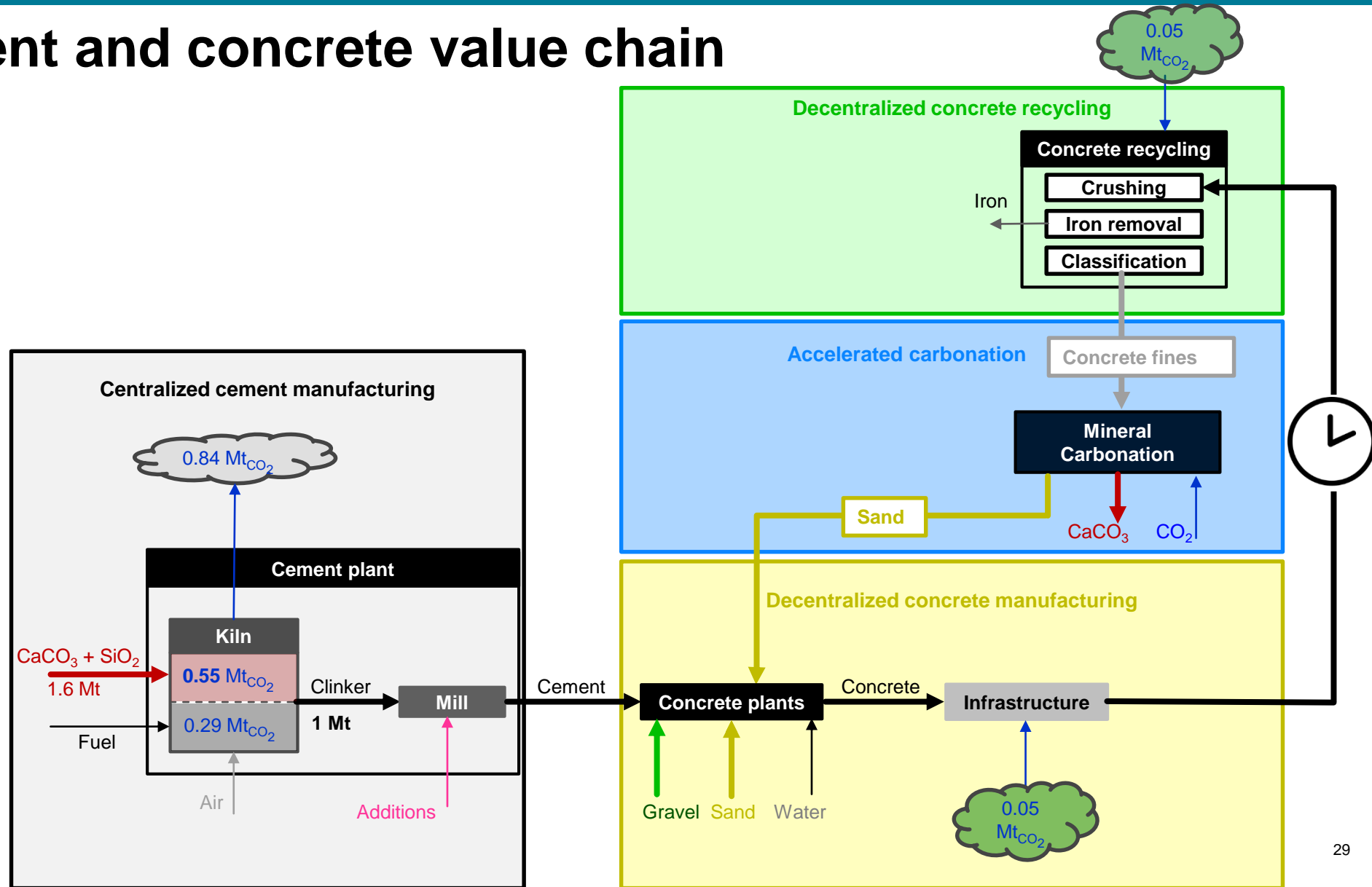
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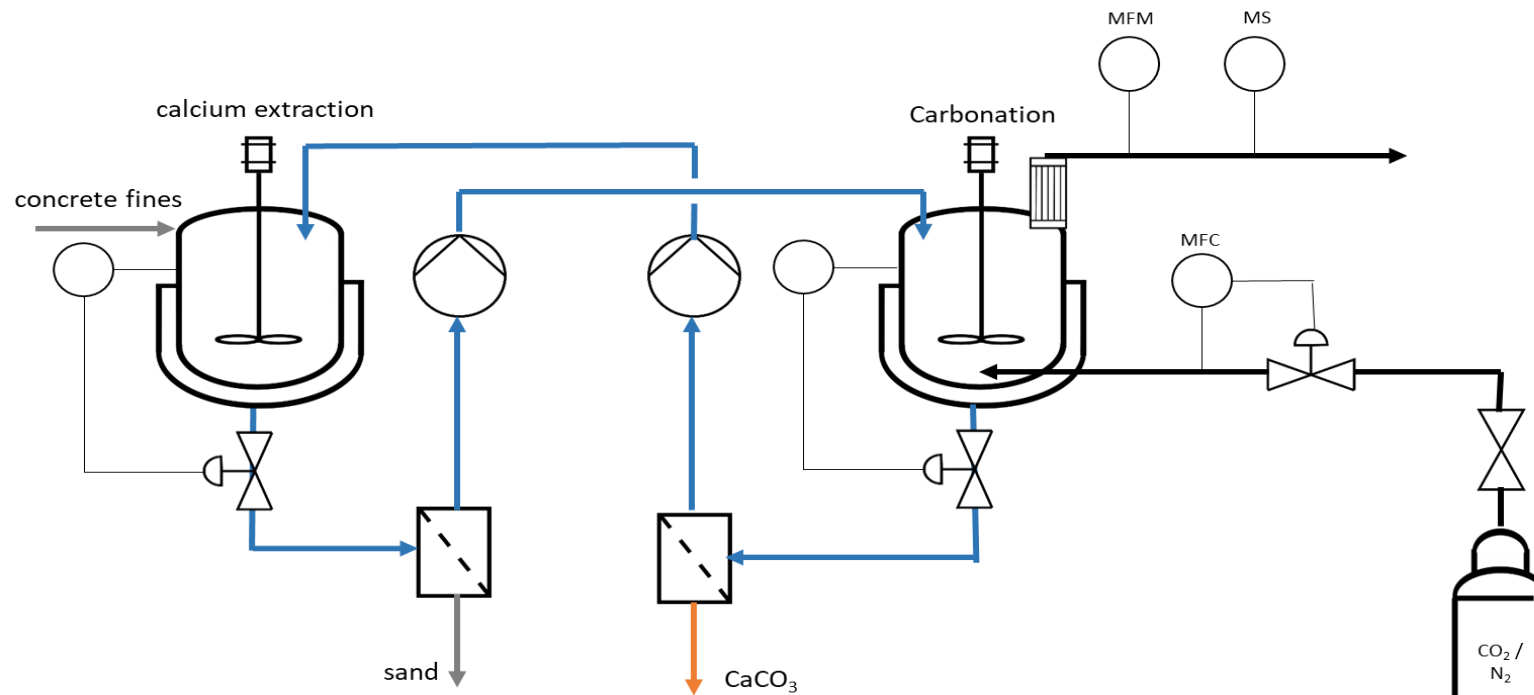
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Cement and concrete value chain

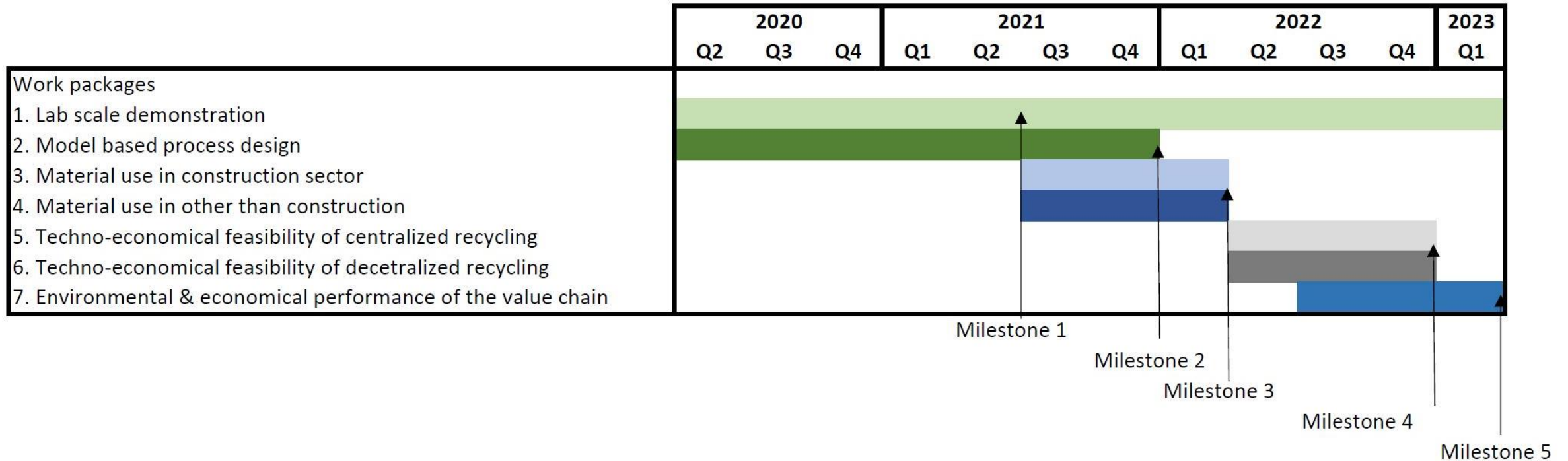


The technology

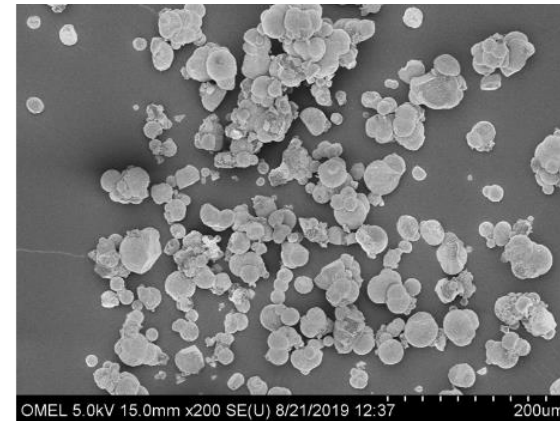
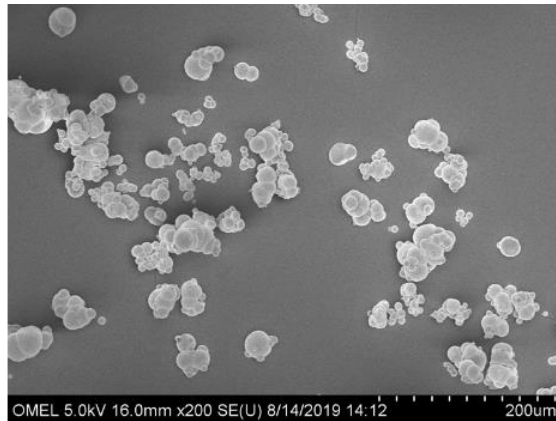
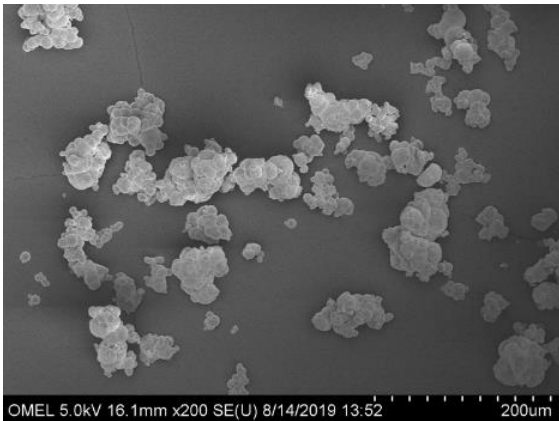
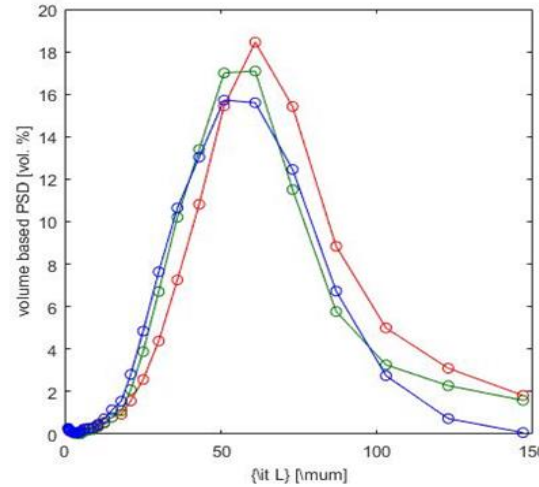
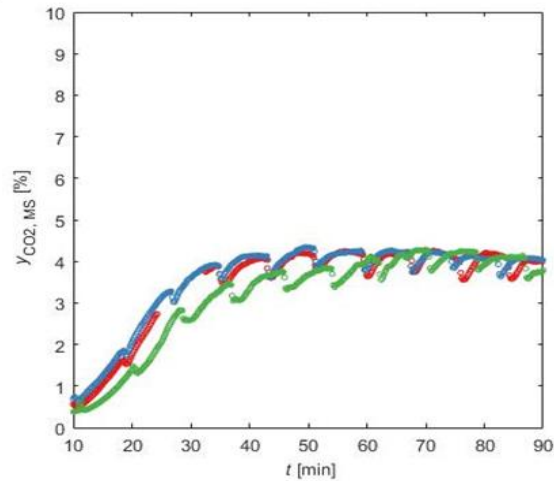
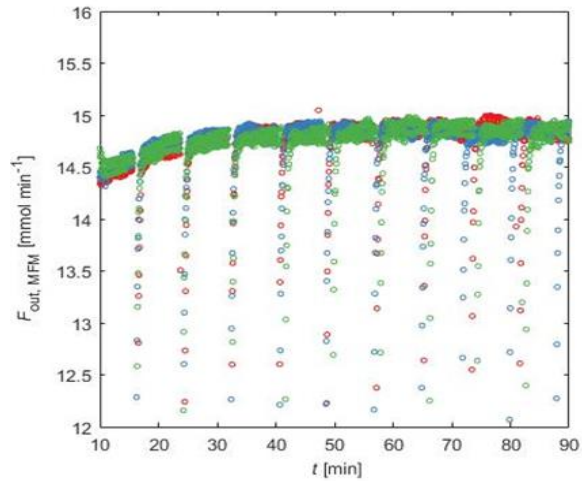


1. Concrete fines are suspended in an aqueous solution – the calcium of the cement phases is selectively leached.
2. The particles of the suspension are removed by filtration. These particles can be reused as sand.
3. The calcium rich solution is pumped to a carbonation reactor. Pure or flue gas CO₂ is bubbled through the aqueous solution, CaCO₃ precipitates.
4. The CaCO₃ is removed by filtration and the aqueous solution can be recycled

Project outline



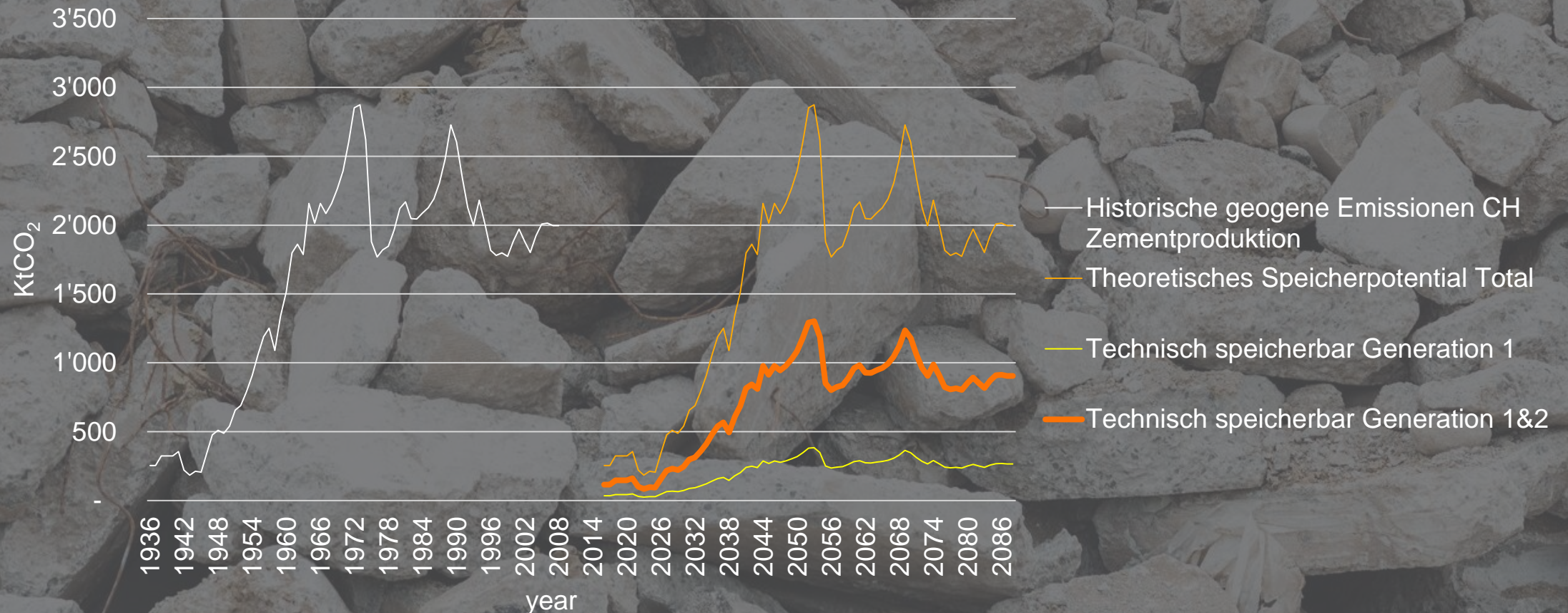
Preliminary experimental results



1. We could operate the system in a continuous, reproducible manner – the flue gas outlet composition, flow rate, particle size distribution, CaCO_3 yield and particle morphology.

Estimation of CO₂ uptake potential

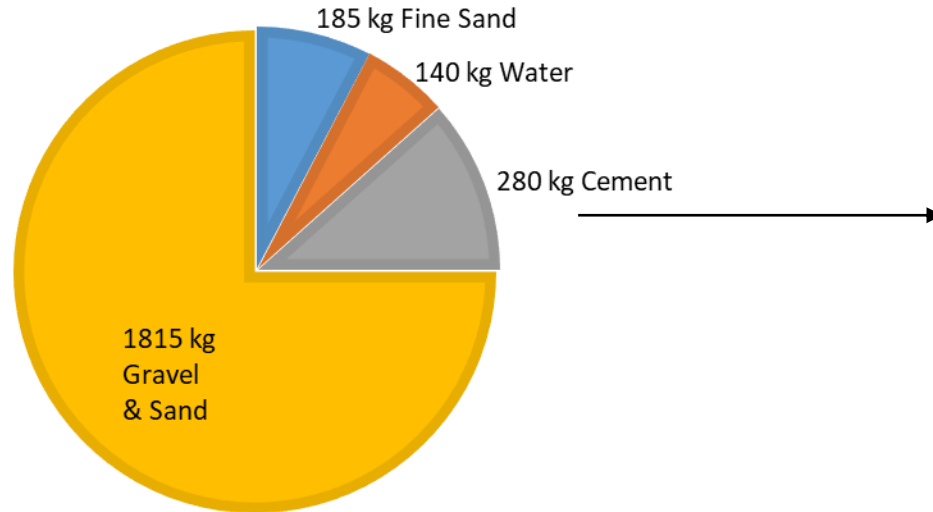
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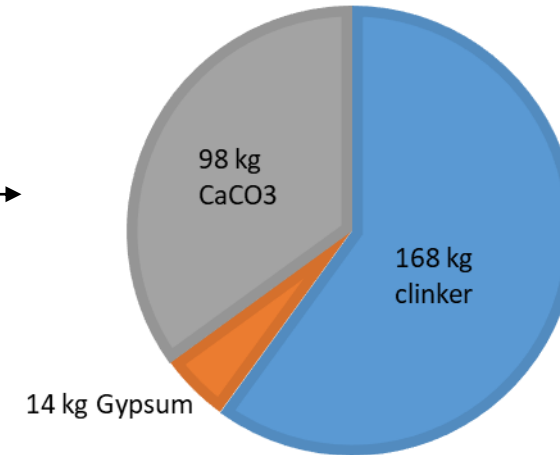
Data Source: Carbon Dioxide Information Analysis Centre, Oak Ridge National Laboratory

Vision of a net-zero emission concrete

COMPOSITION OF 1M3 CONCRETE



COMPOSITION OF CEMENT



Emissions for 1 m³ concrete

Clinker	143 kg CO ₂
Carbonated concrete aggregate	-18 kg CO ₂
CaCO ₃ in cement	-43 kg CO ₂
CaCO ₃ as fine sand	-82 kg CO ₂
Balance	0 kg CO₂

Summary & conclusion

- The cement manufacturing process accounts for 2.25 Gt CO₂/y. CCS is the only option to cut emissions drastically, since processes are highly efficient.
- However, CCS still has to turn into a business case and required CO₂ transport infrastructure needs to be developed.
- Early on, by mineralizing CO₂ in demolition concrete 1) CO₂ can be stored, 2) the material can be upcycled – yielding a business case.
- Within RECARB, Neustark's technology generation 1 will be scaled to pre-commercial level until 2021
- Within an Innosuisse project, technology generation 2 will be developed.
- Swiss Concrete can offer a CO₂ storage capacity of 1 Mt CO₂/y in 2050
- In principle, both technologies should allow to manufacture net-zero concrete in the future