Betonhuis

CO_2-reduction – options for cement

EUPAVE webinar 23 June 2021

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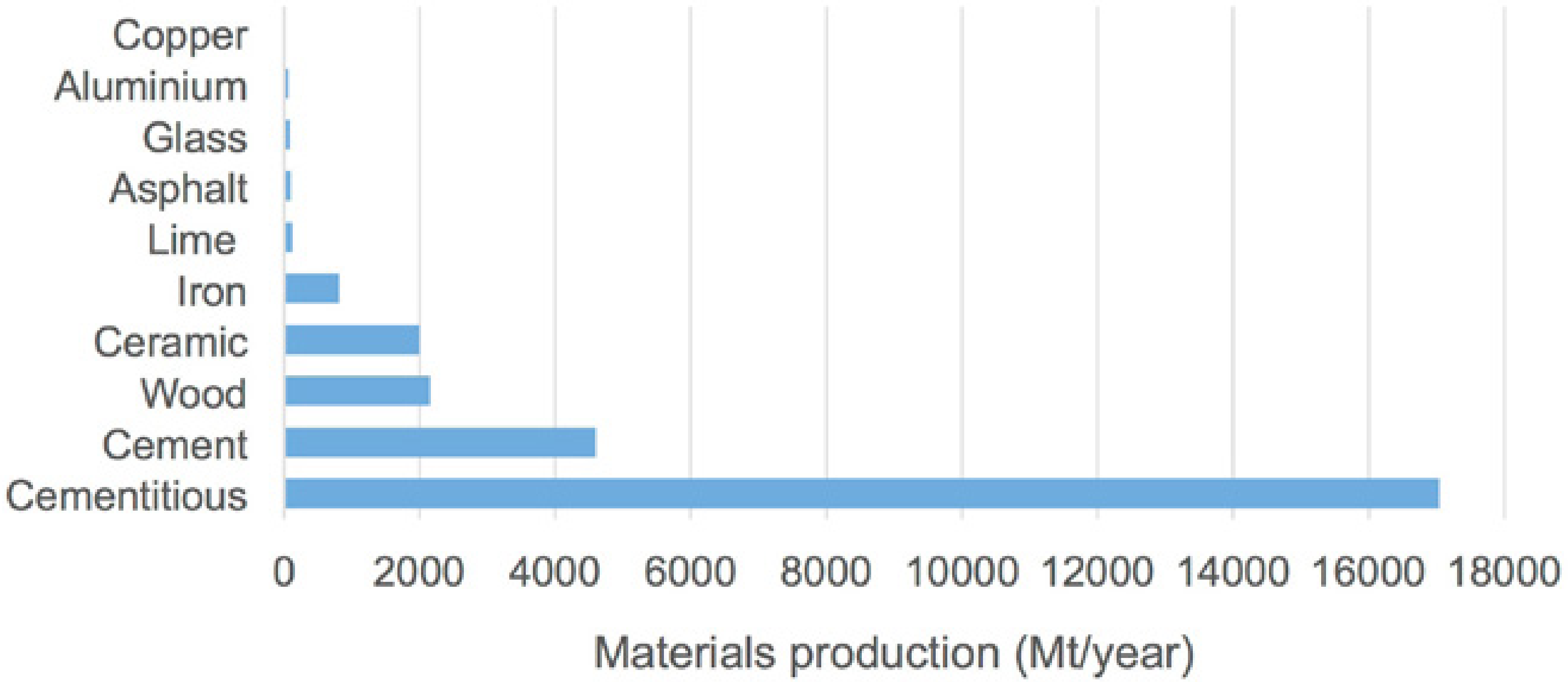
Topics presentation

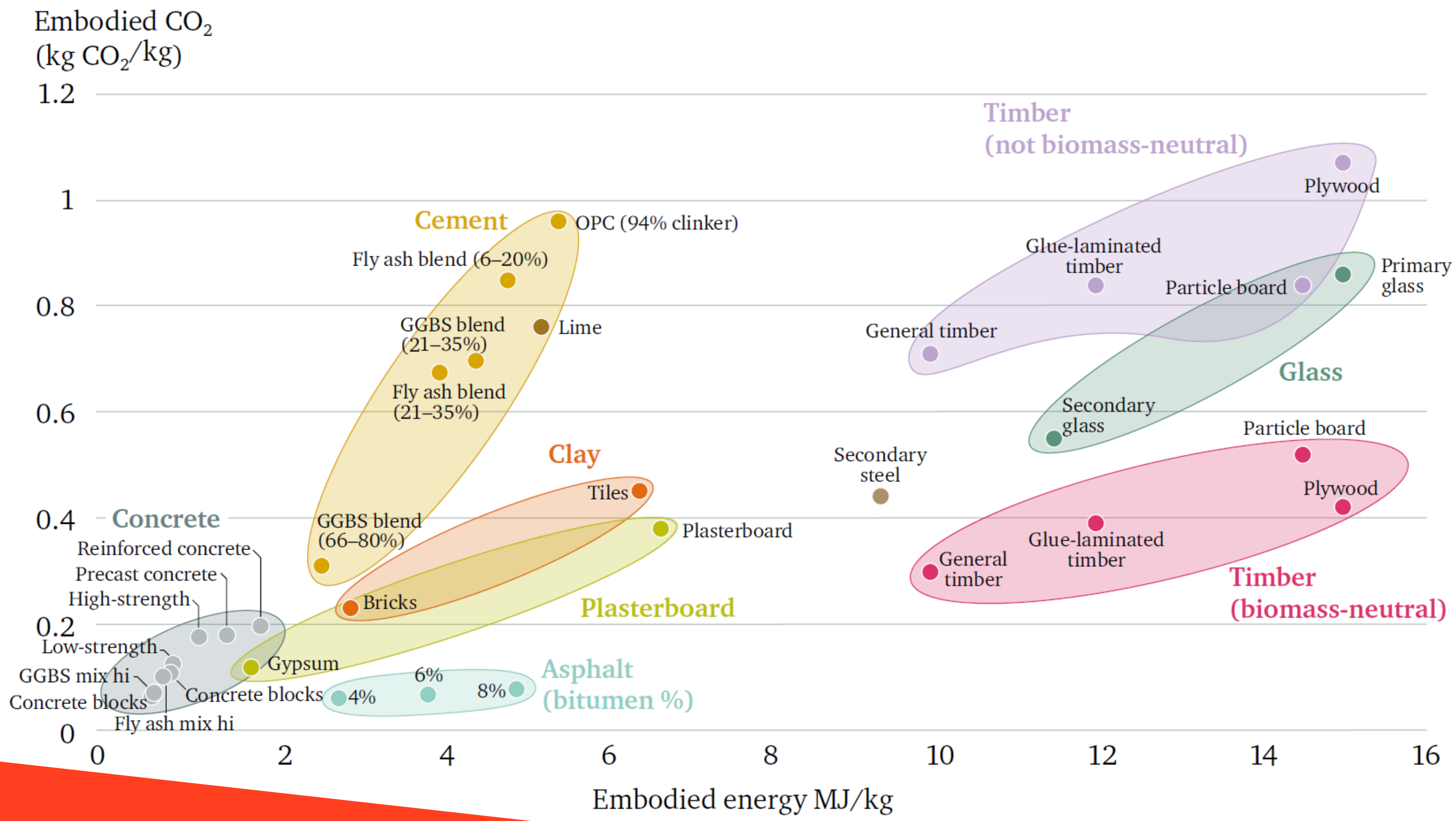
- Raw materials
- History
- Reducing content Portland cement clinker in cement
- Alternative binders
- Carbon capture
- ‘Quick wins’

World production materials



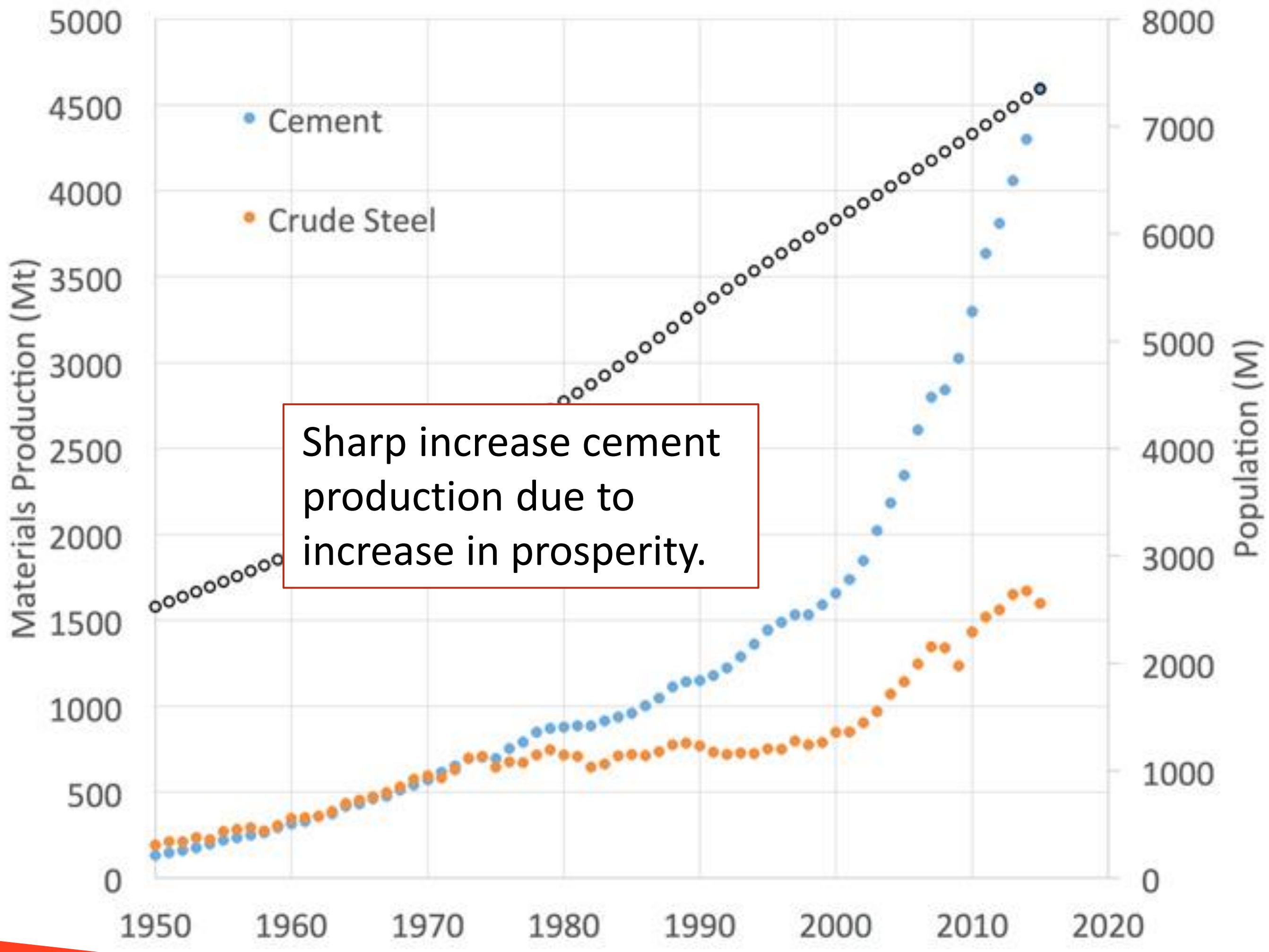
Source: Eco-efficient cements: Potential, economically viable solutions for a low-CO2, cement- based materials industry, Karen L. Scrivener, Vanderley M. John, Ellis M. Gartner, 2016

Embodied emissions UK



Source: Chatham House Report, Johanna Lehne and Felix Preston, Making Concrete Change - Innovation in Low-carbon Cement and Concrete, juni 2018

World production cement



Sharp increase cement production due to increase in prosperity.

Source: Eco-efficient cements: Potential, economically viable solutions for a low-CO2, cement- based materials industry, Karen L. Scrivener, Vanderley M. John, Ellis M. Gartner, 2016

Limestone

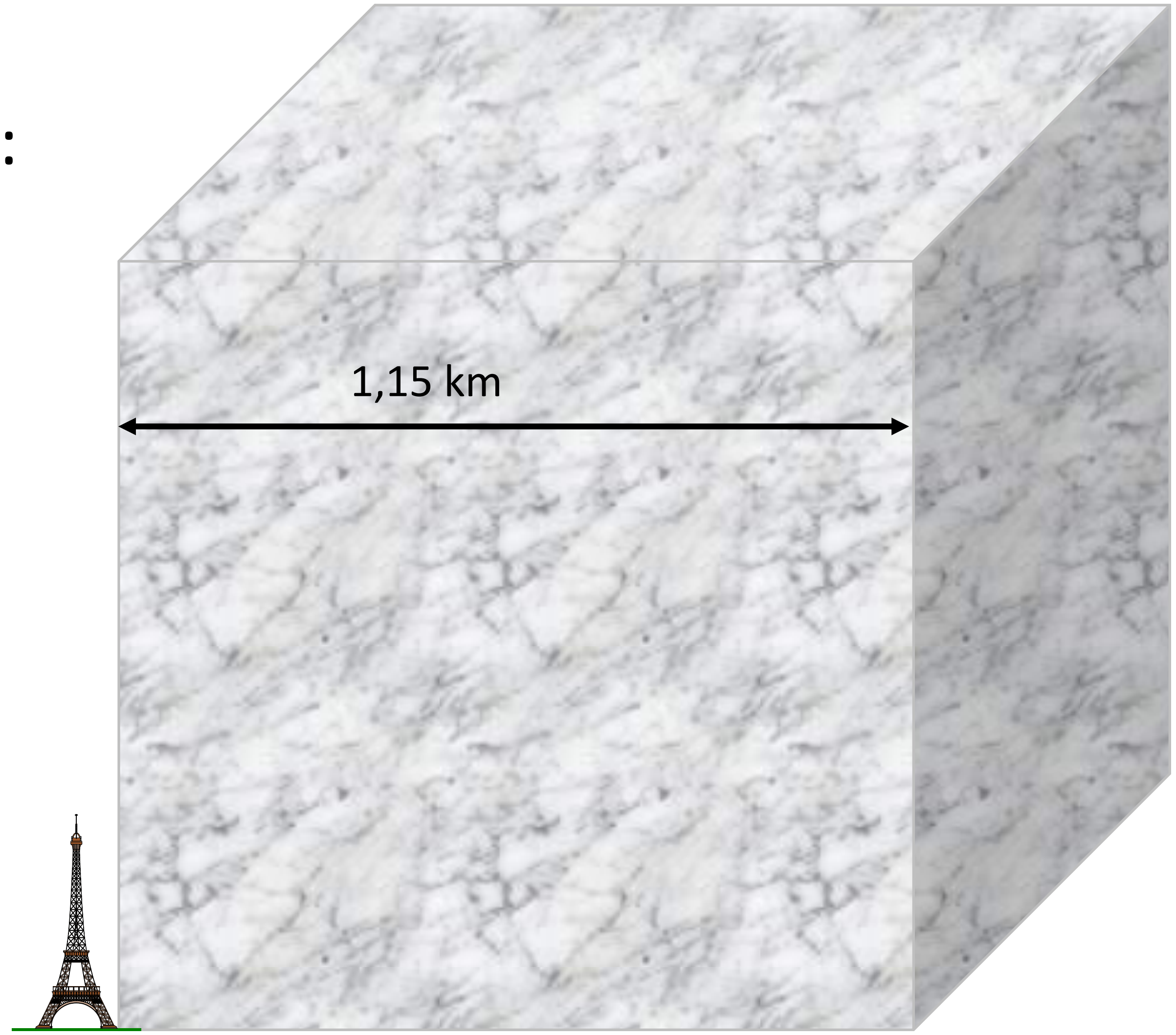
World cement production 2015:

~ 4,6 billion ton cement =

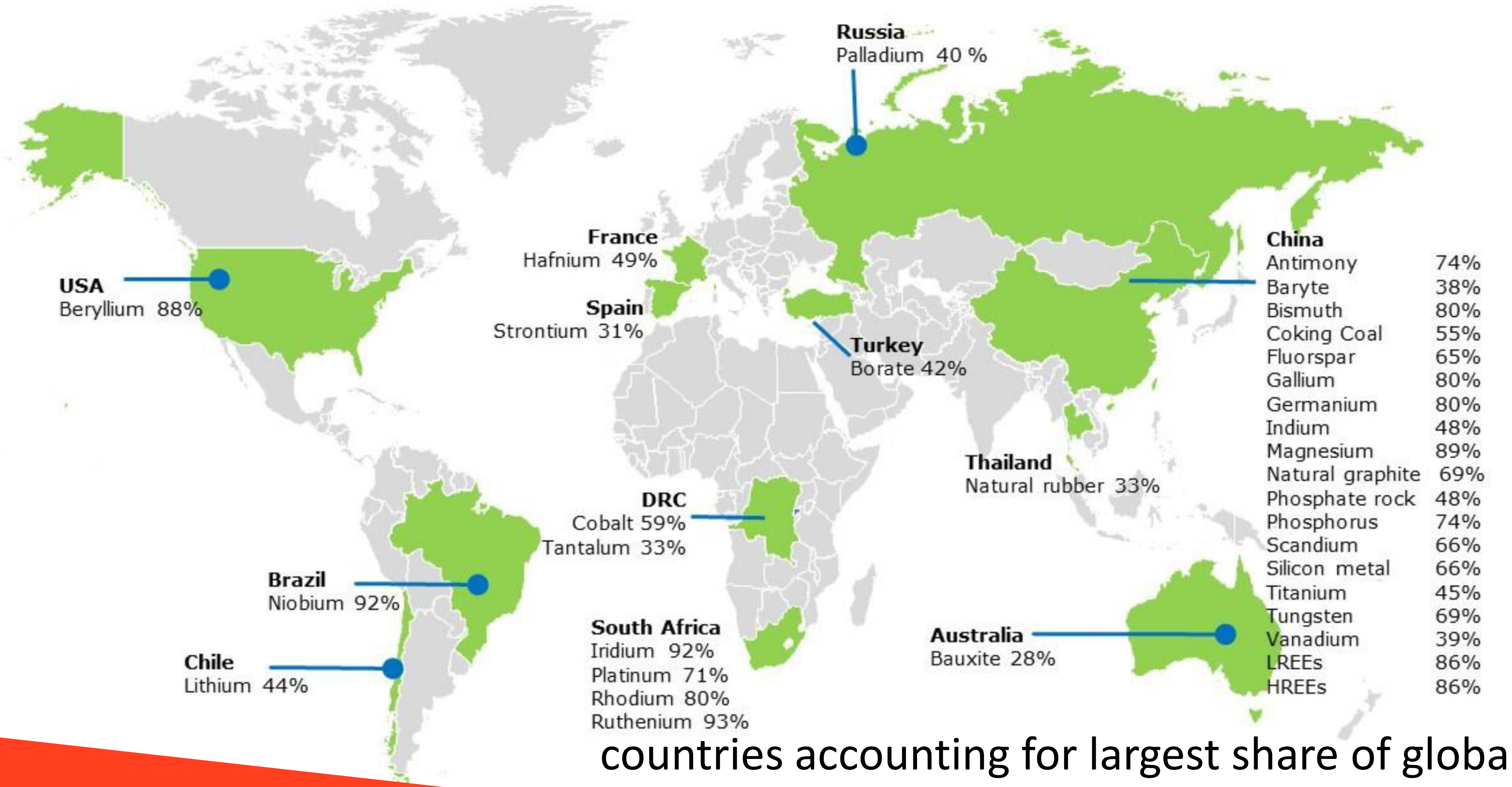
~ 4,3 billion ton limestone =

~ 1,6 billion m^3 limestone

Alternatives have to be abundantly available!



Critical raw materials



Of the critical materials for Europe, 90% have to be imported, mainly from China.

countries accounting for largest share of global supply

Source: European Commission, Study on the EU's list of Critical Raw Materials (2020)

Scarce materials

(3 % growth until 2050, then flat)

Moderately scarce (EGR exhaustion time between 100 and 1000 years after 2050)		Not scarce (EGR exhaustion time > 1000 years after 2050)	
Arsenic	400	Aluminum	20,000
Bismuth	200	Barium	1000
Boron	200	Beryllium	200,000
Cadmium	500	Cobalt	2000
Chromium	200	Gallium	1,000,000
Copper	100	Germanium	200,000
Iron	300	Indium	10,000
Lead	300	Lithium	9000
Nickel	300	Magnesium	30,000
Silver	200	Manganese	2000
Tin	200	Mercury	400,000
Tungsten	300	Niobium	2000
		Platinum Group Metals	1000
		Rare Earth Metals	20,000
		Selenium	300,000
		Strontium	10,000
		Tantalum	20,000
		Thallium	1,000,000
		Titanium	10,000
		Uranium	2000
		Vanadium	20,000
		Zirconium	2000

Source: Mineral resources: Geological scarcity, market price trends, and future generations, Elsevier 2016

Calcium ∞
Silicium ∞

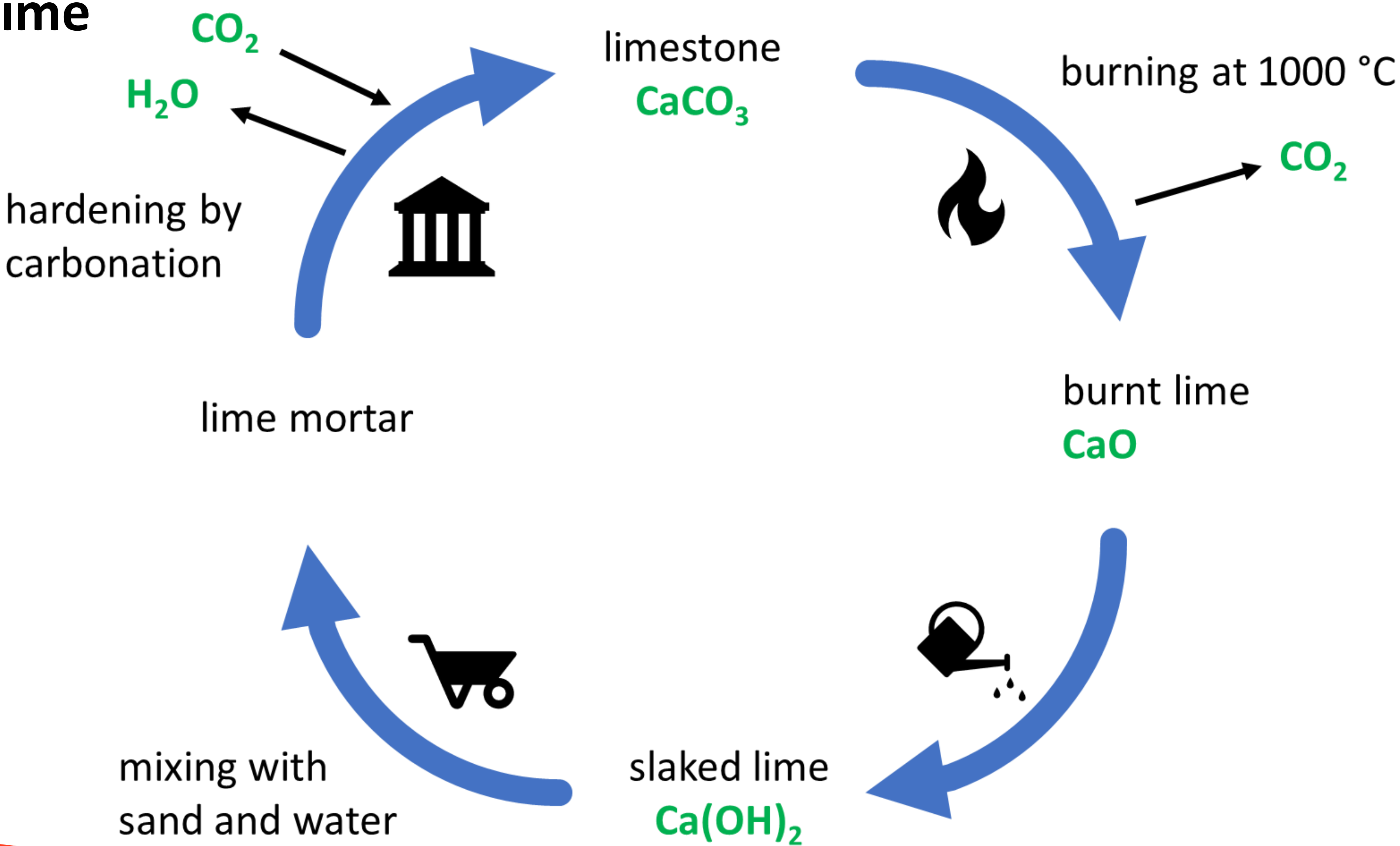
Raw materials for cement are unlimited and regional available

Limestone: skeletons of plankton and others
(~ 5 billion tons/year)

Refuse is (not) an option

Adobe
(since ~ 8000 BC)

Lime



since ~ 4000 BC

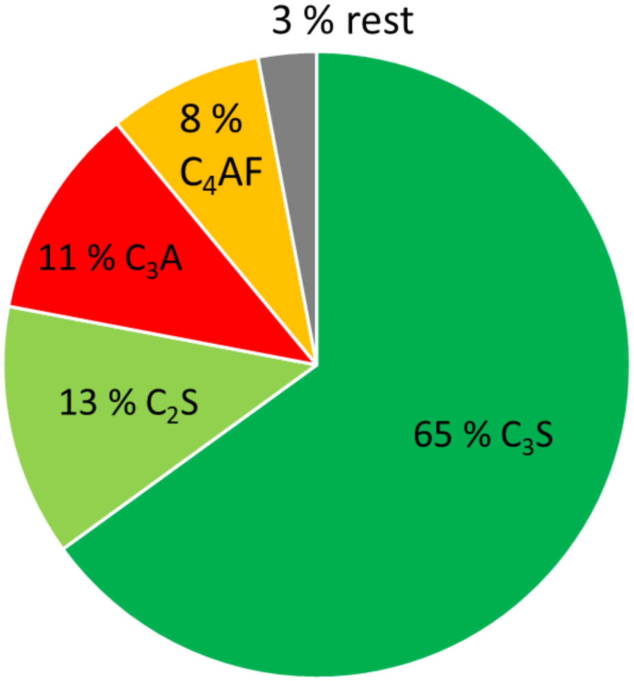
Roman concrete

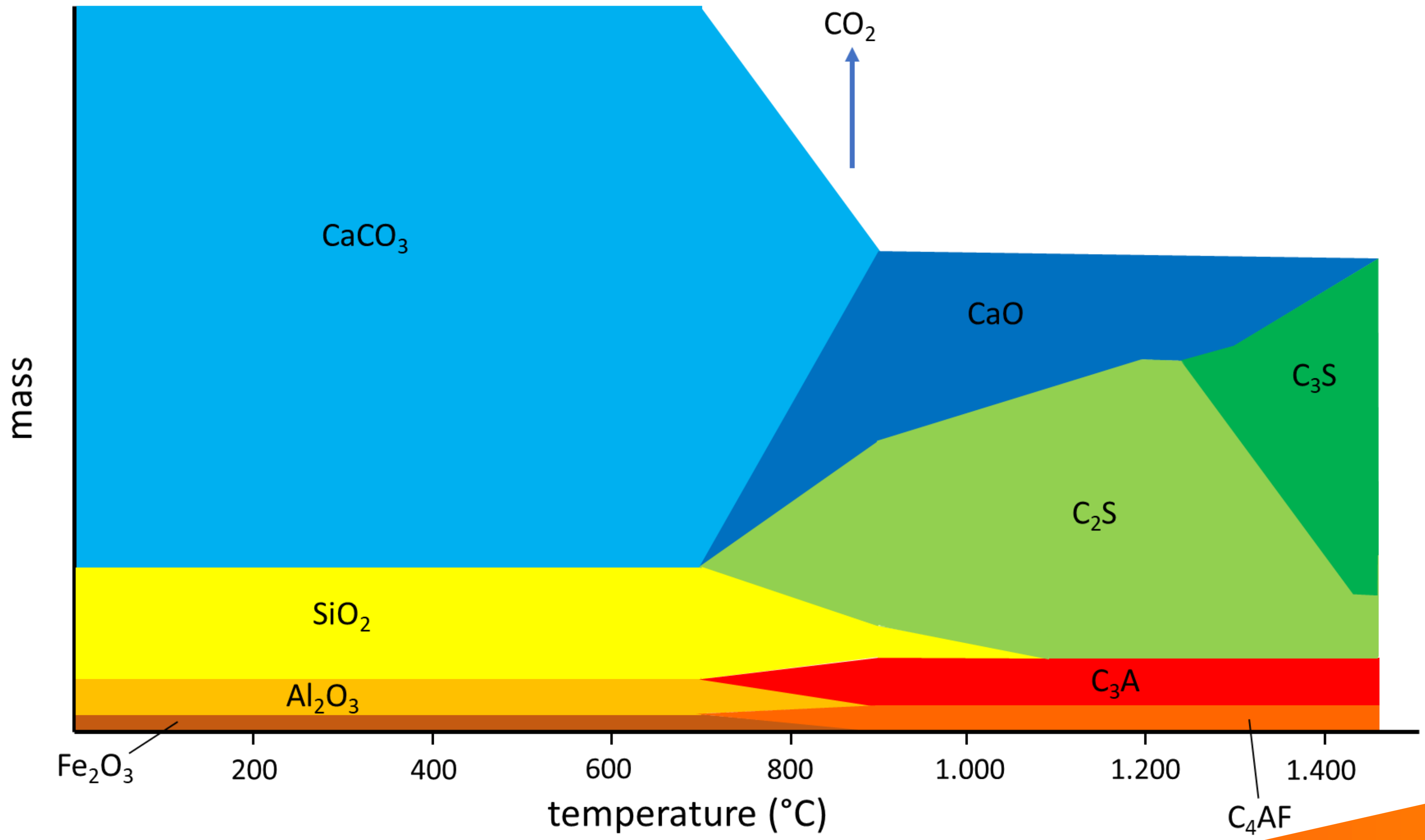
Slaked lime + pozzolan

Hydraulic lime

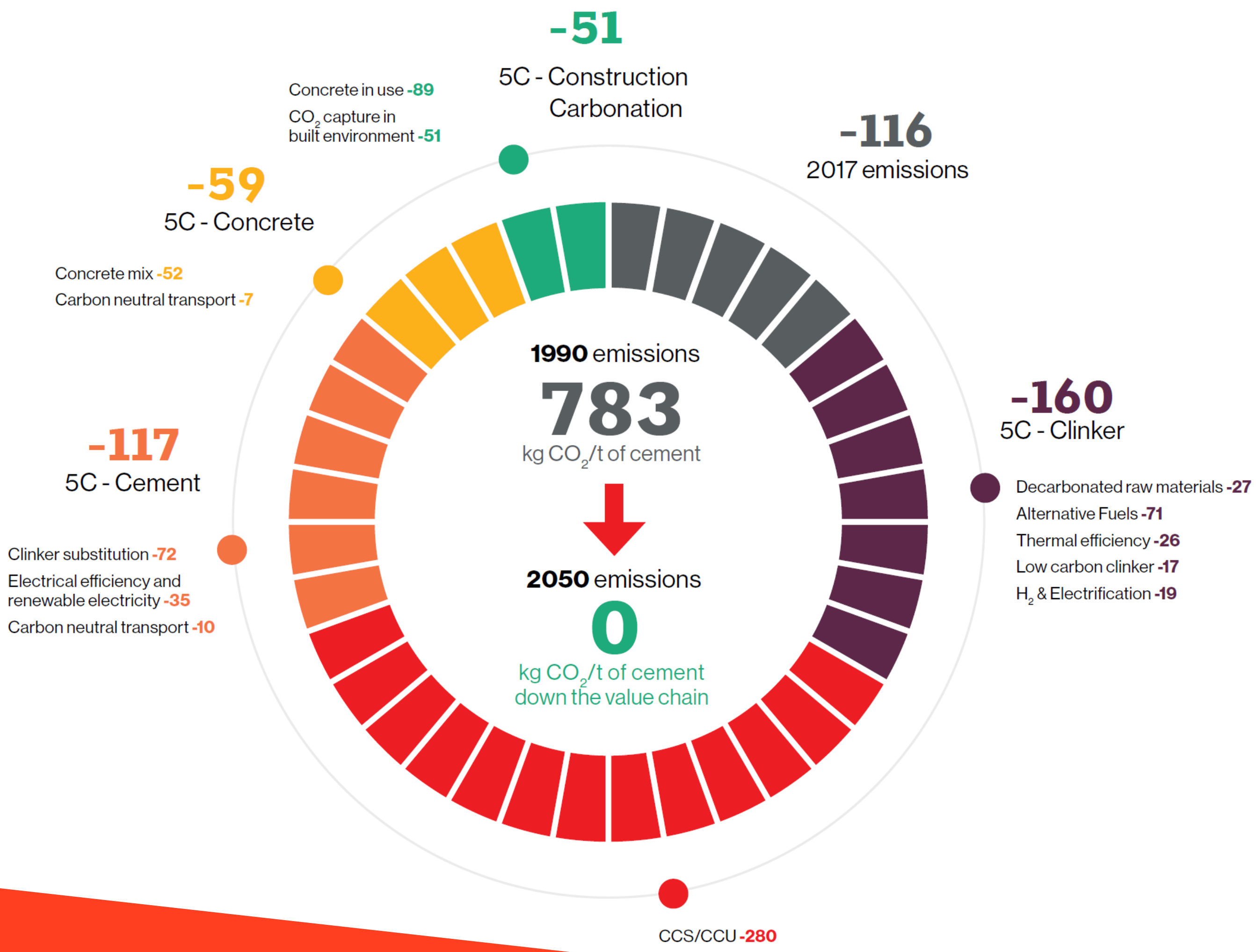
Next to $CaCO_3$
also CSH-gel

Clinker minerals



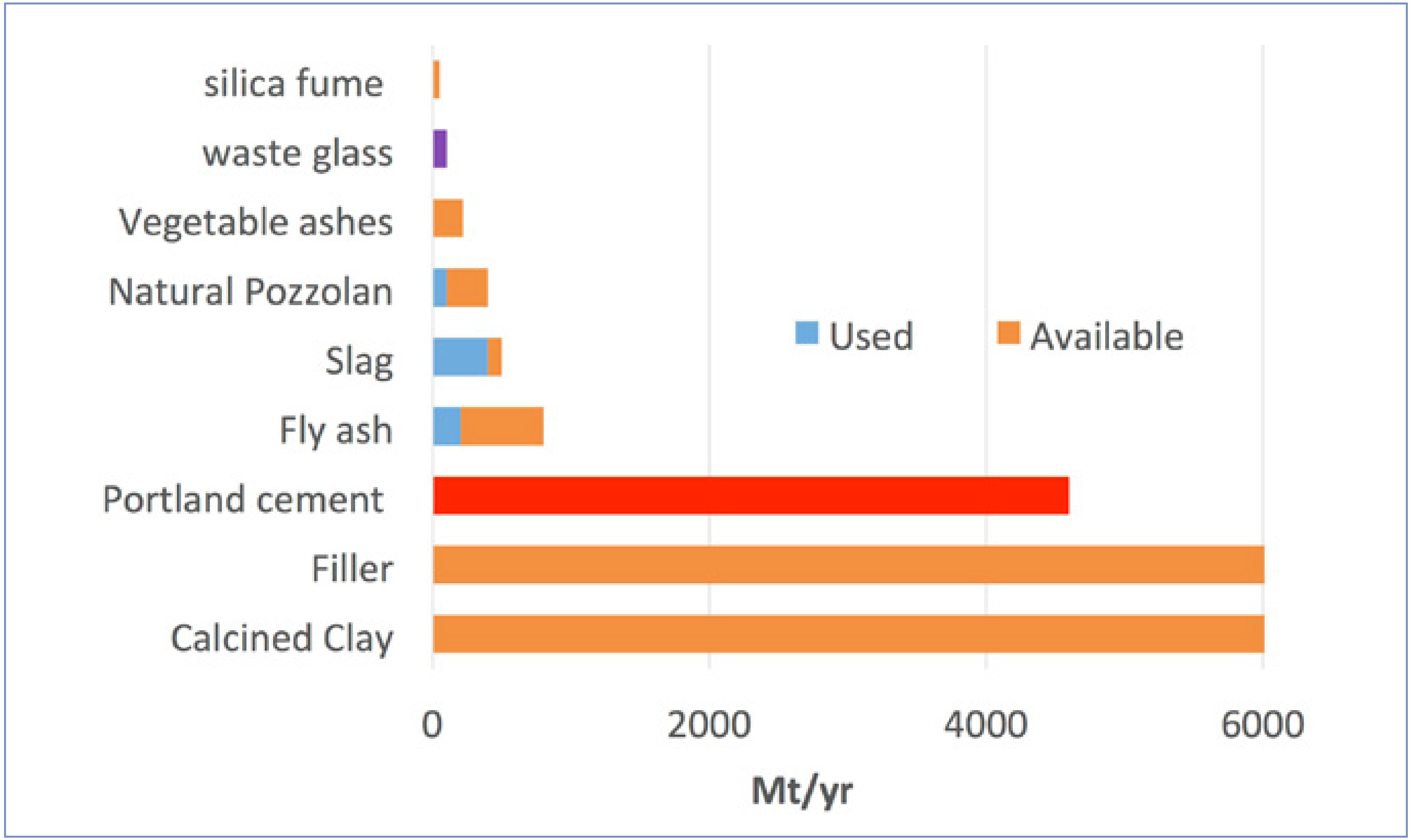


Roadmap CO2-reduction



Source: Cementing the European Green Deal, CEMBUREAU, 2020

Clinker substitution



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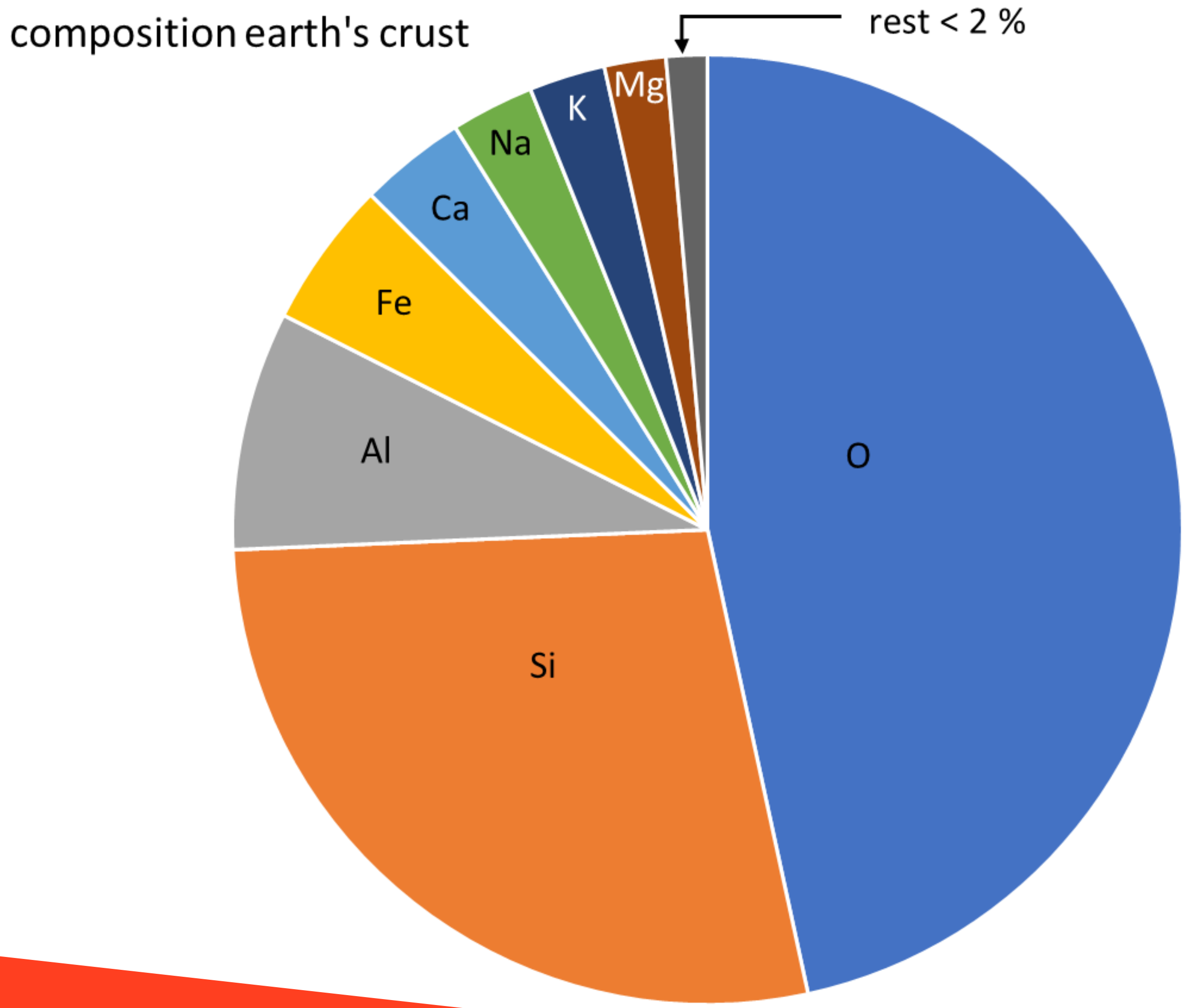
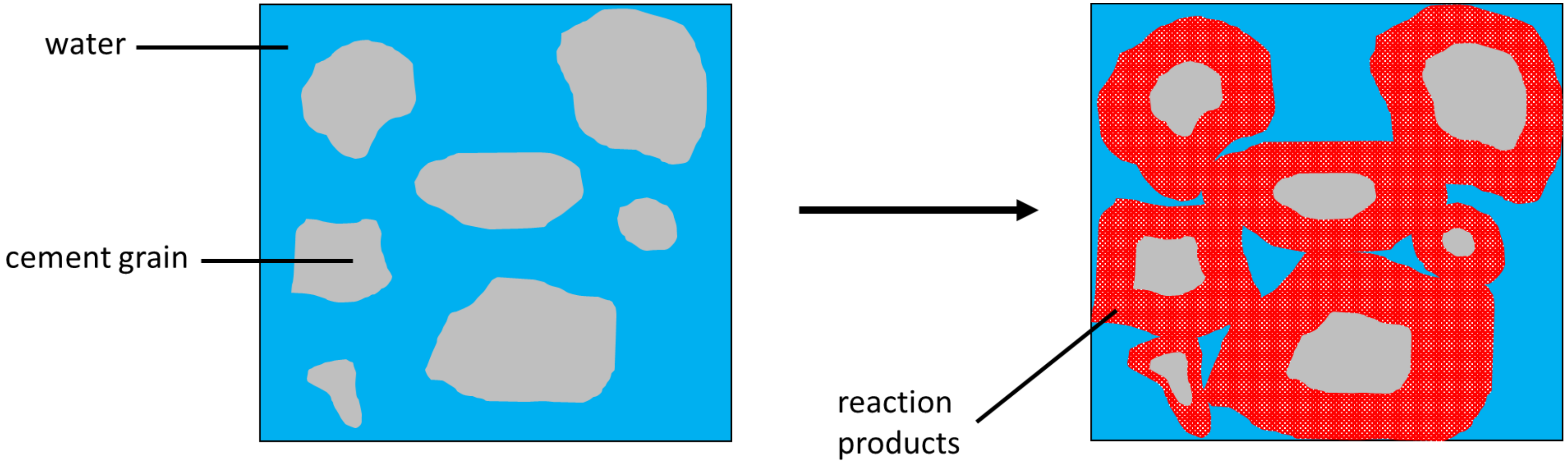
Availability raw materials



Requirements hydraulic cement

- Cement particles must be able to dissolve in water
- Hydrates must have a larger volume than dissolving cement
- Hydrates must be poorly water soluble



Calcium silicates
Calcium aluminates
Calcium sulfo-aluminates

Belite-rich Portland cement (HBC)

	C_3S	C_2S
HBC	24.7 %	53.0 %
PC	52.4 %	24.5 %

Three Gorges Dam
(1994-2006)
2.7 million m^3 concrete

- About 10 % lower CO_2 emissions. Very slow strength development. Used mainly in China in specific applications.

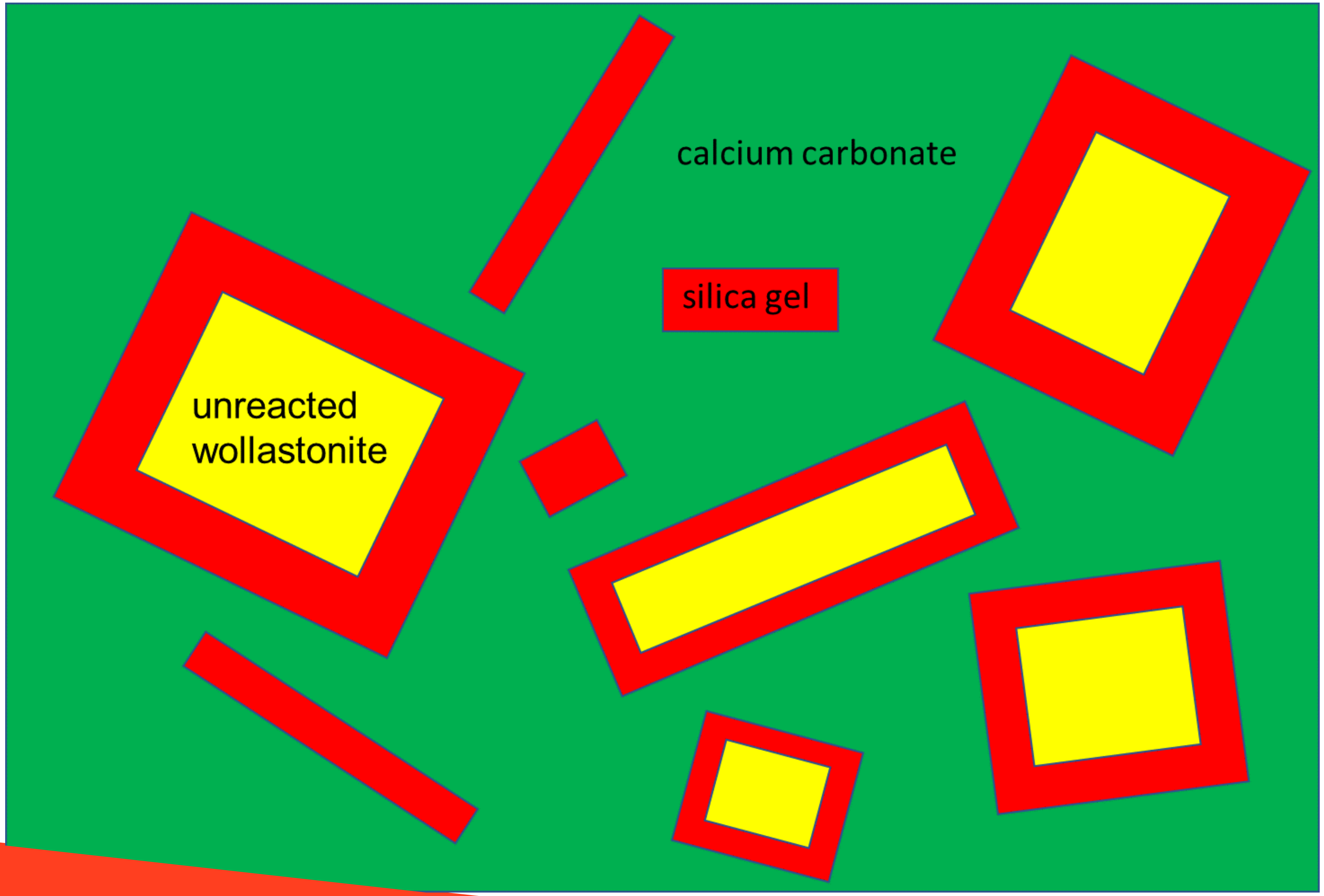
Belite calcium sulfo-aluminate cement

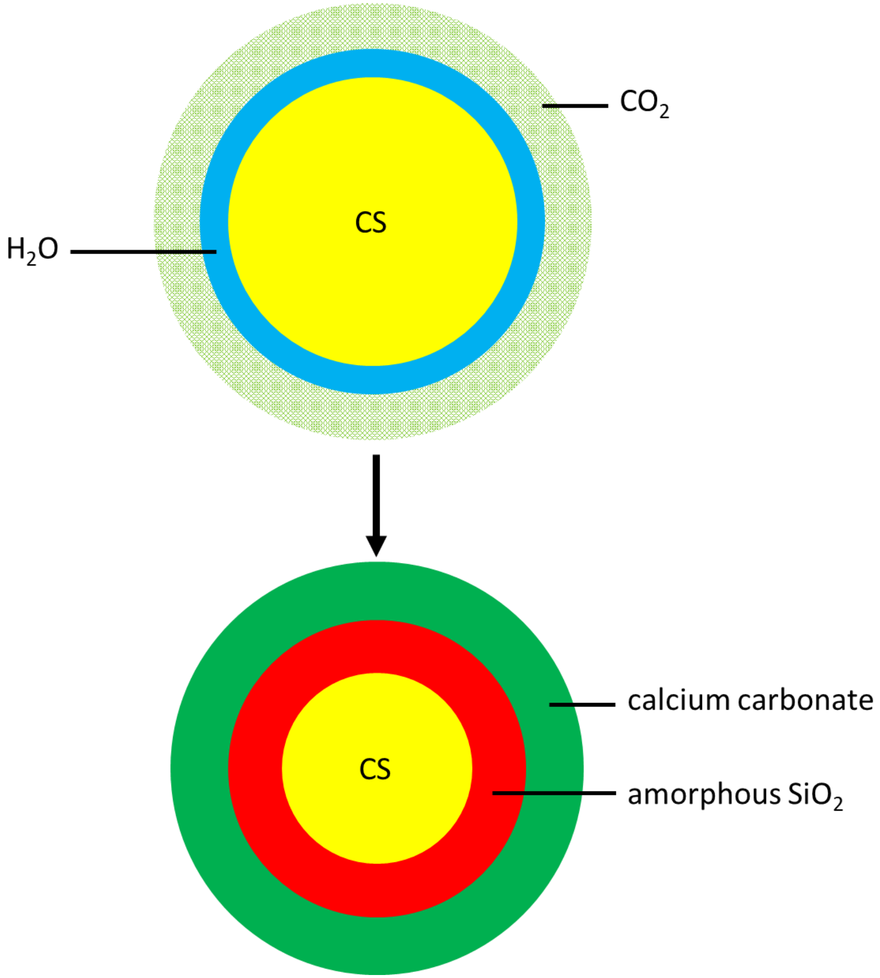
- Approximately 25 % lower CO_2 emissions (compared to CEM I).
- Contains, in addition to belite (C_2S), approx. 35 % ye'elimite ($C_4A_3\$$).
- Rapid strength development through hydration of ye'elimite (ettringite formation).
- Expensive aluminium-rich raw materials required.
- Can, in principle, replace Portland cement clinker (pH ~ 10.5 is on the low side).
- Production process comparable to Portland cement. Raw materials: limestone, bauxite (or secondary aluminium source such as fly ash) and (large amounts of) $CaSO_4$.

Solidia cement (Wollastonite)

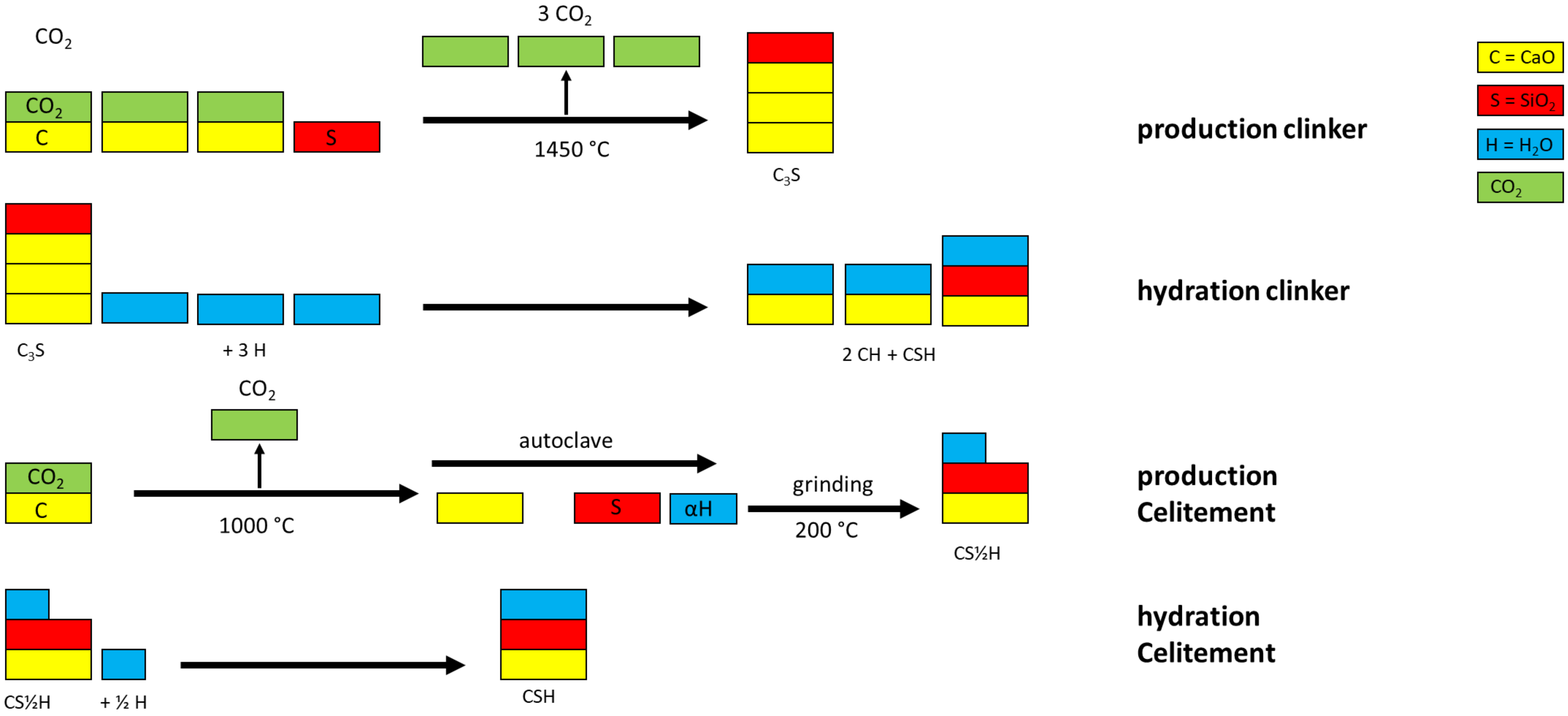
- Mainly CS (wollastonite) instead of C_3S.
- Lower reaction temp. (1250 - 1350 °C instead of 1450 °C).
- Same raw materials and furnace.
- Reaction with CO_2 instead of water (water as medium).
- Fast strength development but curing in CO_2 chamber.
- Limited thicknesses (for CO_2 penetration).
- No high pH pore solution -> not suitable for reinforced concrete.
- CO_2-saving during production (~30 % compared to CEM I) and CO_2-absorption during curing (~30 % compared to CEM I).

Solidia cement





Celitement (calcium hydrosilicate cement)



Celitement

- Predominantly $CS \cdot ½H_2O$ instead of C_3S
- Lower reaction temperature (1000 °C instead of 1450 °C)
- Same raw materials
- Production in a (limestone) oven, autoclave with steam (CSH) and then 'activation' grinding (- 0.5 H_2O).
- Reaction with water. Can be processed as Portland cement.
- No high pH pore water -> not yet suitable for reinforced concrete.
- CO_2-saving during production (~ 50 % compared to CEM I).

Geopolymers

A 24-storey building built with alkali-activated slag cement concrete on Berezinsa street 2, city of Lipetsk, Russia, 1994.

Geopolymers

2015

Geopolymers

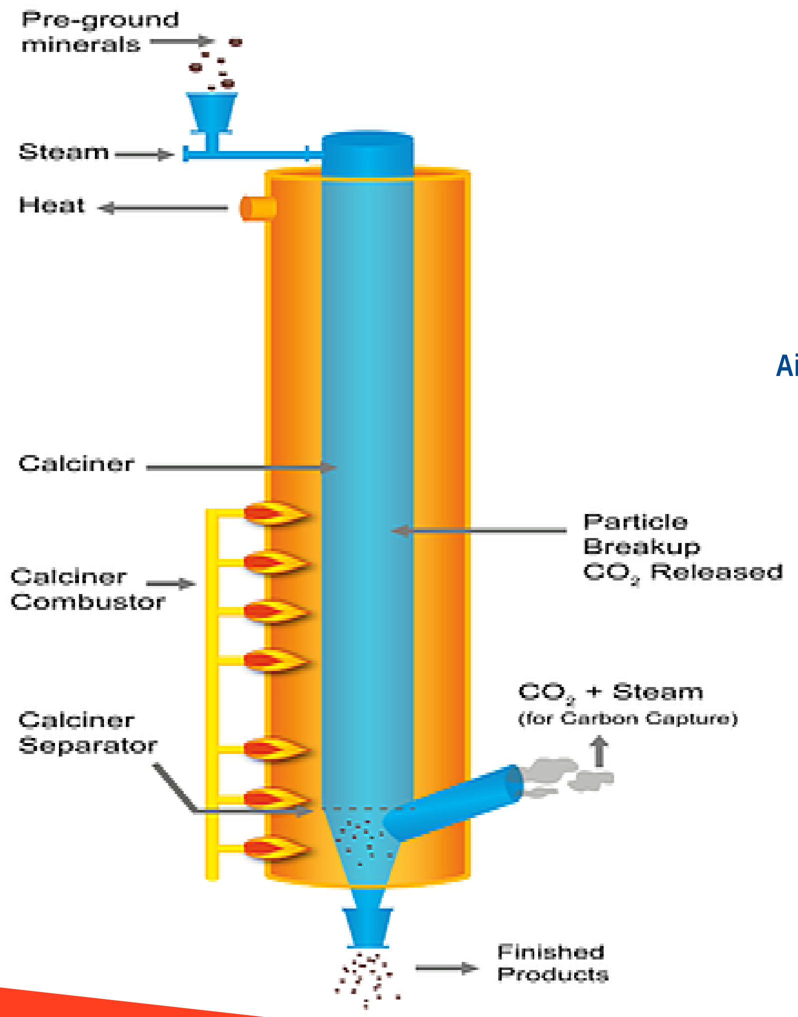
Cycle path (Croeselaan, Utrecht)
Construction: spring 2018
Picture: February 2021

Cycle path (Aadorpweg, Almelo)
Construction: autumn 2019
Picture: February 2021

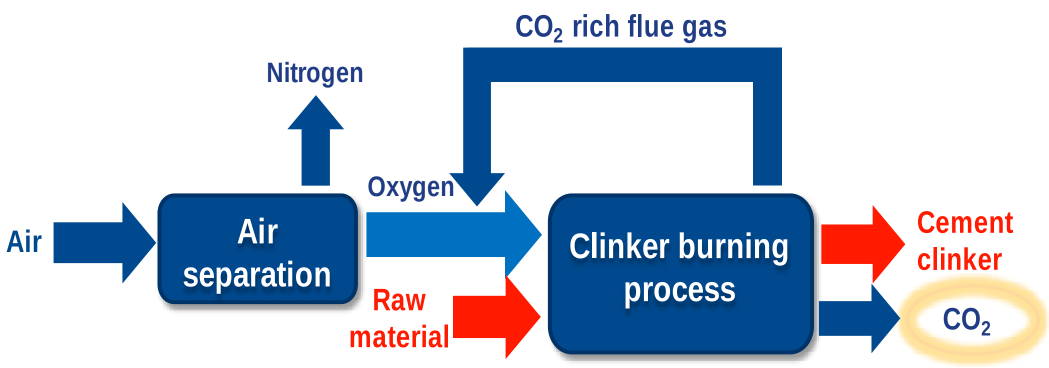
Geopolymers

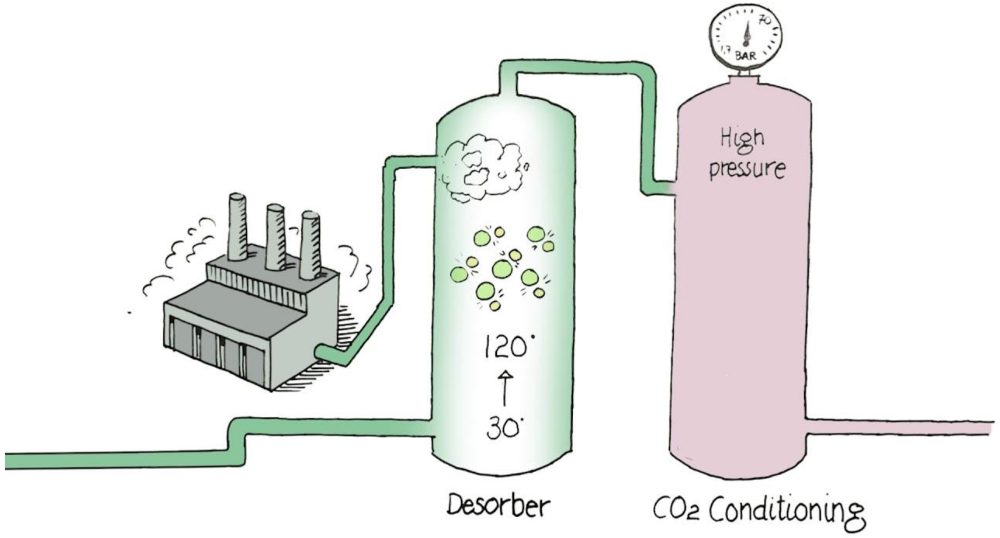
- Large-scale applications already in the 1950s in Belgium and in the 1960s in the Soviet Union. Research since 1930.
- No environmental benefit from the use of slag and fly ash (already used in cement and concrete), but environmental loss due to additional activators.
- Environmental benefit possible when using other materials like calcined clay.

Carbon capture

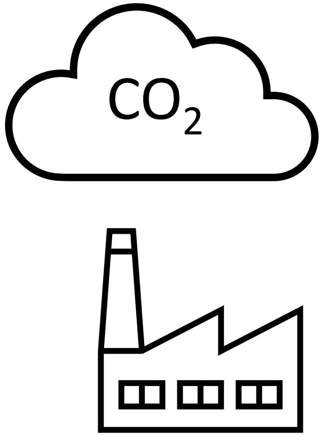


Oxyfuel





CO_2-capture and storage/use



Oxyfuel
Amines
CLEANKER
Leilac

CO_2-capture

use

Ethanol
Polymers
Algae
Recycled hardened cement
…..

storage

Conclusions

- Earth's crust composition and chemistry 'inevitably' lead to Portland cement clinker.
- There is no single alternative that can replace Portland cement clinker in terms of availability and quality.
- A combination of measures is needed to achieve significant CO_2 reduction.
- CSA-belite cement, Solidia cement and especially carbon capture are promising but still require research and time.

Quick wins

- Use low-clinker cements (but not too low because of frost resistance)
- Optimize grain packing.
- Use alternatives such as Carbstone (volumes are limited).
- Use coarser gravel

Questions?