Designing the precursors for a new slag-based cement, the ELCE.

Yiannis Pontikes
27 June 2019

SREMat

Sustainable Resources for Engineered Materials

1 Prof, 3 post-doc, 12+8 PhDs, 3 MSc

Own facilities, approx. 1Meuro invested

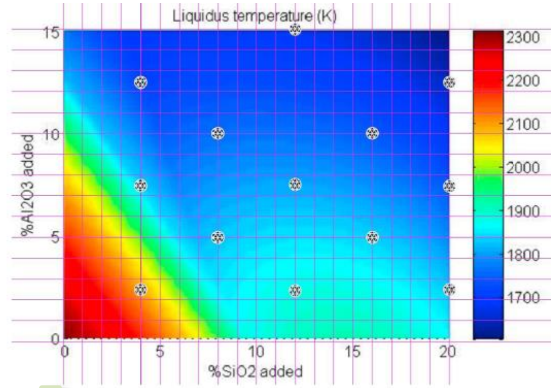
Collaborations with >100 universities, industries and research centers

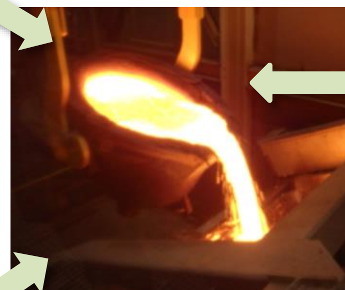
>10 national and international projects running

>10 journal papers a year, >100 in total

In SIM2 and CR3, active in SVS and BR conferences, co-founders of JSM

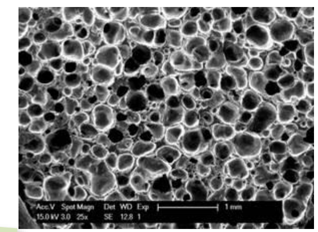
Our work-flow

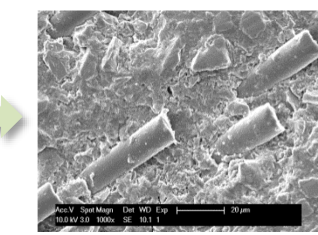


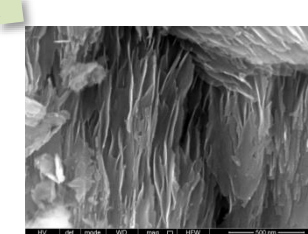


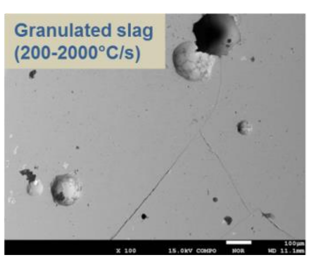
Granulation

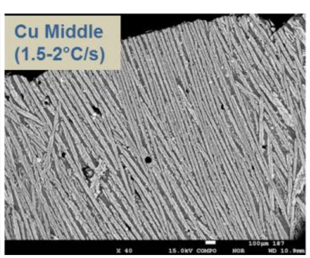
New slag

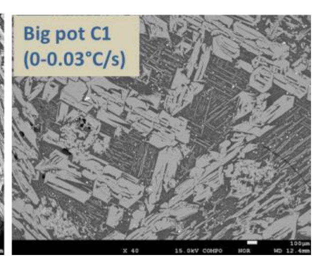








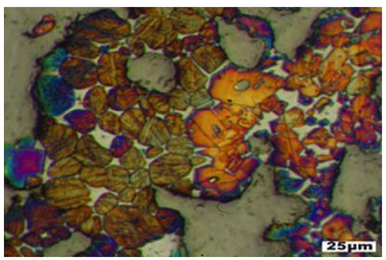




Our structure

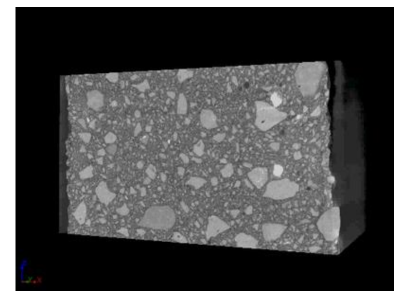
Processing

Cementitious binders



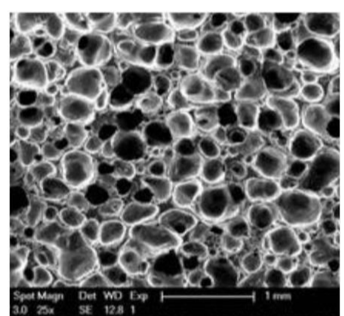
Design new clinkers
Improve performance of mortars

Inorganic Polymers



Design new precursors
Improve performance of mortars

Engineered materials



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Ordinary Portland Cement

Concrete life-time is around 100 y

Not recyclable

Cannot handle fire

Deteriorates with sea-water, chlorides, sulphides, acids, (…)

Annual production ~ 4.2Gt/y

~0.8t CO_2 /t cement clinker

Firing temperature 1450 °C

Mostly primary raw materials used

Can incorporate residues

Blended cements have lower footprint

To put it differently…

Romans did better!

What if…?

The precursors for the new cement are locally sourced,
and residues are included in the formulation,
where OPC can be incorporated,
leading to a binder that accommodates fluctuations,
without compromising in performance.

Locally-sourced,
with residues,
just-in-time,
of high quality

We must rethink "cement"

Abundant raw materials (with low CO_2)

Process (low temp)

To deliver a powder that I will be able to shape in a form (I need a gas/liquid)

Make a crystal-growing binder

Make an amorphous binder

Meet ELCE

Meet the Extraordinary Leuven CEment

Called ELCE

Can give similar mechanical properties

Made with the 5 most abundant elements

Is fire-resistant, reusable+++

At least 30% lower CO_2 footprint

Raw material exists already (slag)

$$\alpha CaO - \beta\text{“}FeO\text{”} - \gamma Al_2O_3 - \delta SiO_2,$$

$$\alpha \leq 35,\ 25 \leq \beta \leq 75,\ \gamma \leq 10,\ \delta \leq 45;\ \alpha < \beta, \text{ in mol\%}$$

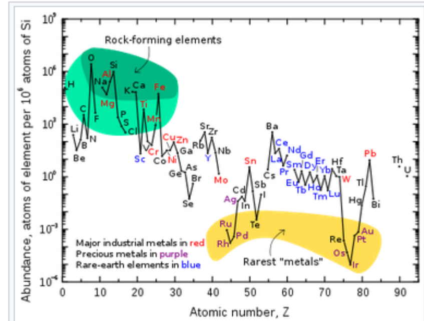
A cement from abundant elements

From Wikipedia, the free encyclopedia

The **abundance of elements in Earth's crust** is shown in tabulated form with the estimated crustal abundance for each chemical element shown as either percentage or parts per million (ppm) by mass (10,000 ppm = 1%).

Abundance of chemical elements in Earth's crust, from various sources

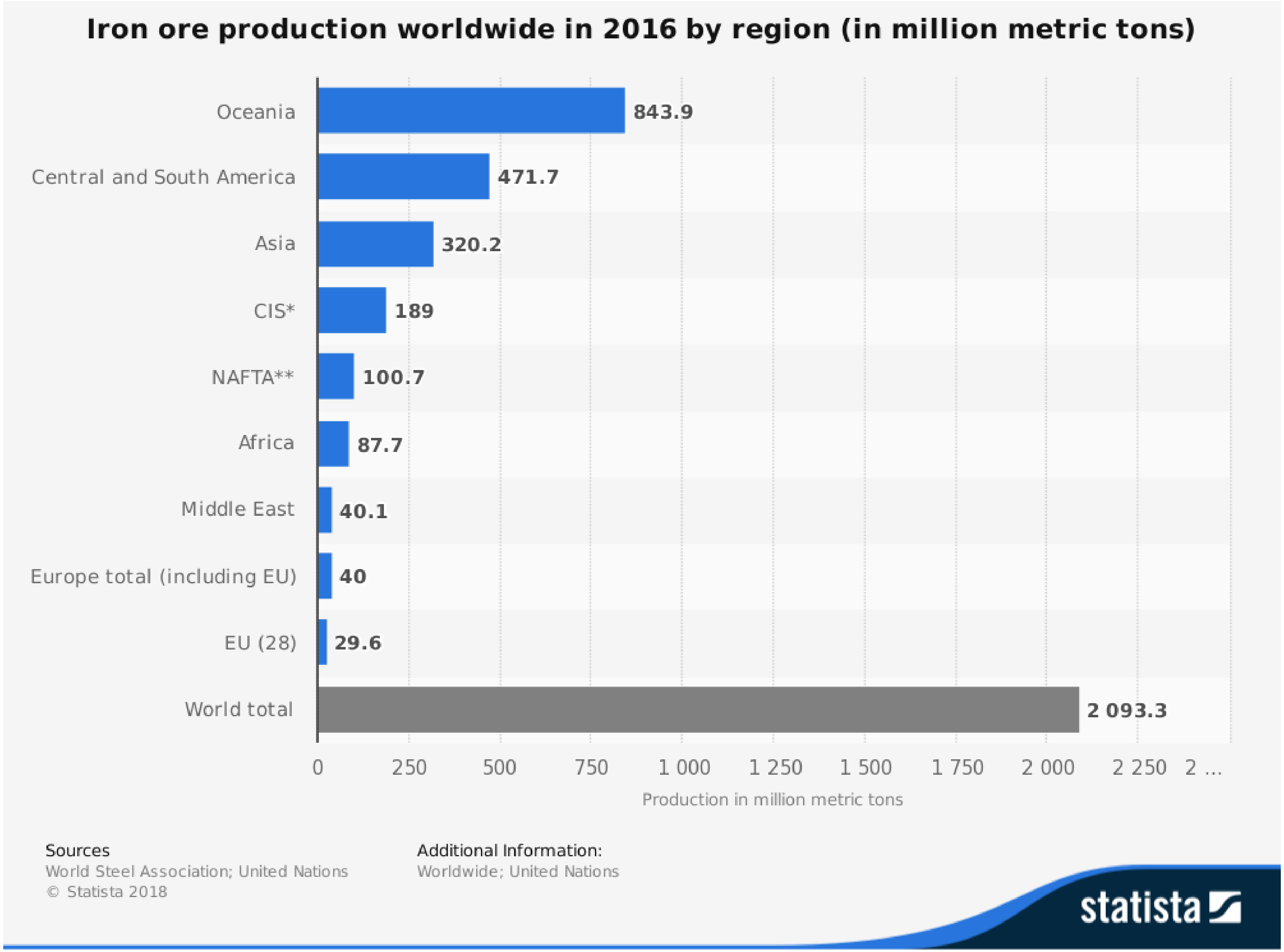
Rank	Z, element & symbol			Abundance in crust (ppm) by source					Annual production
				Darling[1]	Barbalace[2]	WebElements[3]	Israel Science and Technology[4]	Jefferson Lab[5]	(2016, tonnes)[6]
1	8	oxygen	O	466,000	474,000	460,000	467,100	461,000	
2	14	silicon [A]	Si	277,200	277,100	270,000	276,900	282,000	7,200,000
3	13	aluminium	Al	81,300	82,000	82,000	80,700	82,300	57,600,000
4	26	iron	Fe	50,000	41,000	63,000	50,500	56,300	1,150,000,000
5	20	calcium	Ca	36,300	41,000	50,000	36,500	41,500	
6	11	sodium	Na	28,300	23,000	23,000	27,500	23,600	255,000,000
7	12	magnesium	Mg	20,900	23,000	29,000	20,800	23,300	1,010,000
8	19	potassium	K	25,900	21,000	15,000	25,800	20,900	
9	22	titanium	Ti	4,400	5,600	6,600	6,200	5,600	6,600,000
10	1	hydrogen	H	1,400		1,500	1,400	1,400	



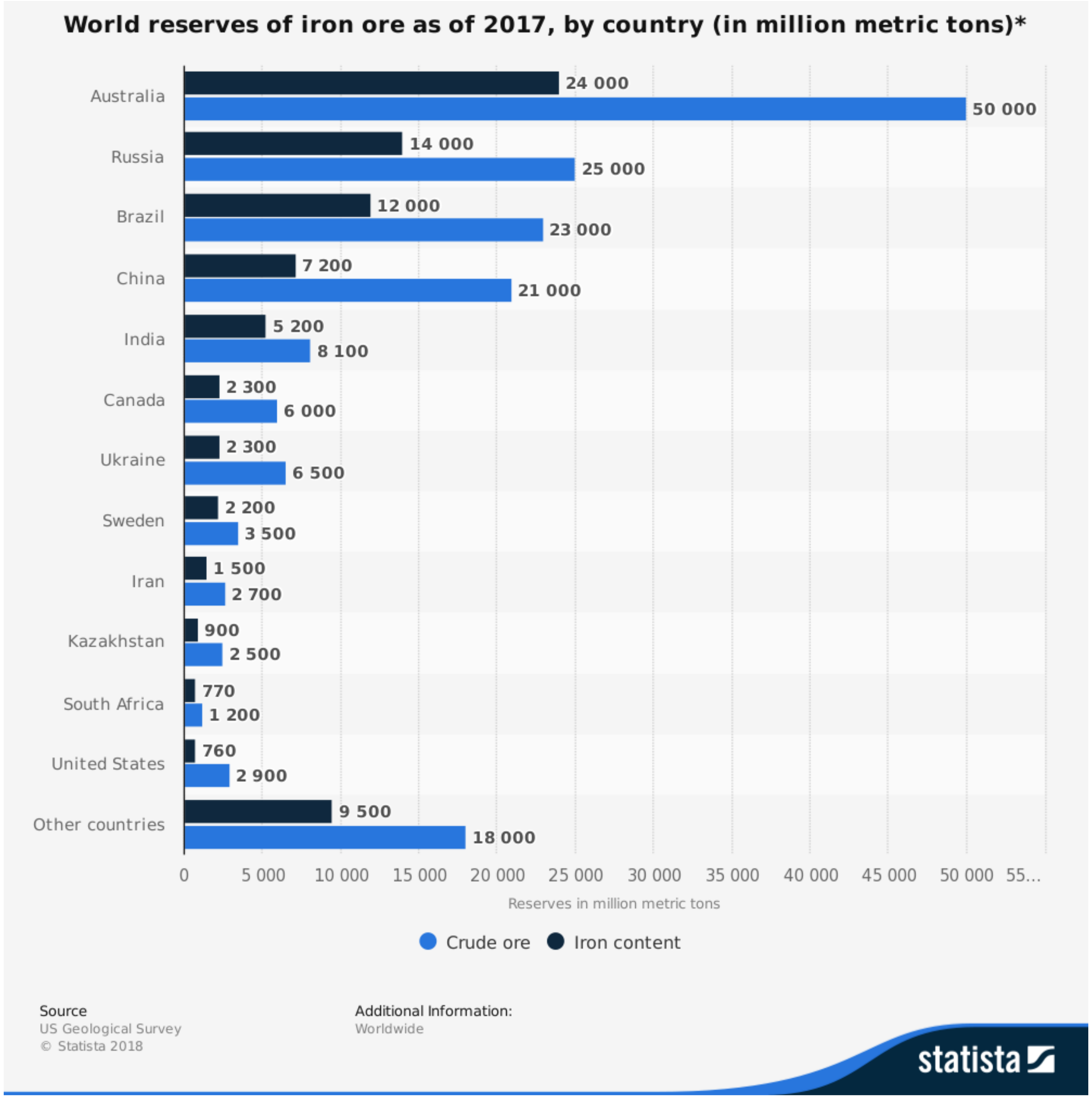
Abundance (atom fraction) of the chemical elements in Earth's upper continental crust as a function of atomic number. The rarest elements in the crust (shown in yellow) are not the heaviest, but are rather the siderophile (iron-loving) elements in the Goldschmidt classification of elements. These have been depleted by being relocated deeper into the Earth's core. Their abundance in meteoroids is higher. Additionally, tellurium and selenium have been depleted from the crust due to formation of volatile hydrides.

O, Si, Al, Fe, Ca, Na, Mg, K…

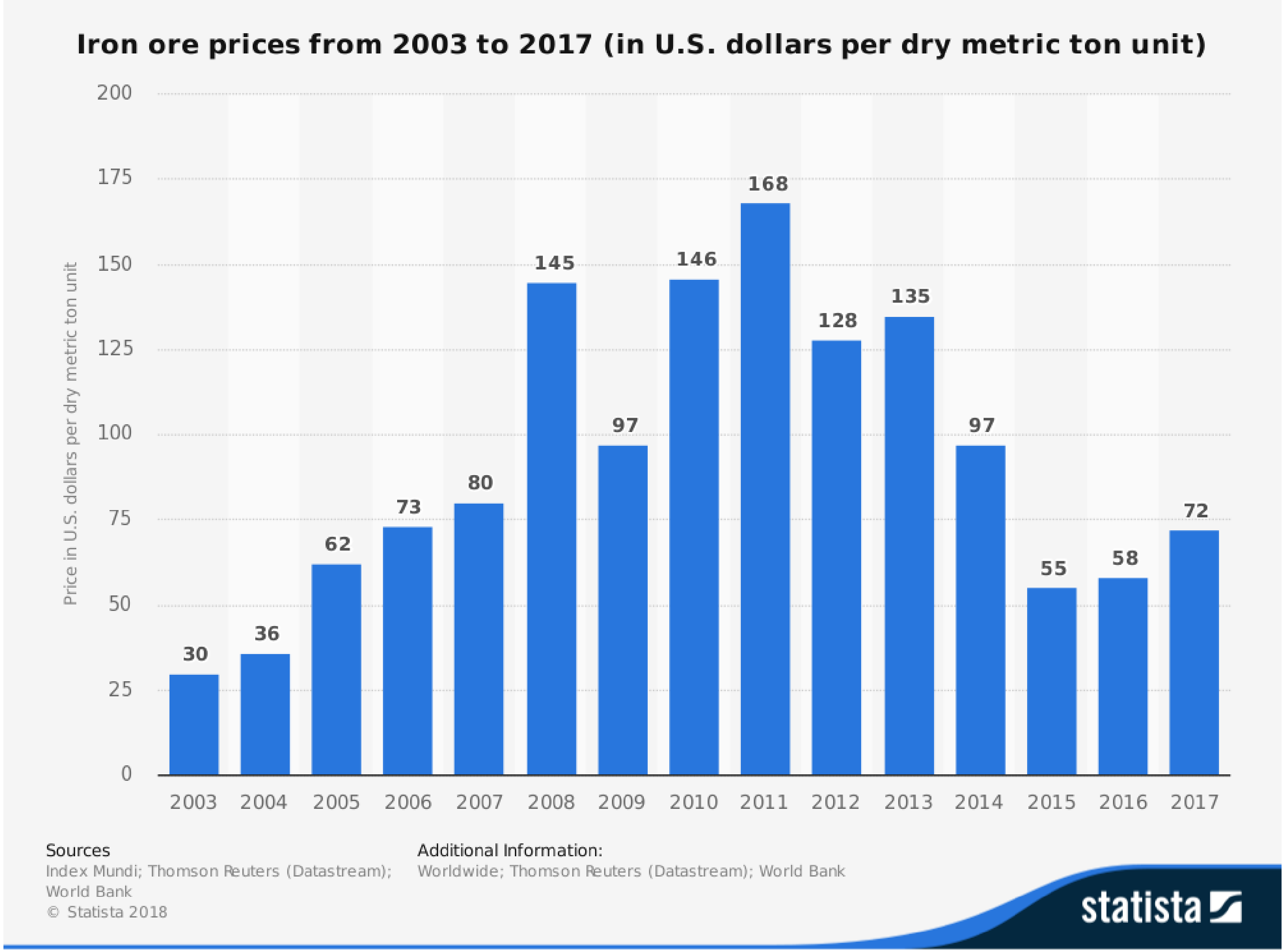
A cement from abundant elements



A cement from abundant elements



A cement from abundant elements



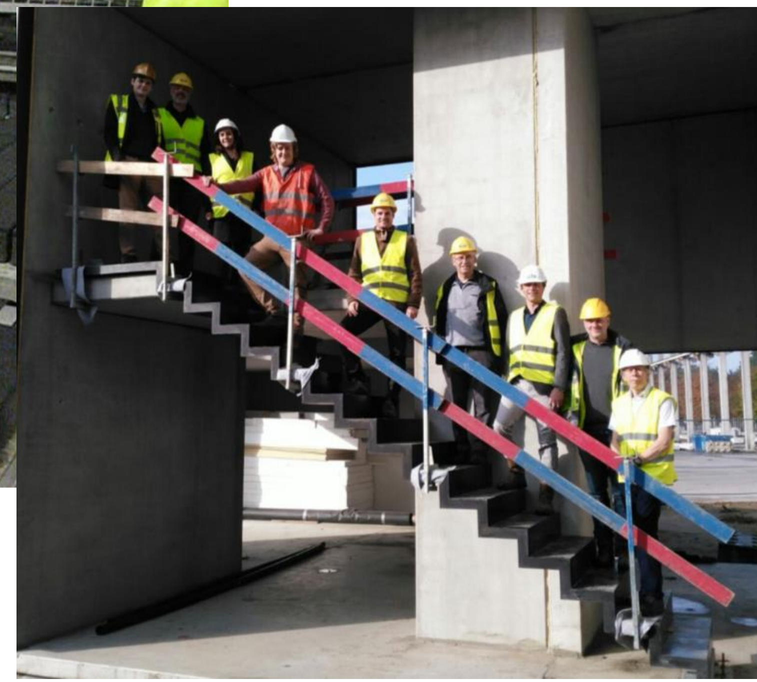
That can be sourced nearby

Reserves landfilled: >100 Mtons, in more locations not listed above

From 2015 to 2018

2015

2016



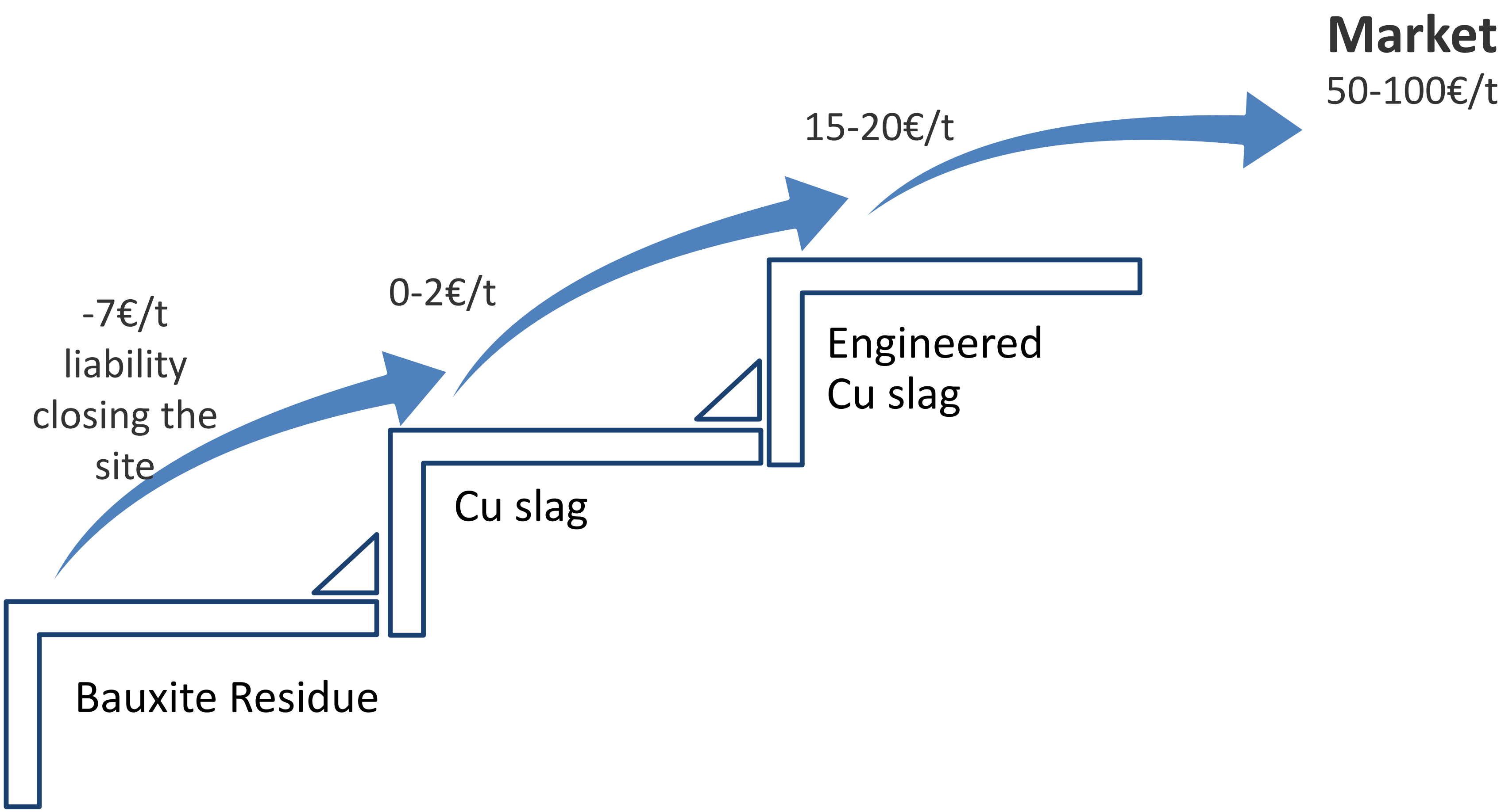
2018

Cement industry: 8% of total CO_2

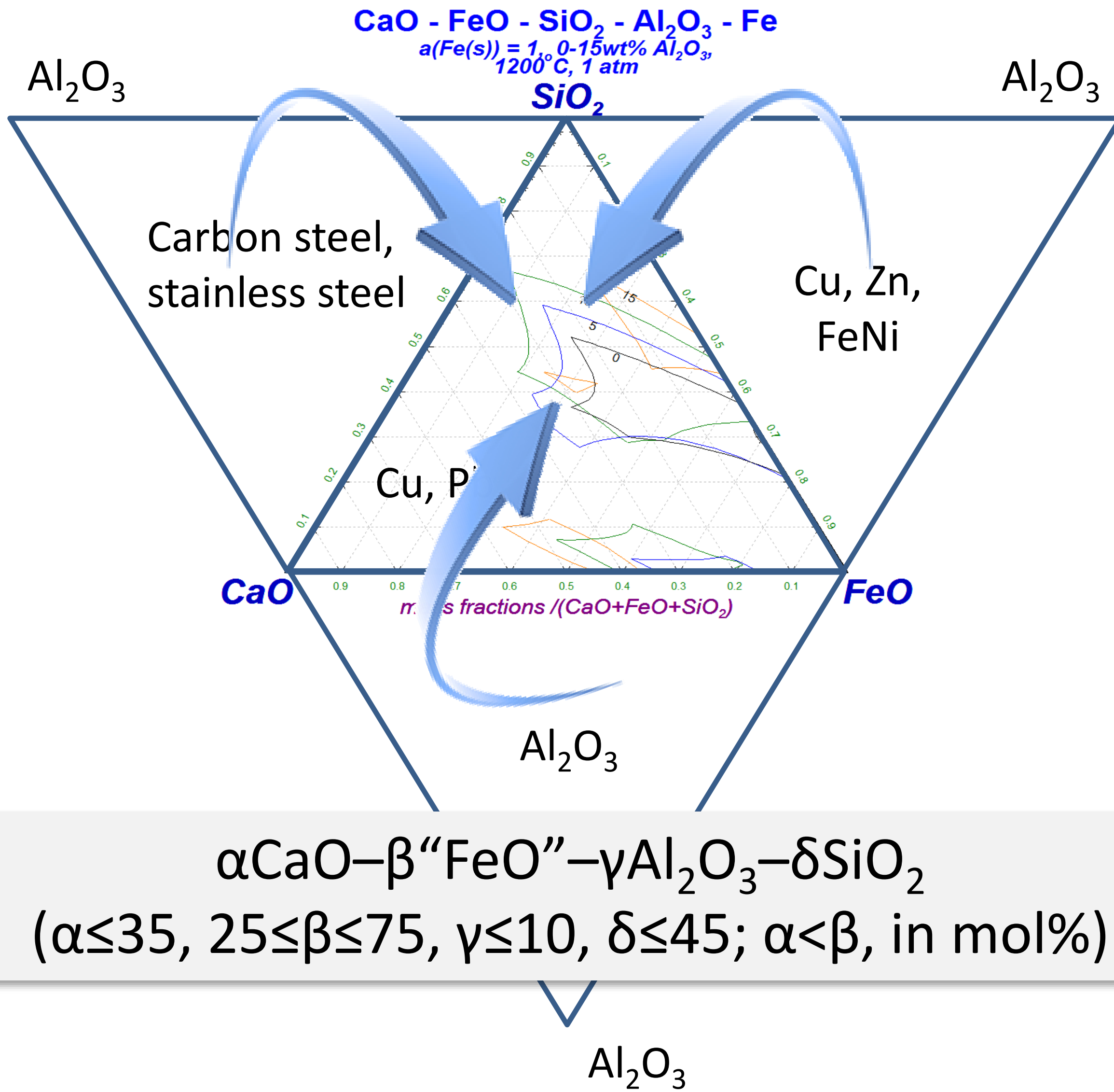
No Ordinary Portland Cement used!

We use ELCE!

Stairway to heaven



Blended in the right proportions

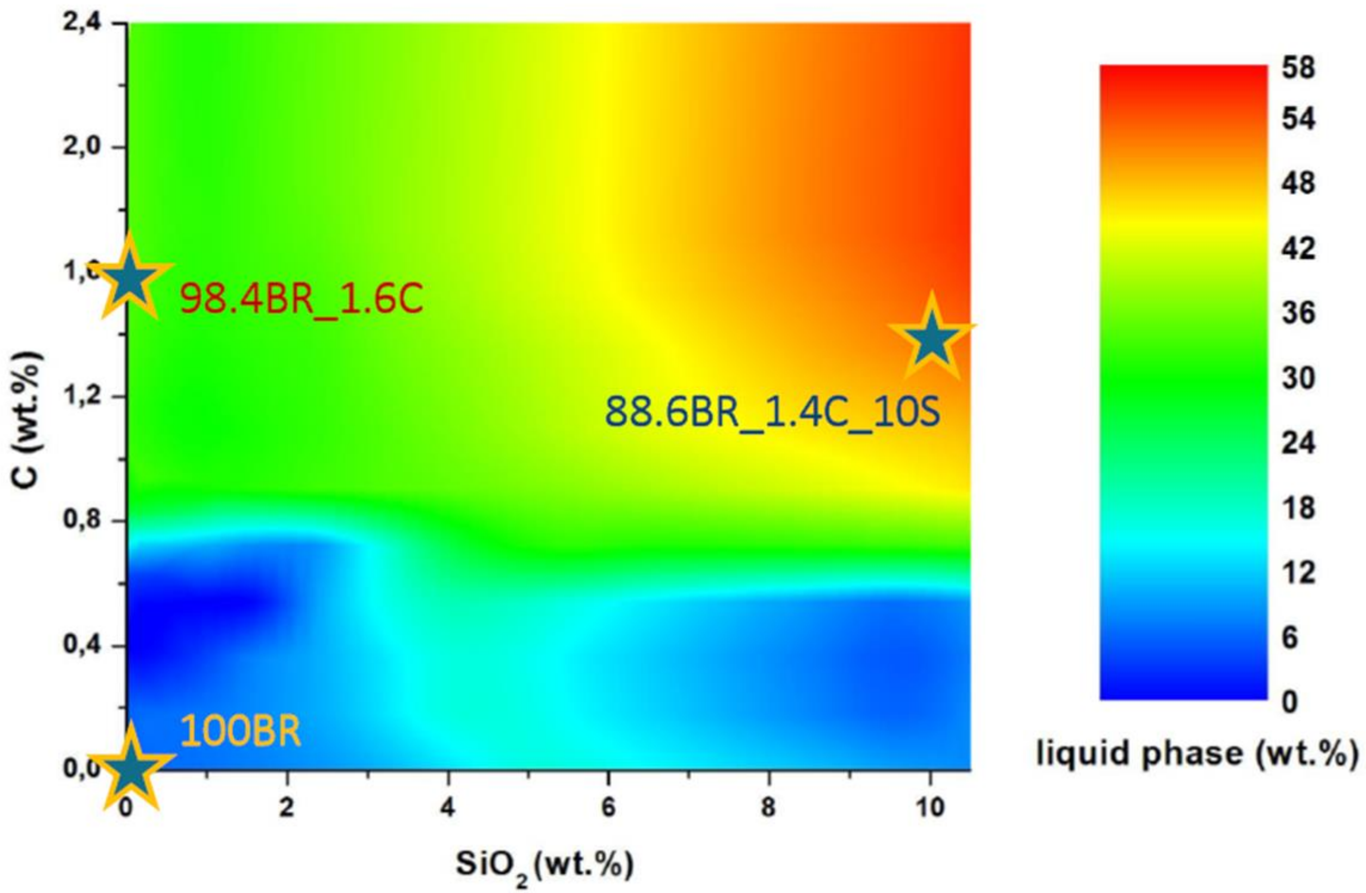


αCaO–β"FeO"–γAl_2O_3–δSiO_2

($\alpha \leq 35$, $25 \leq \beta \leq 75$, $\gamma \leq 10$, $\delta \leq 45$; $\alpha < \beta$, in mol%)

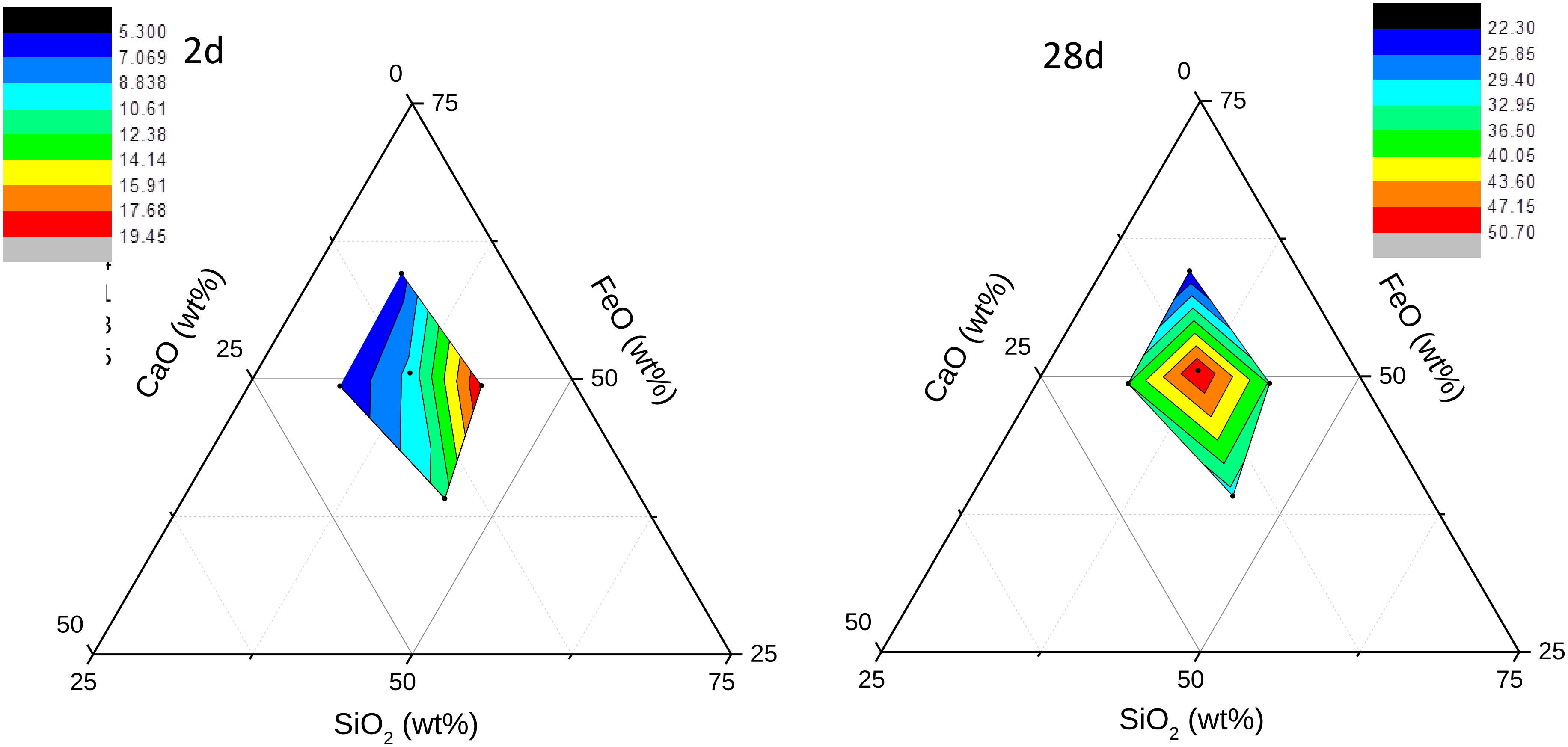
The process

FactSage calculation 1100 °C – Carbon + silica



Hertel, T. et al., Bauxite Residue Valorisation and Best Practices Conference, 5-7 October, 2015, Leuven, Belgium

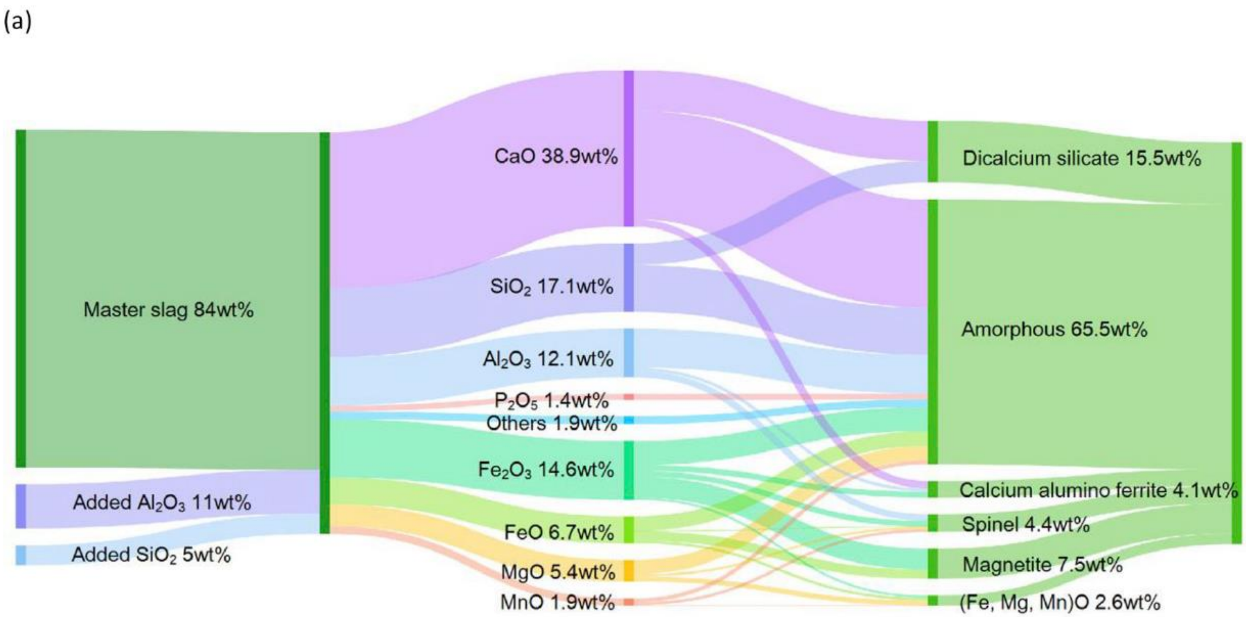
The new precursor

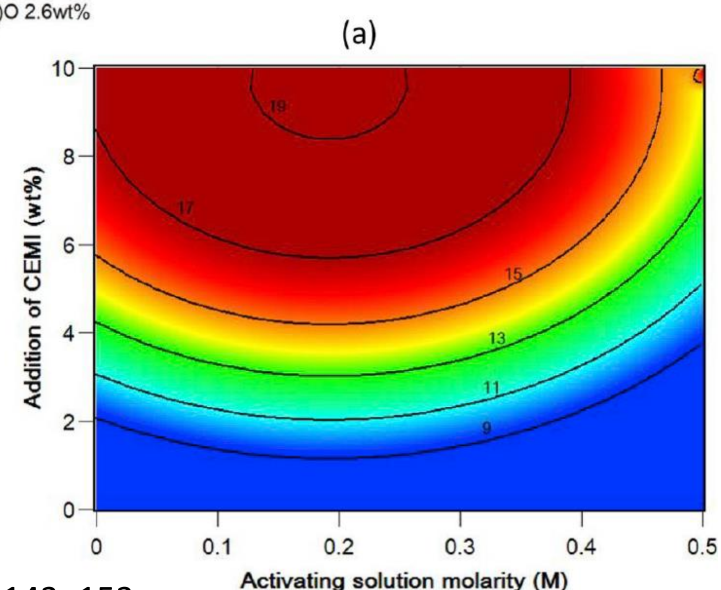


Find the right slag chemistry that respects the metallurgical process and delivers the best possible IP

J. Van de Sande, 2017, MSc thesis, KU Leuven

As an example



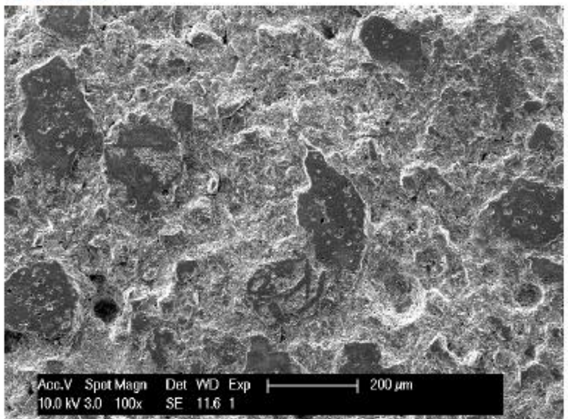


P.L. Lopez Gonzalez et al., Cement and Concrete Composites 97 (2019) 143–153

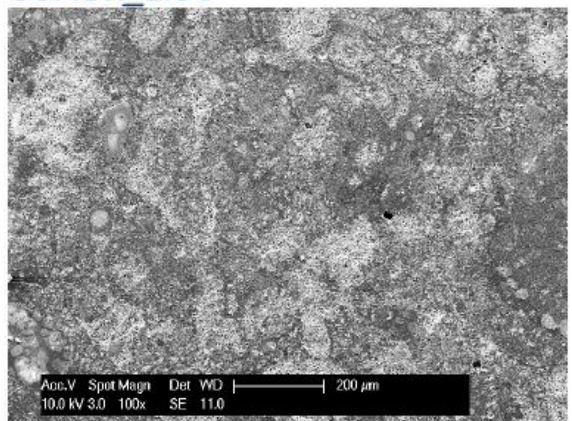
Microstructure of the IP

- K-silicate activation solution, $SiO_2/K_2O = 1.6$, $H_2O/K_2O = 16$
- activation solution/solid ratio = 0.25
- Curing: 60 °C, 72 h

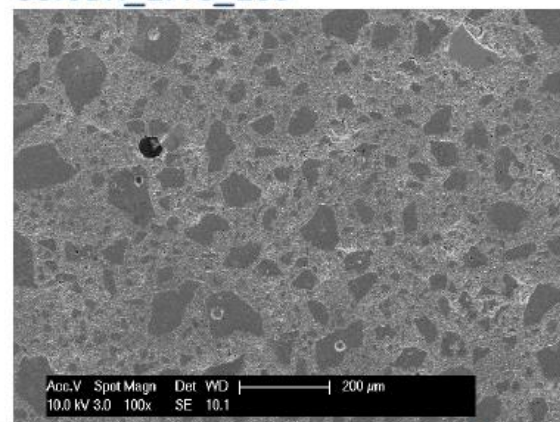
100BR



98.4BR_1.6C



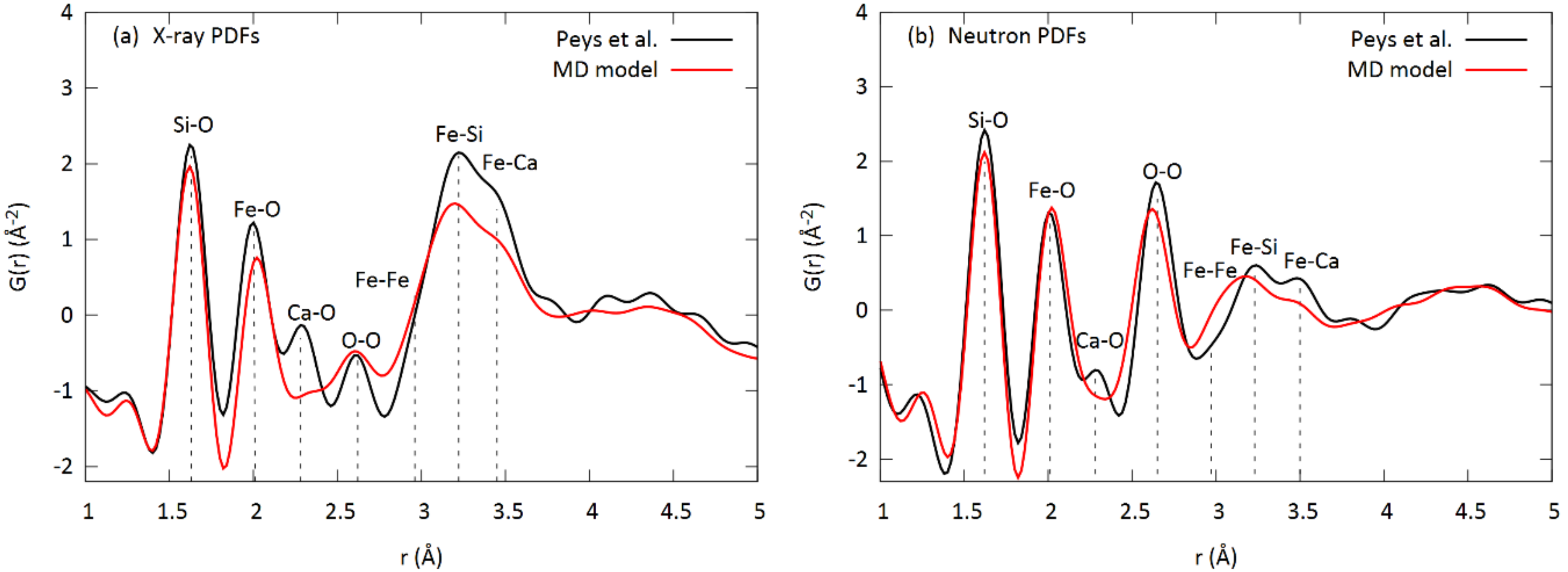
88.6BR_1.4C_10S



Compressive	13 MPa	20 MPa	44 MPa
Flexural	4 MPa	6 MPa	10 MPa

Hertel, T. et al., Bauxite Residue Valorisation and Best Practices Conference, 5-7 October, 2015, Leuven, Belgium

Microstructure of the IP

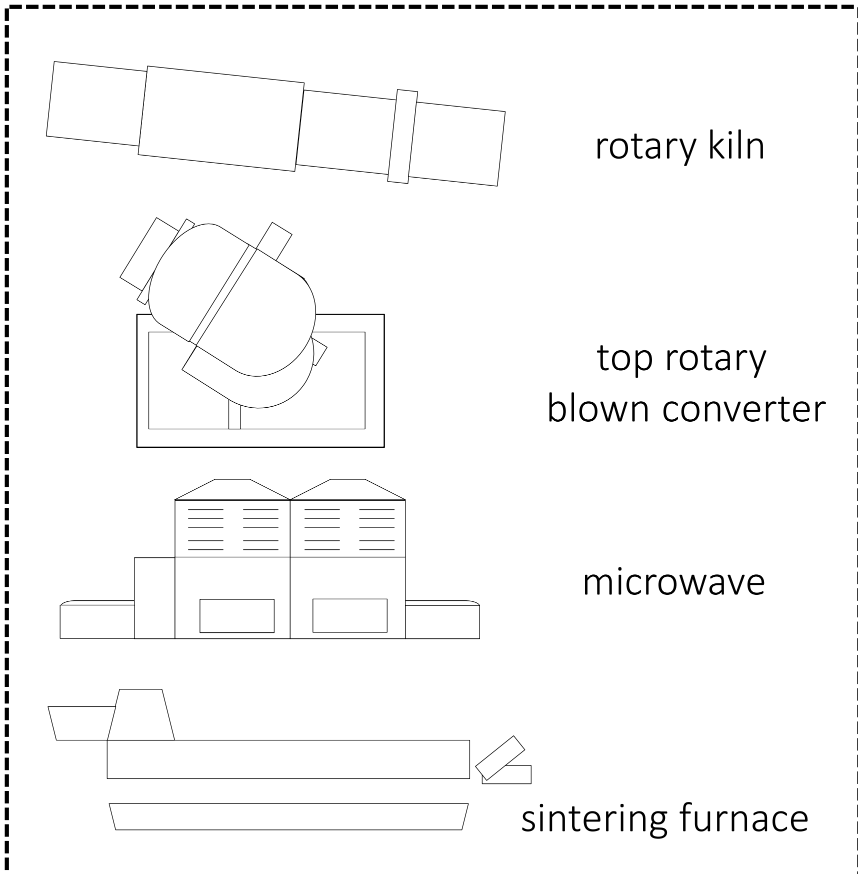


X-ray (a) and neutron (b) pair distribution functions derived from molecular dynamics simulation and compared with experimental data from the work of Peys et al.

Siakati et al, unpublished data

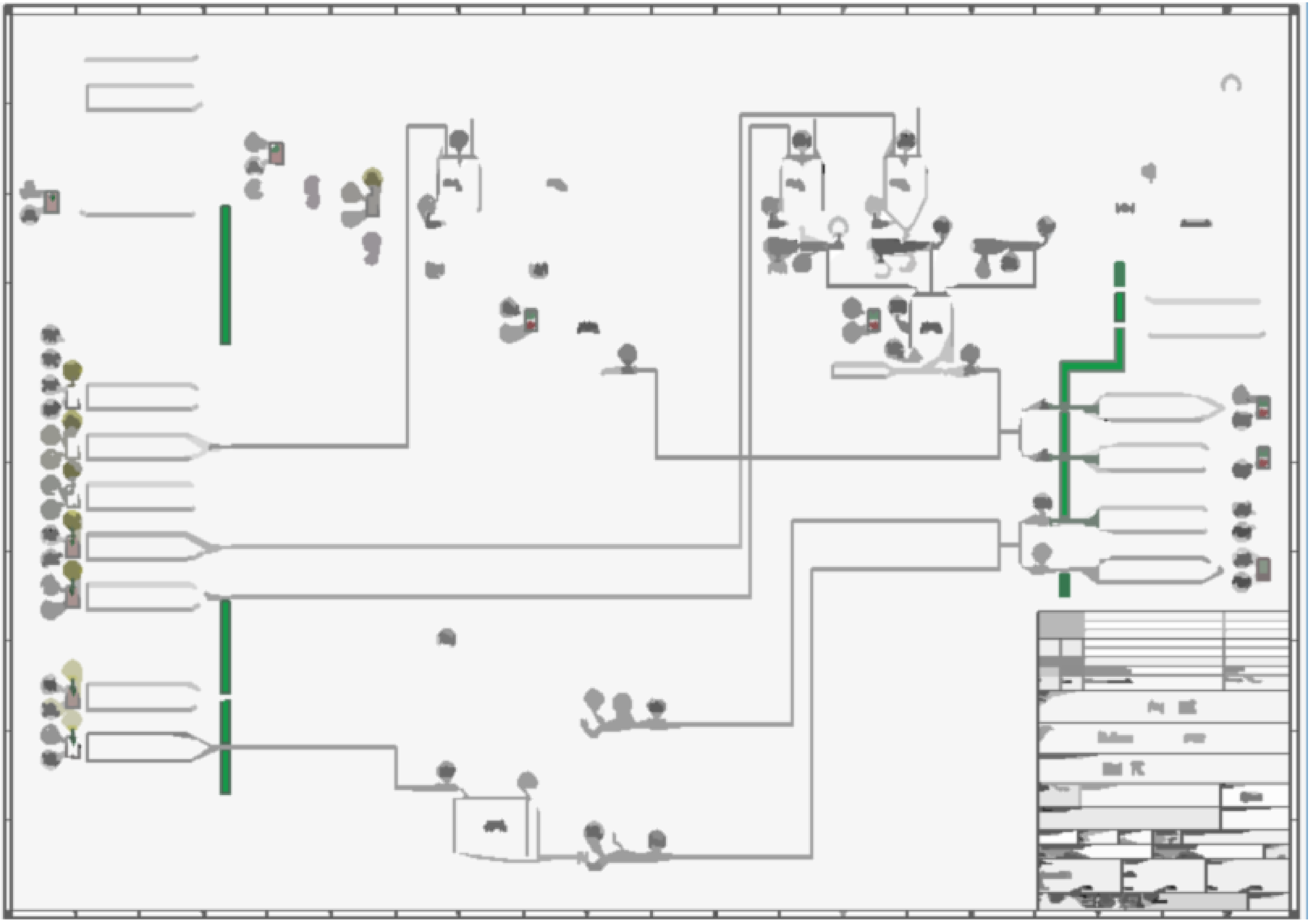
The process

Iron ore blend
Bauxite residue
…

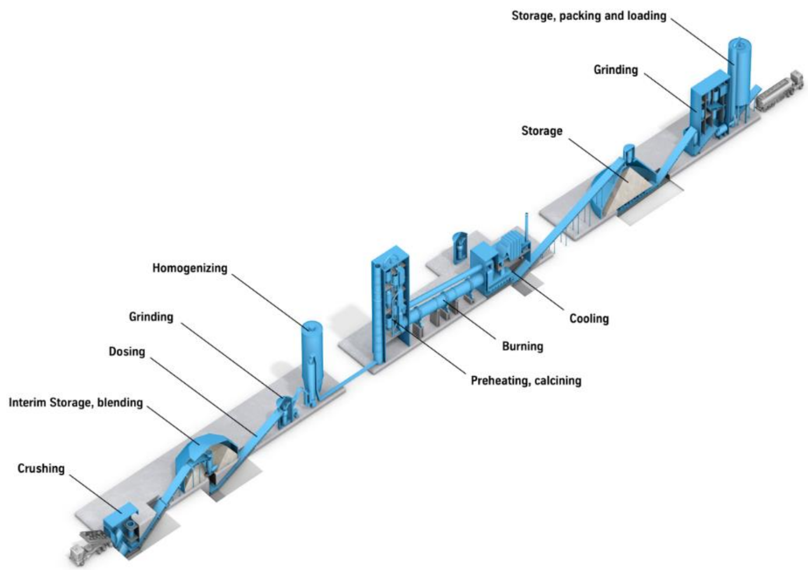


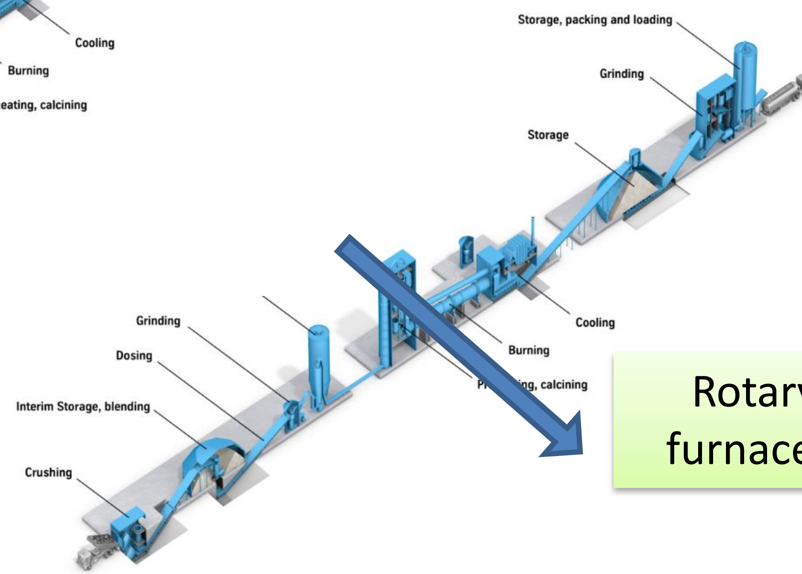
Precursor
("slag")

The process (P&ID, cont.#3)



Putting things in perspective…





New cement types

Rotary melting furnace, electric?

Go to a Fe-rich blend

Source: https://www.thyssenkrupp-industrial-solutions.com

Sustainable?

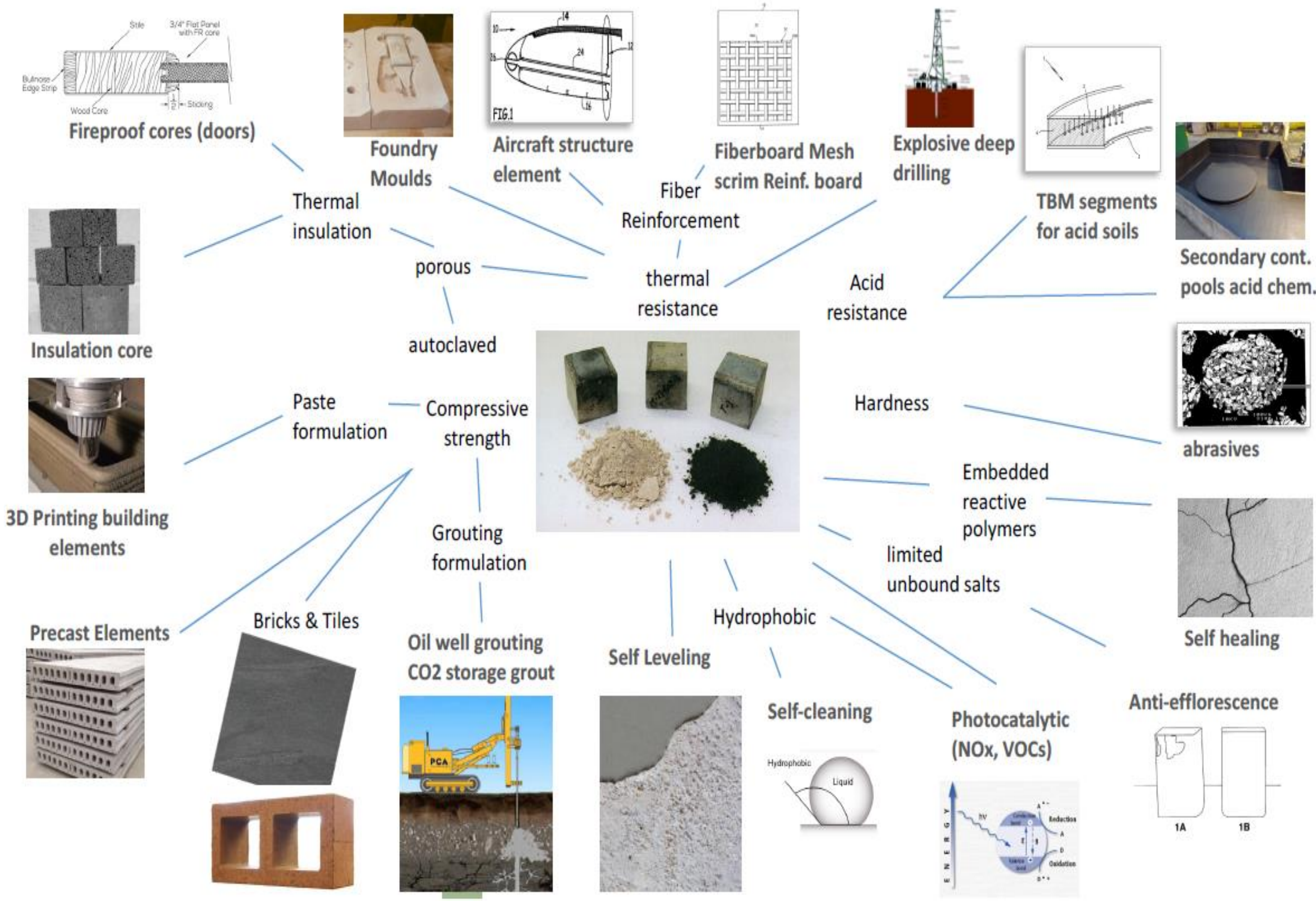
Firing between 1150 and 1200 °C	Firing at 1450 °C
Can go lower than 1000 °C with fluxes	Formation of crystals limits the range of options
Low CO_2 (if any) in raw materials	Limestone is the major raw material
CO_2 still emitted due to Fe^{3+} reduction; but H_2 is coming up!	Cannot avoid CO_2 production
CO_2 capturing possible	CO_2 capturing possible

The most important thing: leveraging metallurgical knowhow

And this is not just a cement alternative

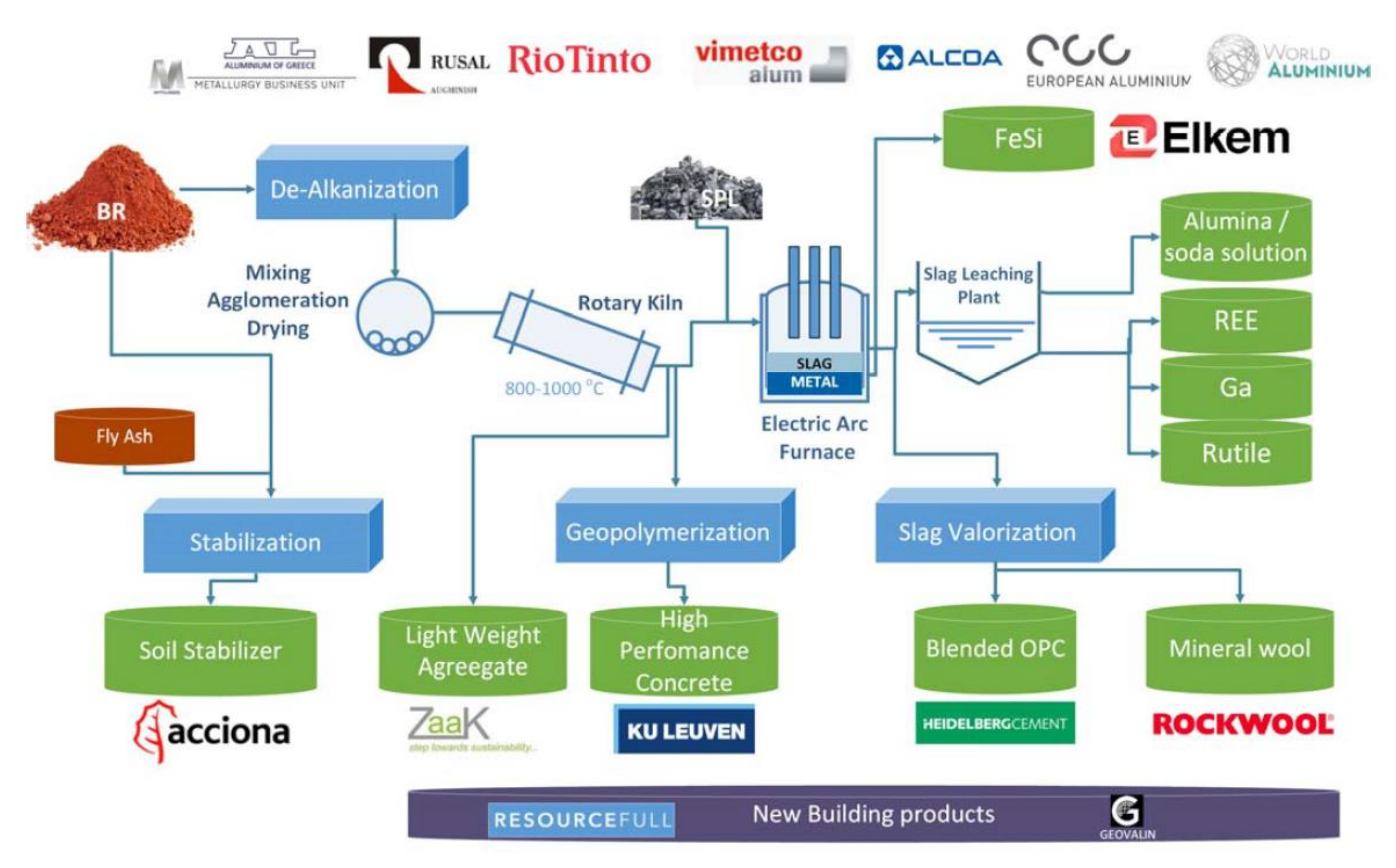
Data mining: Inorganic Polymers Patent Mapping

Main Functionalities and Applications

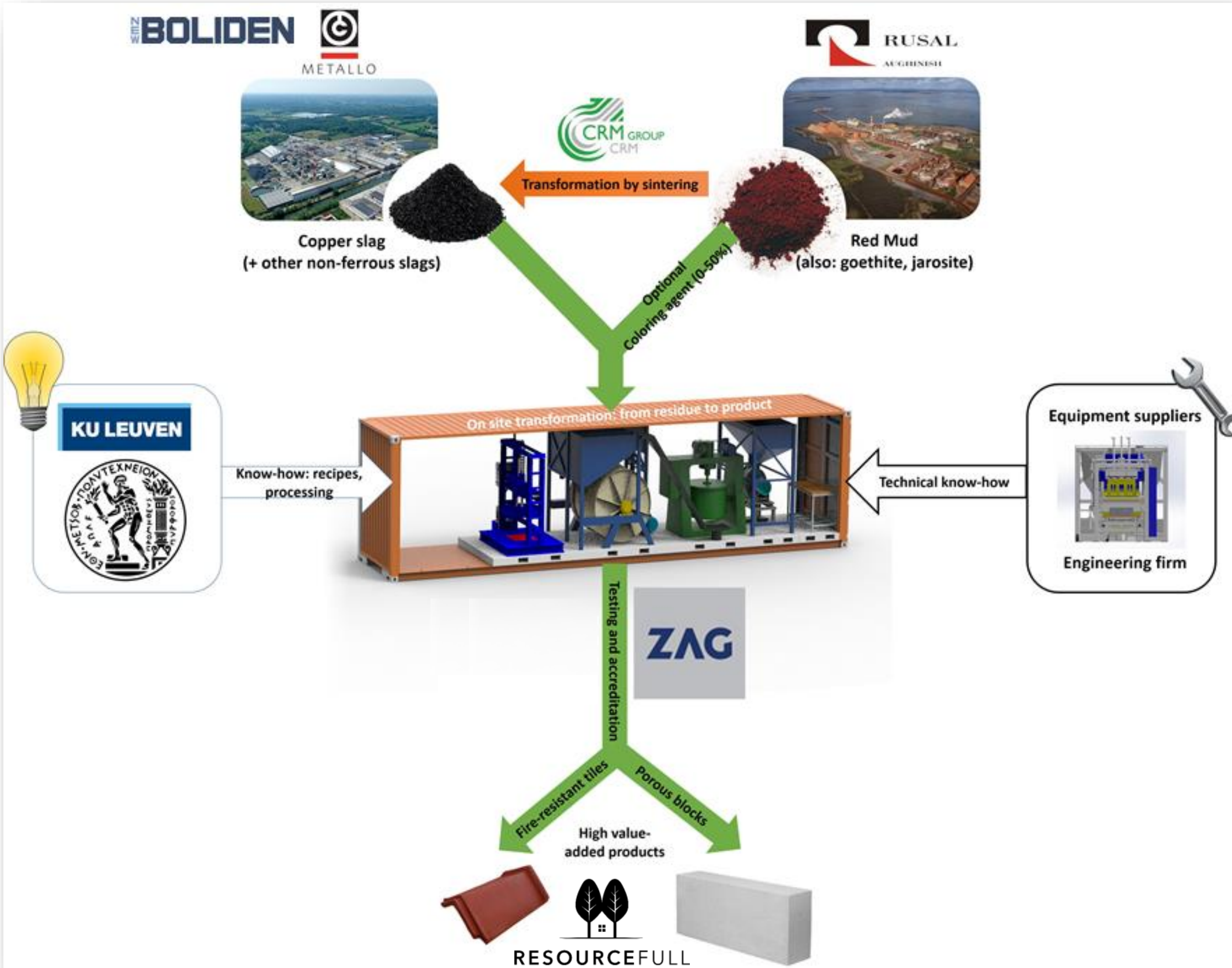


Going “big”

On-going work



On-going work

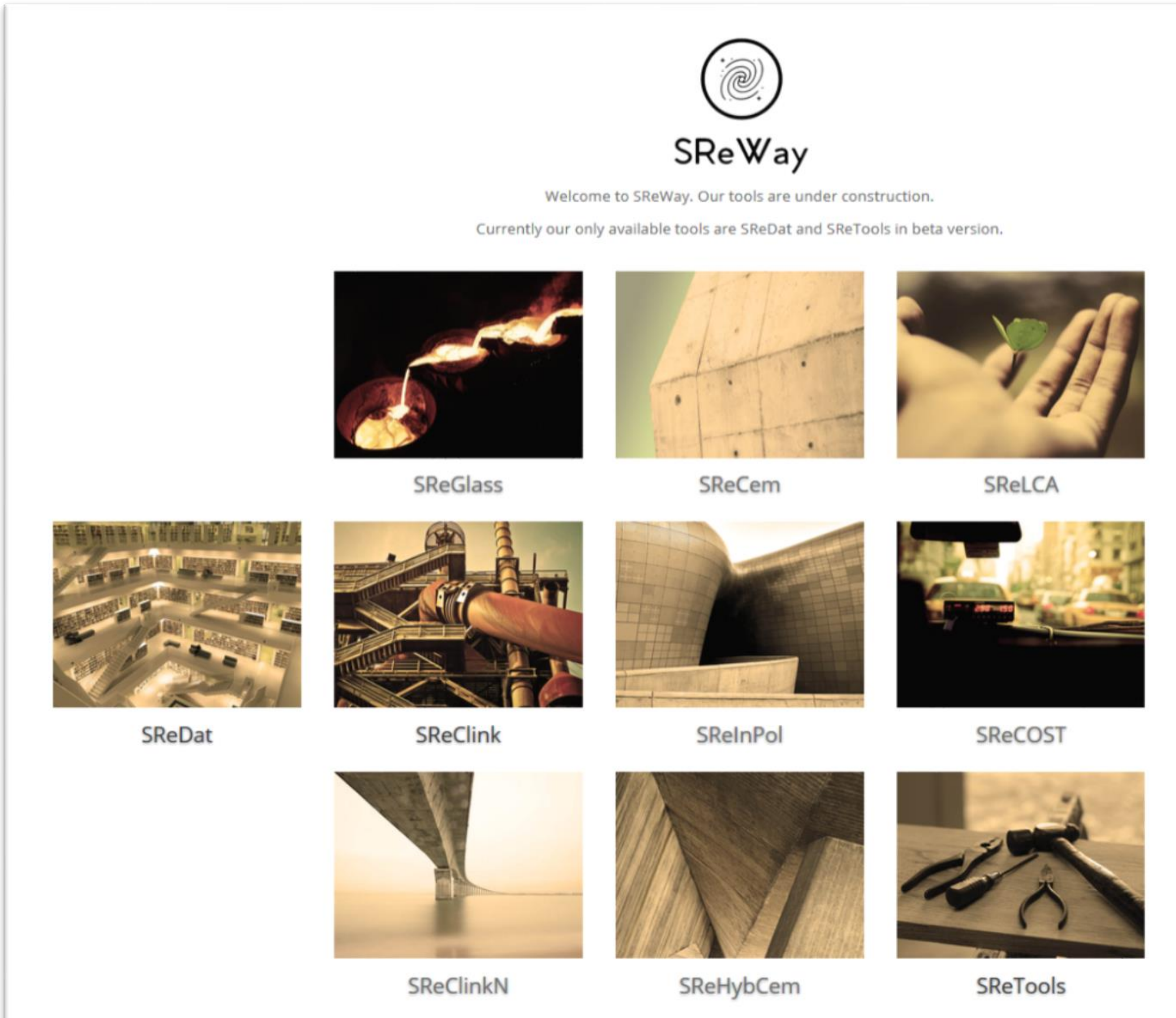


See more: recover.technology

Now and coming up

Now and coming up

Now and coming up



https://www.sreway.info/

Now and coming up

SReDat — SECONDARY RESOURCE DATABASE

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$(FeO)1.28(SiO_2)1(CaO)0.62$

SR

Basic Information

SReWay code	58
Name	$(FeO)1.28(SiO_2)1(CaO)0.62$
Critically Assessed	No
Resource Category	Not available / Not listed / Not available / Not listed / Not available / Not listed (EEA code: 999.999.999)
Category Type	Synthetic
Basic information/introduction	Synthetic slag S1
Location	KU Leuven Department of Materials Engineering, Leuven, Belgium
Location Longitude	(not set)
Location Latitude	(not set)
Source	Jorn Van De Sande
Status	

Chemistry

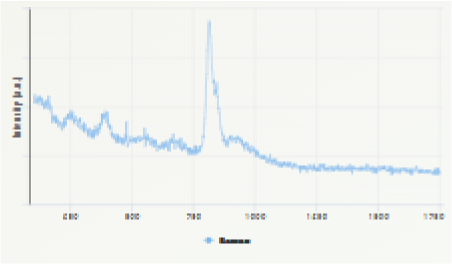
FeO - Iron Oxide (48.7 wt. %)
SiO_2 - Quartz (31.7 wt. %)
CaO - Calcium Oxide (18.2 wt. %)
Al_2O_3 - Corundum (0.8 wt. %)
Remainder: 0.8 wt. %

Crystallites Composition

"amorphous" - 70 wt. %
Fayalite - 28 wt. %

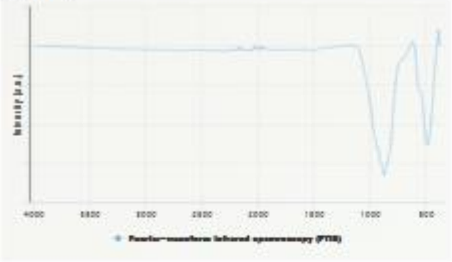
Raman

Description	
Details	Laser wavelength (nm): 532
Raw File	Download me



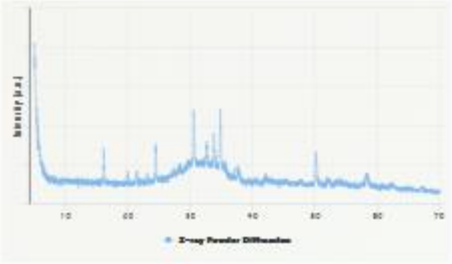
Fourier-transform infrared spectroscopy (FTIR)

Description	ATR-FTIR (Transmittance)
Details	Sample scans=32 Background scans=32 Resolution (cm^{-1})=4 Aperture (cm^{-1})=0
Raw File	Download me



X-ray Powder Diffraction

Description	
Details	XRD tube: Cu kV=30 mA=10 step size (deg)=0.02 time per step (s)=0.6
Raw File	Download me



https://www.sreway.info/

Thank you!