KU LEUVEN

An alternative path to follow in the pursuit of more “green” cements: introducing the Extraordinary Leuven Cement

Y. Pontikes
m2i conference
December 2018

Chapter 1

The motivation

The sustainable development goals

The sinking boat priorities; forecasts

Consequences of climate change might include:

*Between **25 million to 1 billion people** might become environmental migrants by the end of the century.*

*An additional **52 million people in 84 developing countries** might be affected by coastal storm surges, by 2100.*

*Yields of most important crops in developing countries will decline, exposing an additional **25 million children to malnutrition by 2050**.*

*An estimated **200 million more people** will be exposed to malaria by 2050, as a result of climate change.*

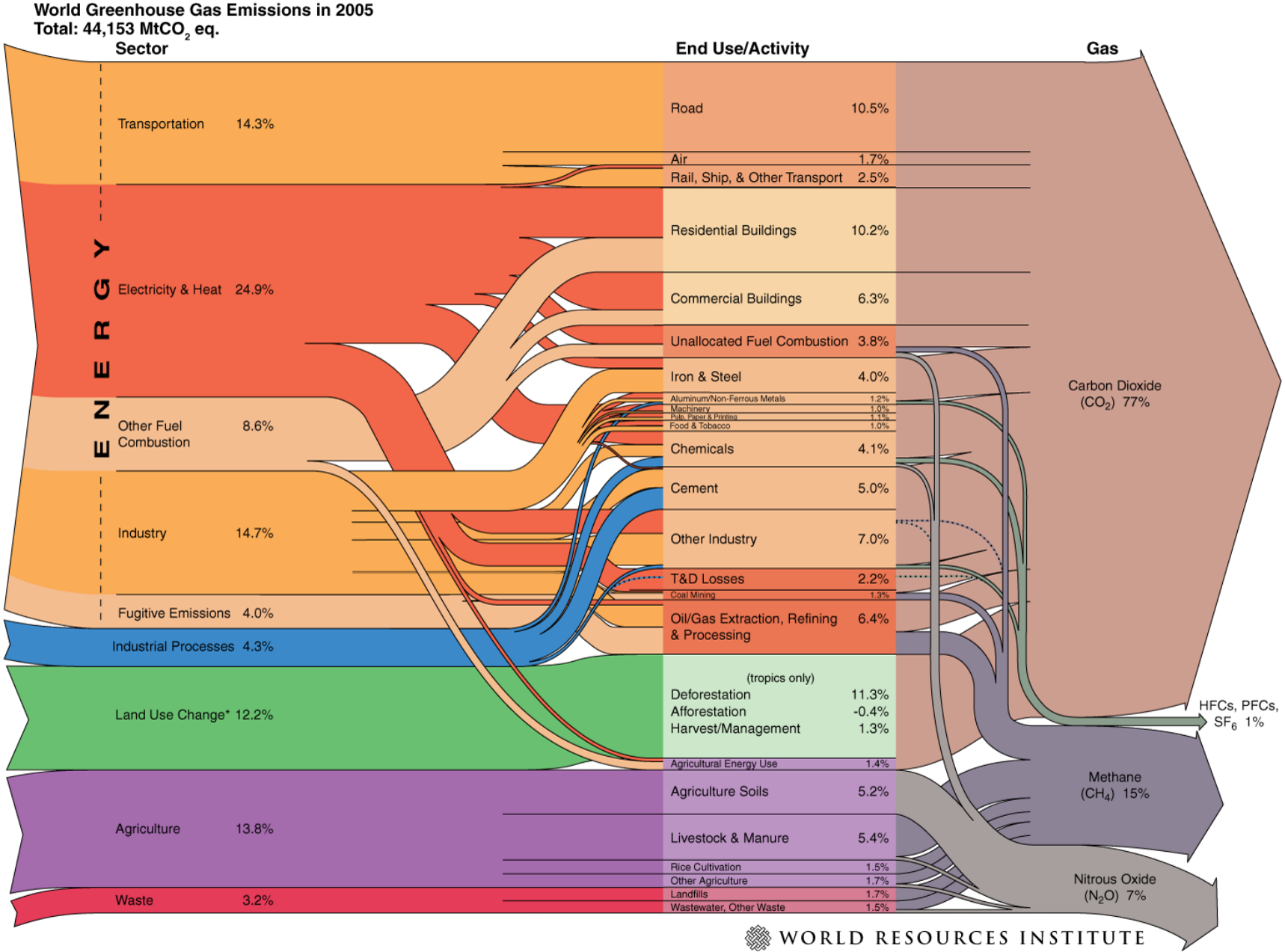
https://ec.europa.eu/knowledge4policy/foresight/topic/climate-change-environmental-degradation_en

https://thejigsawpuzzles.com

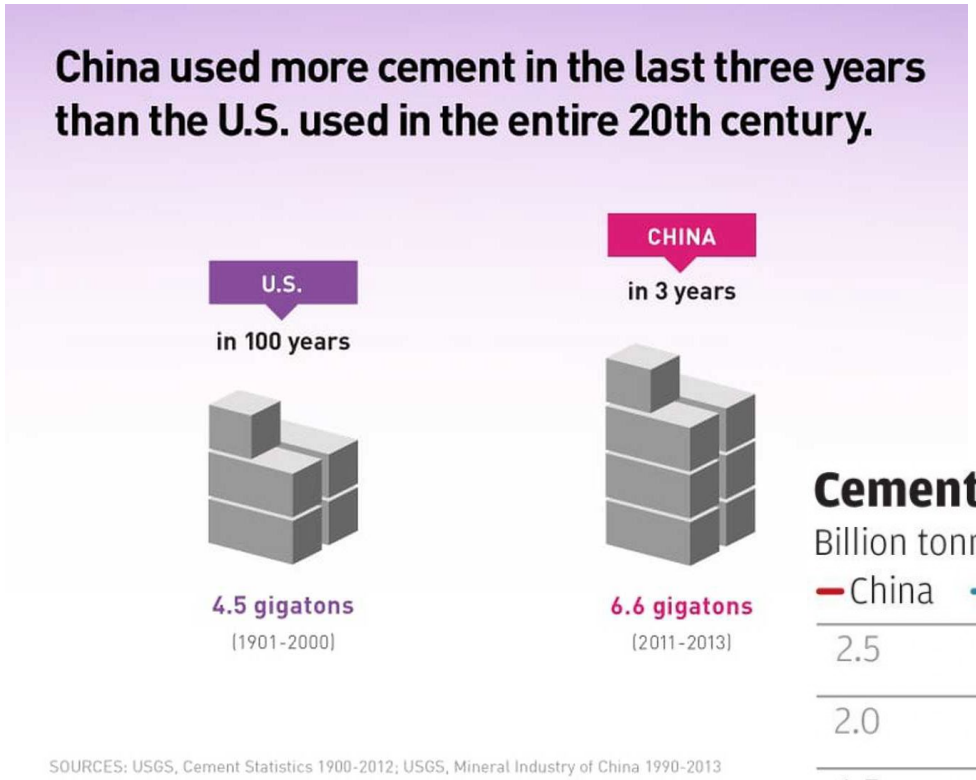
Chapter 2

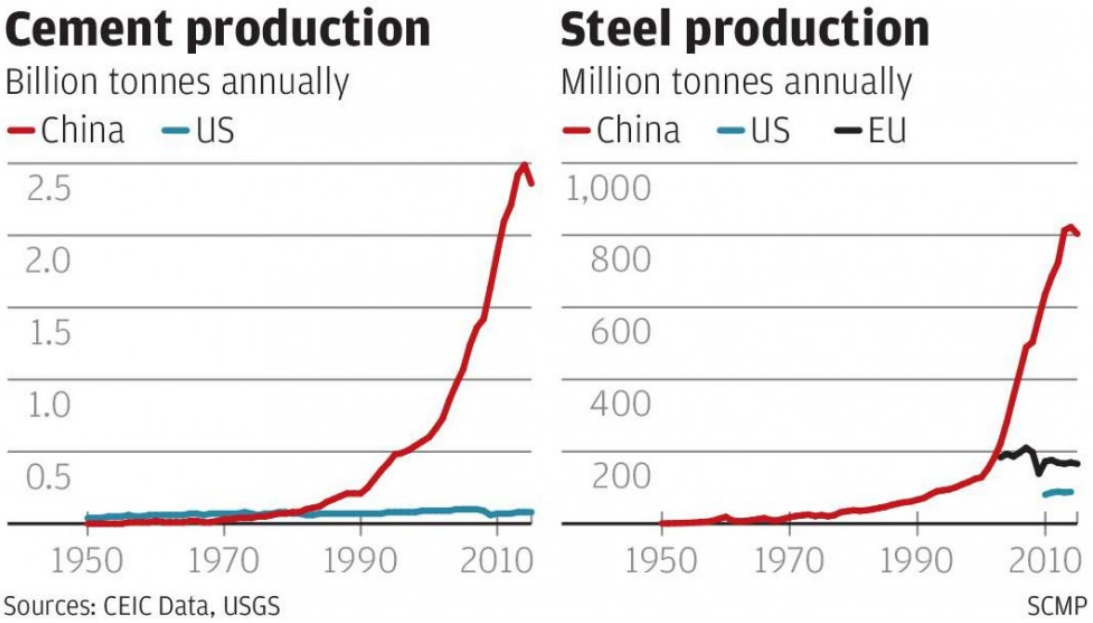
Defining the goal

Breakdown the sources



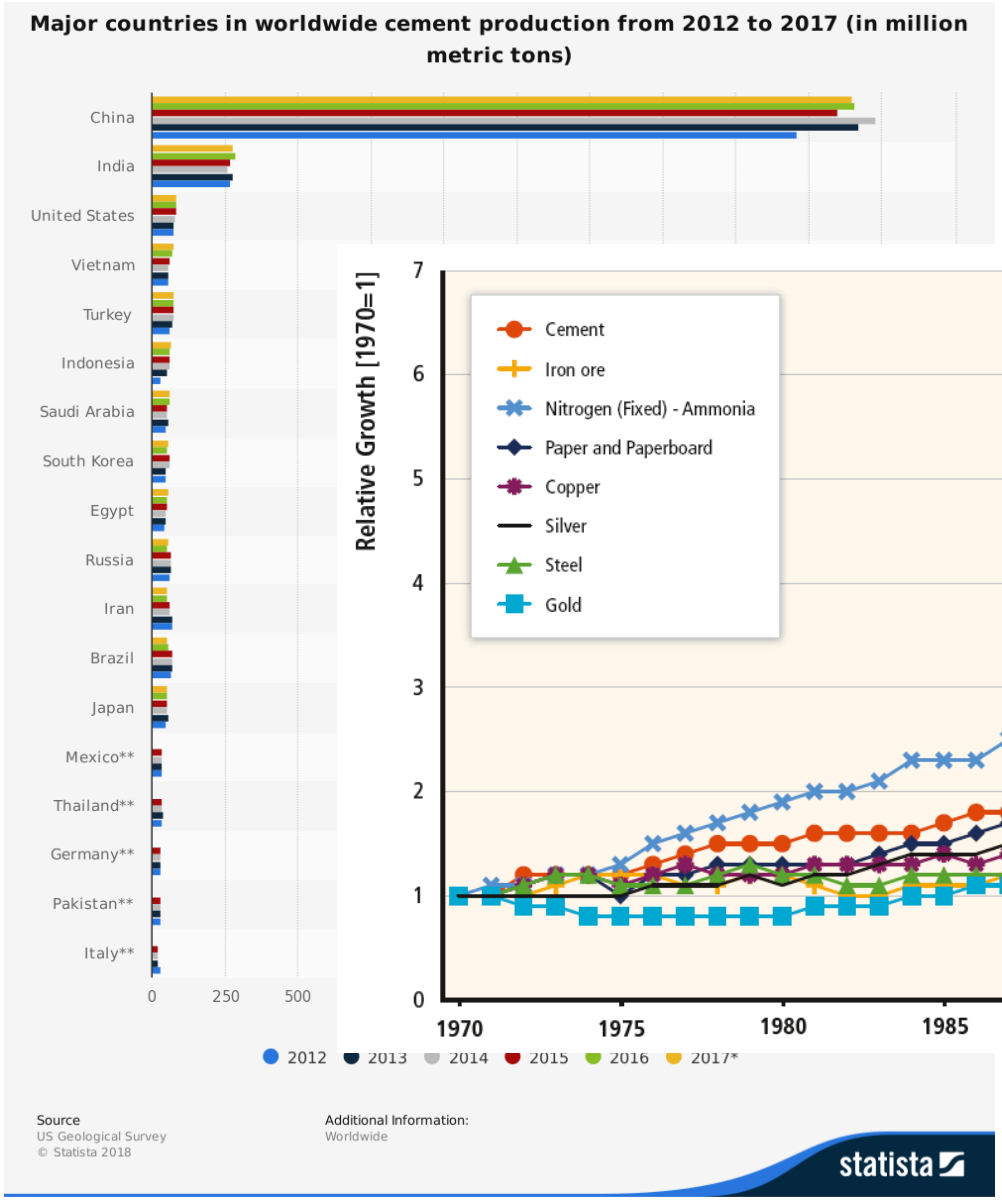
But…food for thought

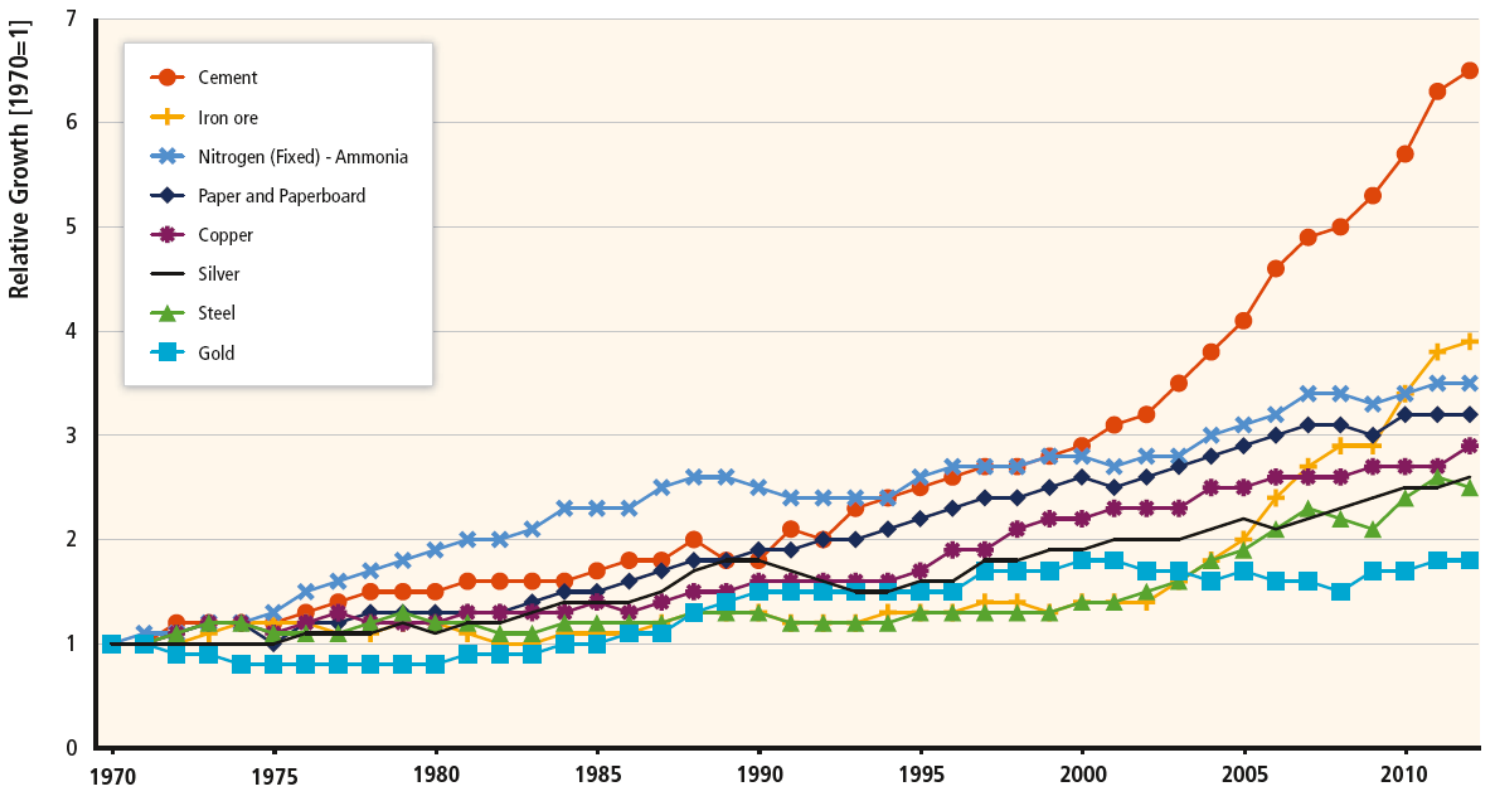




Source: (left) https://www.washingtonpost.com/ and (right) http://www.scmp.com/

Food for thought





Source: Industry. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change

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!

Chapter 3

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)

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

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

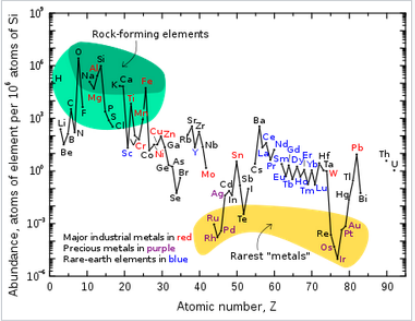
A cement from abundant elements

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

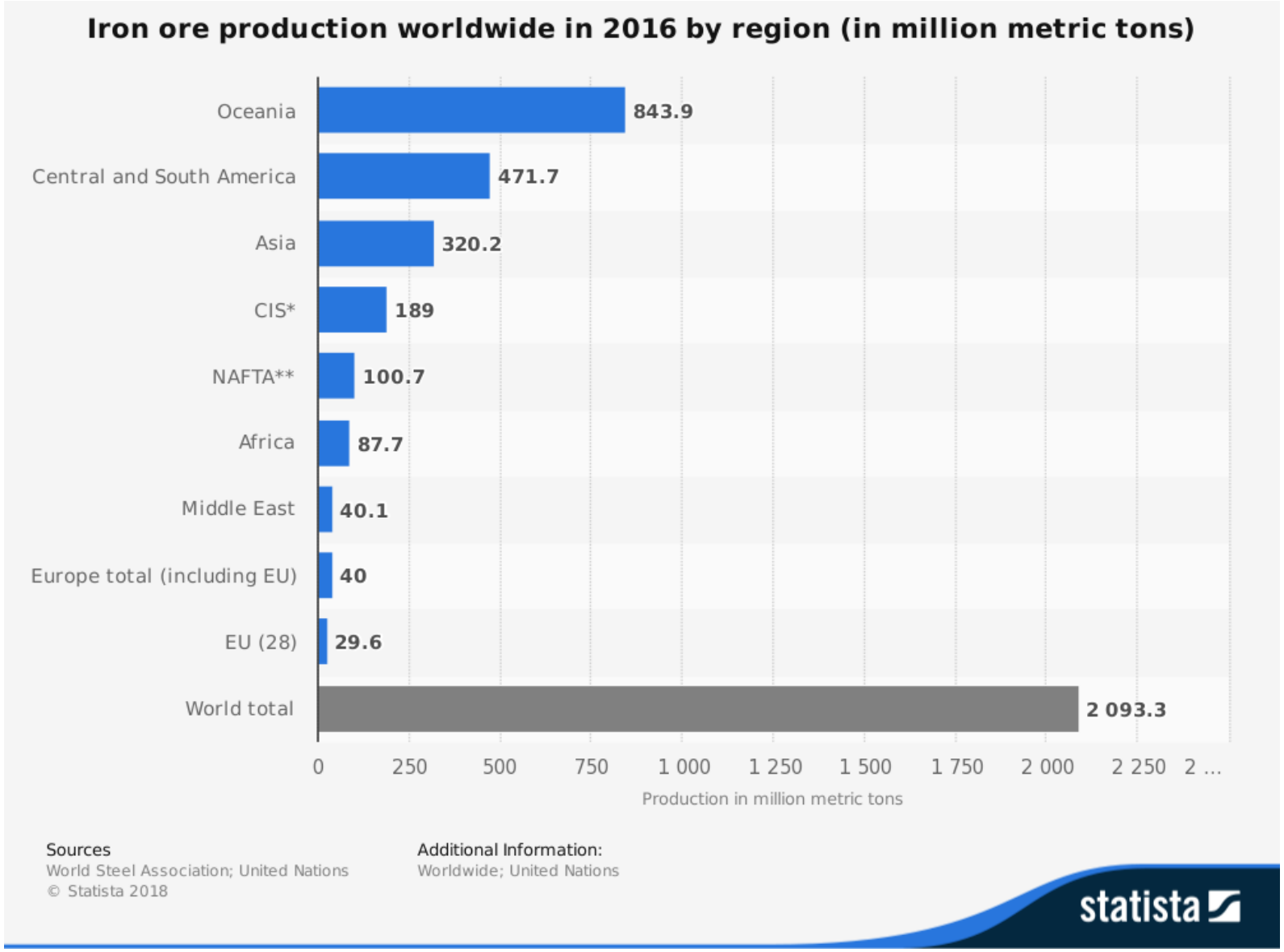
Rank	Z, element & symbol			Abundance in crust (ppm) by source					Annual production
				Darling[1]	Barbalace[2]	WebElements[3]	Israel Science and Technology[4]	Jefferson Lab[5]	(2016, tonnes)[6]
1	8	oxygen	O	466,000	474,000	460,000	467,100	461,000	
2	14	silicon [A]	Si	277,200	277,100	270,000	276,900	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	



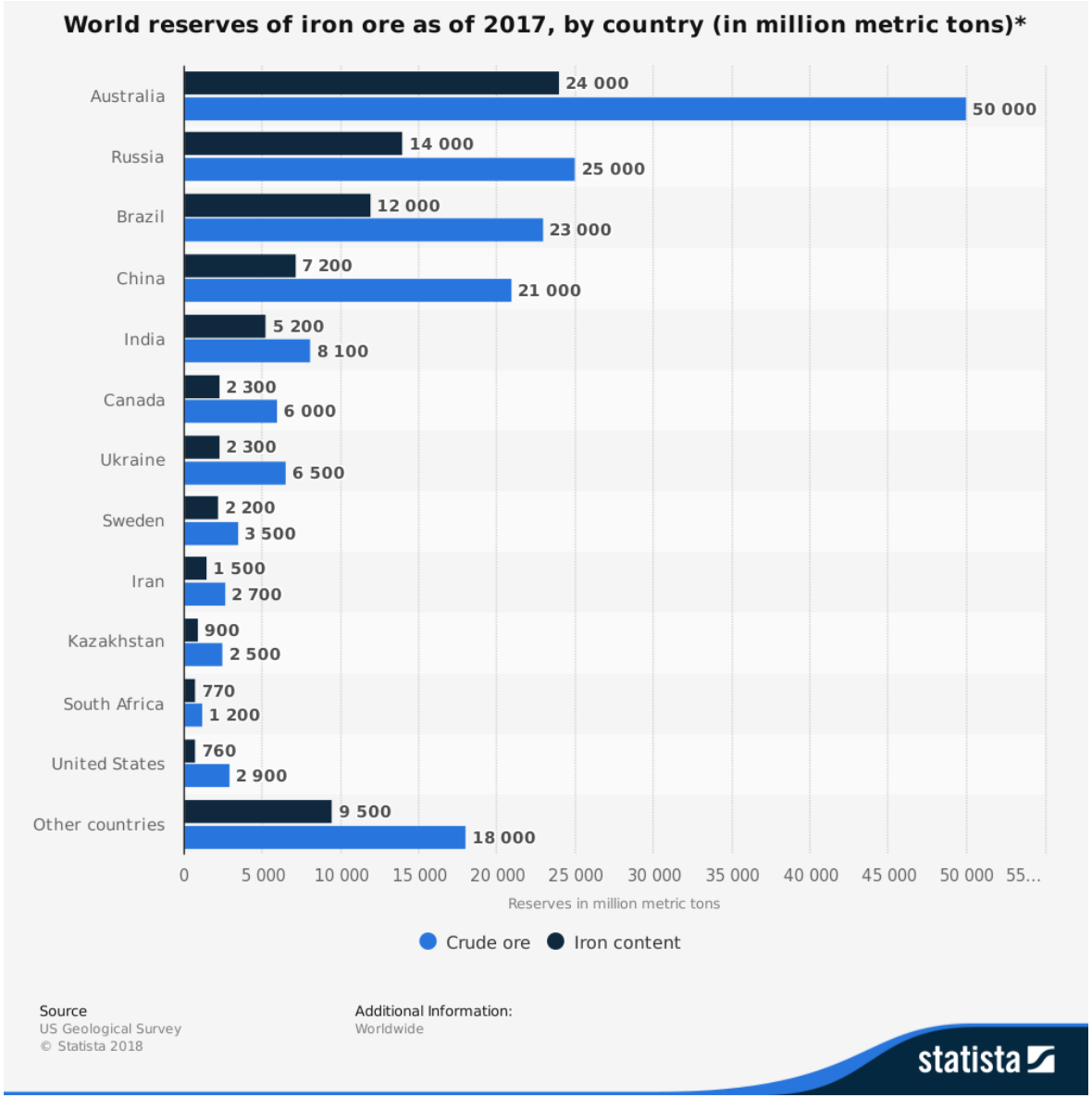
Abundance (atom fraction) of the chemical elements in Earth's upper continental crust as a function of atomic number. The rarest elements in the crust (shown in yellow) are not the heaviest, but are rather the siderophile (iron-loving) elements in the Goldschmidt classification of elements. These have 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

Already “up-scaled”

2015

2016

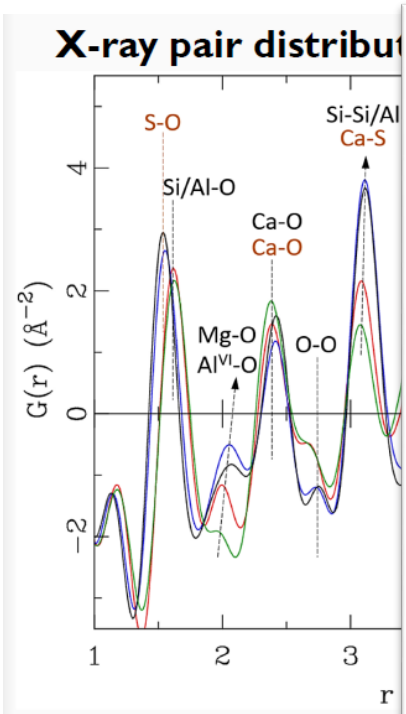
2018

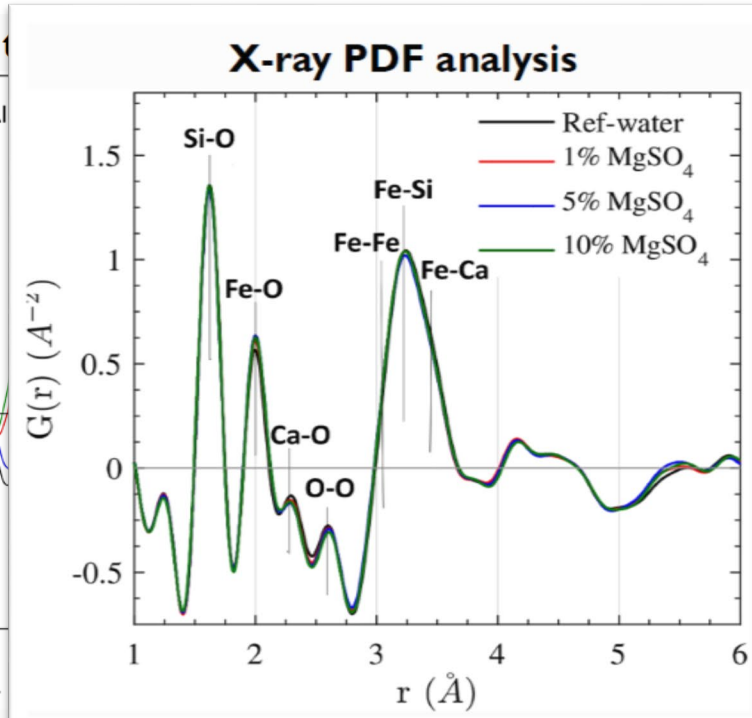
No Ordinary Portland Cement used

With unique properties

#	Precusor	Activator	$MgSO_4$ attack procedures
1	Ca-rich slag	NaOH	1. Cured all the samples at 23 °C for ~40-60 days 2. Crushed the samples into fine powders (d < ~1mm) 3. Immerse the crushed samples in different concentrations of **$MgSO_4$ solutions (i.e., 1, 5, 10 wt. %)** for 10 days (equilibration has reached [1])
2	Ca-rich slag	KOH	
3	**Ca-rich slag**	**Na_2SiO_3**	
4	Ca-rich slag	Na_2SO_4	
5	Ca-rich slag	Na_2CO_3	
6	Ca-rich slag	K_2CO_3	
7	50% Ca-rich slag +50% Metakaolin	NaOH	
8	50% Ca-rich slag +50% Metakaolin	KOH	
9	50% Ca-rich slag +50% Metakaolin	Na_2SiO_3	
10	**Fe-rich slag**	**Na_2SiO_3**	

K. Gong A. Peys, Y. Pontikes, C.E. White, X-ray Pair Distribution Function Analysis of the Chemically Induced Degradation in Alkali-activated Slags, MS&T 18, Columbus, Ohio

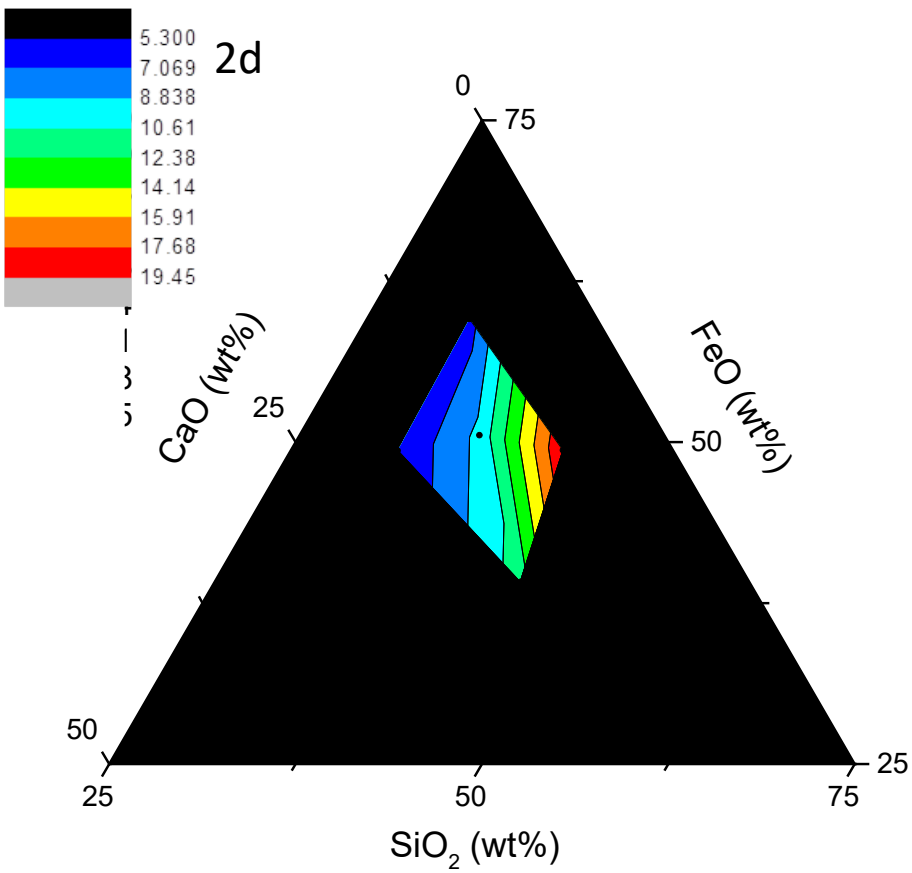


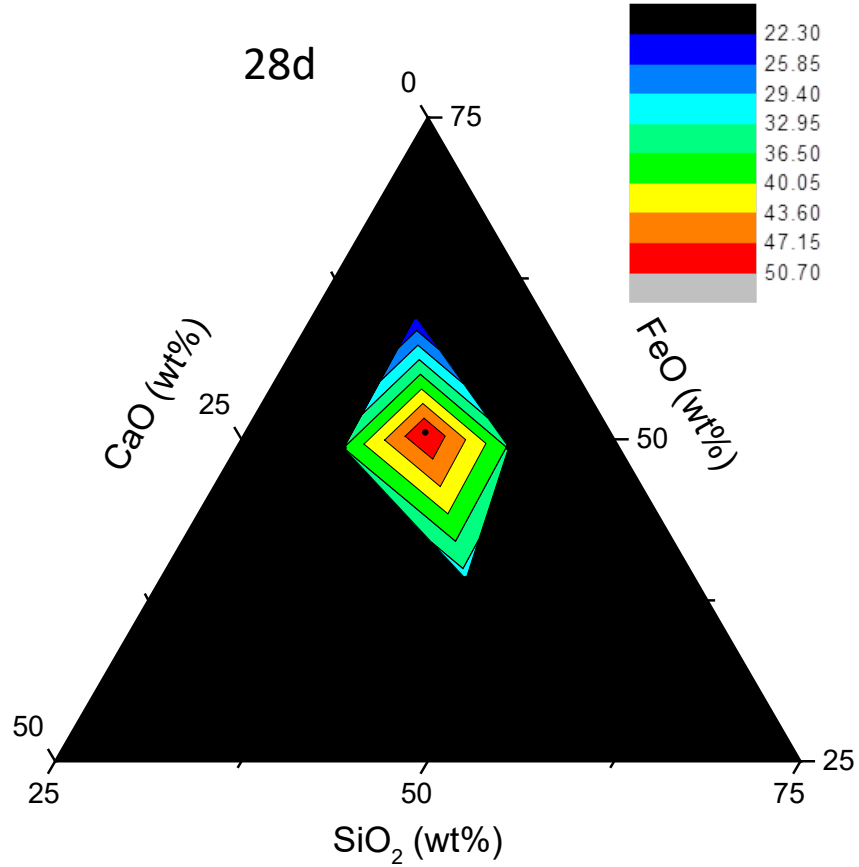


- No obvious changes to the local atomic structure after $MgSO_4$ attack

Na_2SiO_3-activated Fe-rich slag has superior chemical resistance to $MgSO_4$ attack

Well-defined





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

One day in the “standards”

Table 1 — The 27 products in the family of common cements

Main types	Notation of the 27 products (types of common 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	calca-reous				
			K	S	D [b]	P	Q	V	W	T	L	LL	
CEM I	Portland cement	CEM I	95-100	–	–	–	–	–	–	–	–	–	0-5
CEM II	Portland-slag cement	CEM II/A-S	80-94	6-20	–	–	–	–	–	–	–	–	0-5
		CEM II/B-S	65-79	21-35	–	–	–	–	–	–	–	–	0-5
	Portland-silica fume cement	CEM II/A-D	90-94	–	6-10	–	–	–	–	–	–	–	0-5
	Portland-pozzolana cement	CEM II/A-P	80-94	–	–	6-20	–	–	–	–	–	–	0-5
		CEM II/B-P	65-79	–	–	21-35	–	–	–	–	–	–	0-5
		CEM II/A-Q	80-94	–	–	–	6-20	–	–	–	–	–	0-5
		CEM II/B-Q	65-79	–	–	–	21-35	–	–	–	–	–	0-5
	Portland-fly ash cement	CEM II/A-V	80-94	–	–	–	–	6-20	–	–	–	–	0-5
		CEM II/B-V	65-79	–	–	–	–	21-35	–	–	–	–	0-5
		CEM II/A-W	80-94	–	–	–	–	–	6-20	–	–	–	0-5
		CEM II/B-W	65-79	–	–	–	–	–	21-35	–	–	–	0-5
	Portland-burnt shale cement	CEM II/A-T	80-94	–	–	–	–	–	–	6-20	–	–	0-5
		CEM II/B-T	65-79	–	–	–	–	–	–	21-35	–	–	0-5
	Portland-limestone cement	CEM II/A-L	80-94	–	–	–	–	–	–	–	6-20	–	0-5
		CEM II/B-L	65-79	–	–	–	–	–	–	–	21-35	–	0-5
		CEM II/A-LL	80-94	–	–	–	–	–	–	–	–	6-20	0-5
		CEM II/B-LL	65-79	–	–	–	–	–	–	–	–	21-35	0-5
	Portland-composite cement [c]	CEM II/A-M	80-94	<---------- 6-20 ---------->									0-5
		CEM II/B-M	65-79	<---------- 21-35 ---------->									0-5
CEM III	Blastfurnace cement	CEM III/A	35-64	36-65	–	–	–	–	–	–	–	–	0-5
		CEM III/B	20-34	66-80	–	–	–	–	–	–	–	–	0-5
		CEM III/C	5-19	81-95	–	–	–	–	–	–	–	–	0-5
CEM IV	Pozzolanic cement [c]	CEM IV/A	65-89	–	<---------- 11-35 ---------->					–	–	–	0-5
		CEM IV/B	45-64	–	<---------- 36-55 ---------->					–	–	–	0-5
CEM V	Composite cement [c]	CEM V/A	40-64	18-30	–	<-------- 18-30 -------->			–	–	–	–	0-5
		CEM V/B	20-38	31-50	–	<-------- 31-50 -------->			–	–	–	–	0-5

a The values in the table refer to the sum of the main and minor additional constituents.
b The proportion of silica fume is limited to 10 %.
c In Portland-composite cements CEM II/A-M and CEM II/B-M, in pozzolanic cements CEM IV/A and CEM IV/B and in composite cements CEM V/A and CEM V/B the main constituents other than clinker shall be declared by designation of the cement (for example see clause 8).

Because blended cements are also possible!

The best mix is 70 wt% NFMS, 10 wt% GGBFS, 10 wt% of OPC, 8 wt% of ultrafine limestone filler, 0.9 wt% of NaOH, 0.8 wt% plastisizer and 0.3 hemihydrate.
The 1 D, 7D and 28 D compressive strength after ambient curing was respectively 20, 41 and 61 MPa.

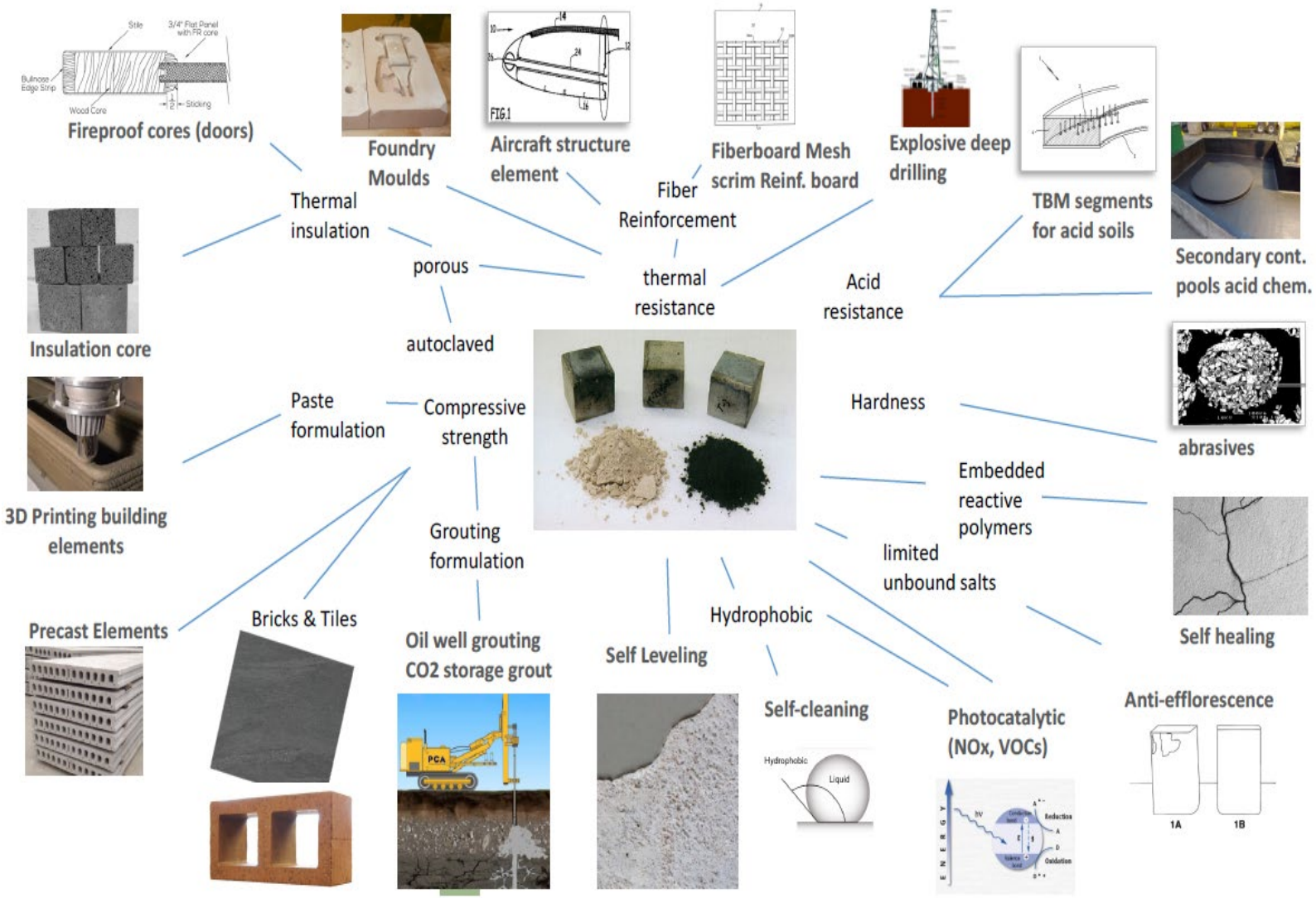
	Cost / ton (€)	CO_2 / ton (kg)
Hybrid	70	76
WG activated NFMS	98	256
CEMI W/C 0.5	74	570
CEMIIIa W/C 0.4	70	285

L. Arnout et al; submitted

And where binder is just one of the options

Data mining: Inorganic Polymers Patent Mapping

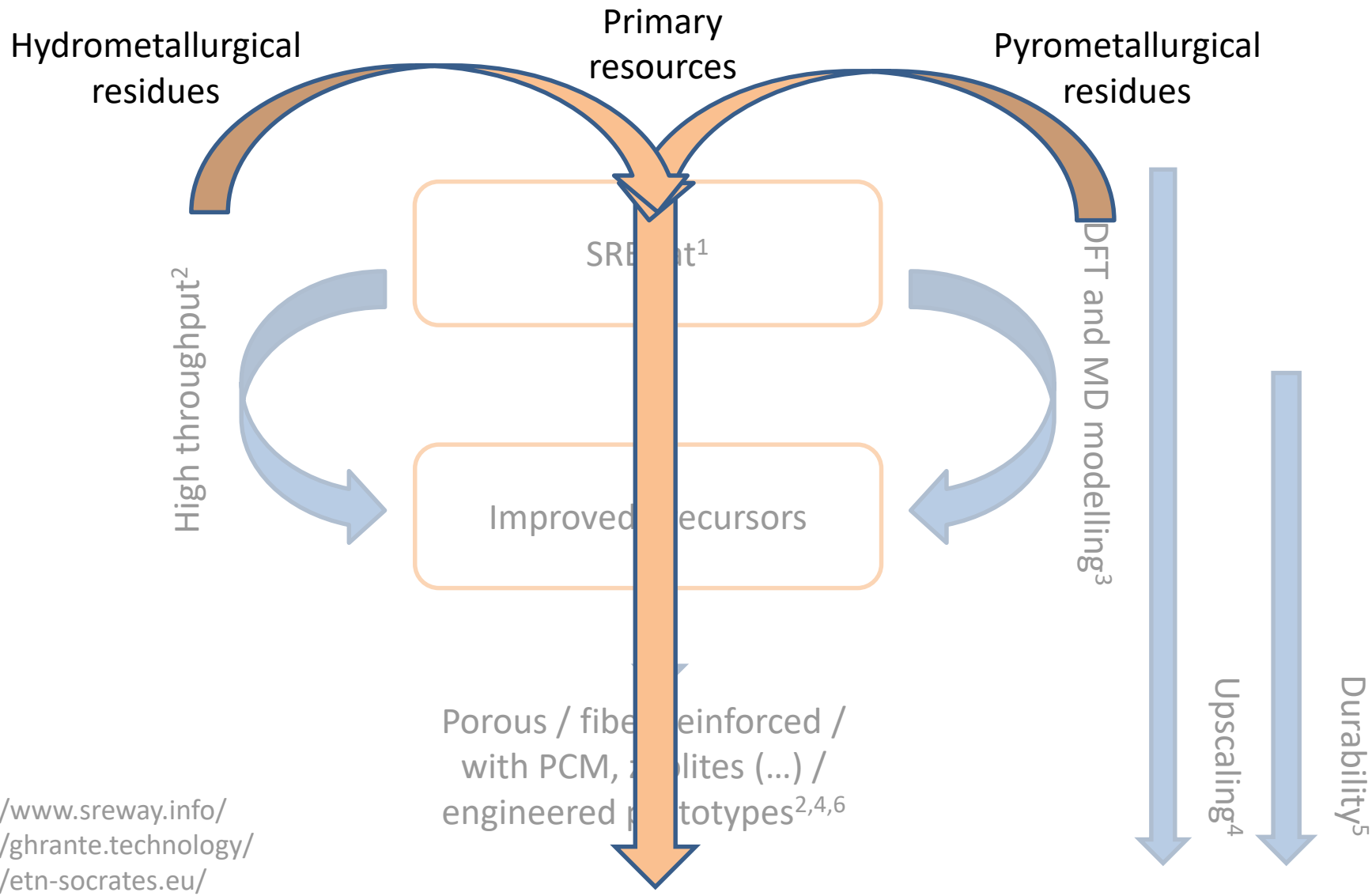
Main Functionalities and Applications



Chapter 4

Coming up

Coming up



[1] https://www.sreway.info/
[2] https://ghrante.technology/
[3] https://etn-socrates.eu/
[4] https://recover.technology/
[5] https://www.removal-project.com/
[6] https://new-mine.eu/

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Thank you!