Inorganic Waste Upcycling: The lessons learned, and the outlook for the future

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From the Glass processing department

Current issues of Upcycling: Where are we at?

Points of success for upcycling[1]:

1) **Reasonable distance** between resource-processing facility

2) Steady **available waste streams** (chemically/by amounts)

3) **Legislation** opening possibility for upcycled products to enter market/existence of subsidies for market to be interested into novel technology

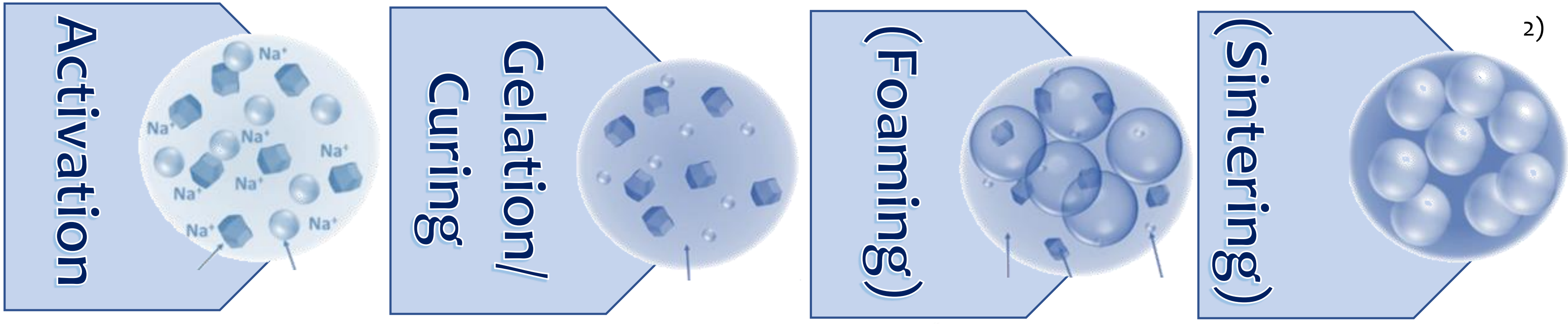
Cooperation with industry? Communication? Comittment?

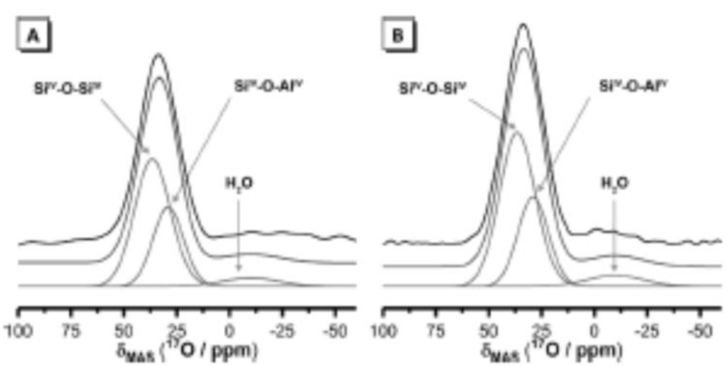
Advantage of Slovakia: legislation is not rigidly set, as it is so in other countries: by the template of other countries (Romania/Ukraine) this could be seen as the advantage for easier implementation of novel construction materials based on wastes

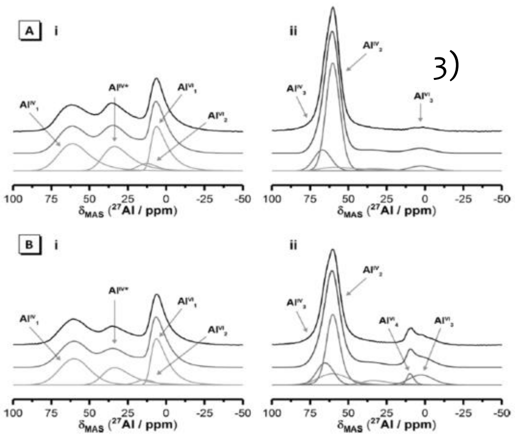
1 Huang et al 2020

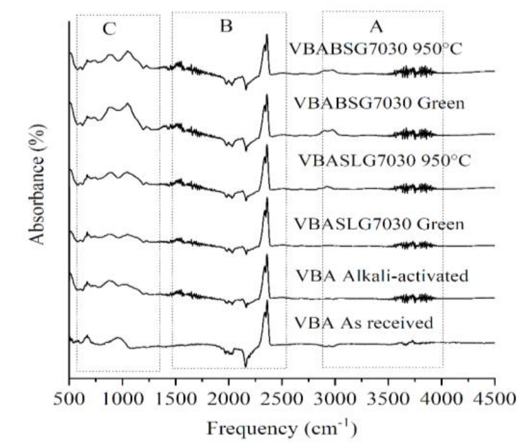
Strategy of inorganic waste upcycling at UNIPD: Alkali-activation

✓ Inexpensive ✓ Safe ✓ Ecological ✓ Employs unlimited amounts of waste









2) Wonderful Graphics courtesy N. Toniolo et al 2018 3) NMR spectra from Walkley et al 2018

Inorganic Waste Upcycling - Issues

Mineralogy

- Amorphous & crystalline
- **Crystallization control**
- XRD
- **Surface effects** (SEM)

Chemistry

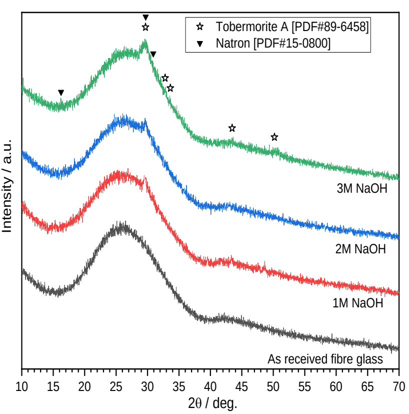
- Si/Al ratio?
- Pollutants **identification**
- XRF
- Characterization of bonds (NMR, FTIR)

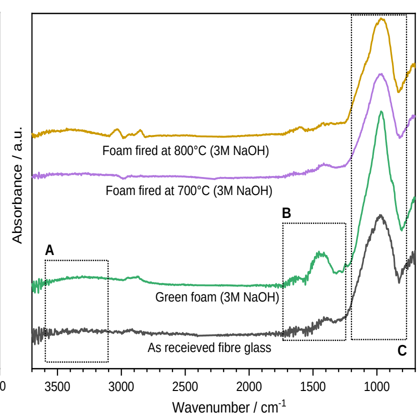
Feasibility

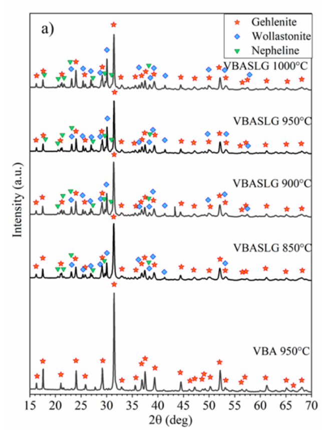
- **Low** T&conc.
- **High waste loading** in material
- Alkali-activation strength/time-temperature regimen

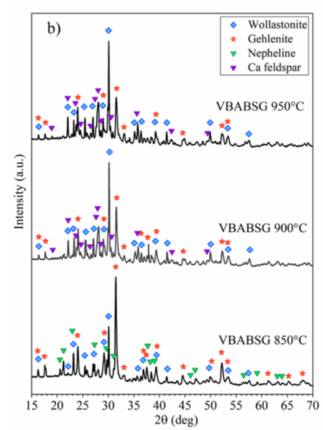
Durability

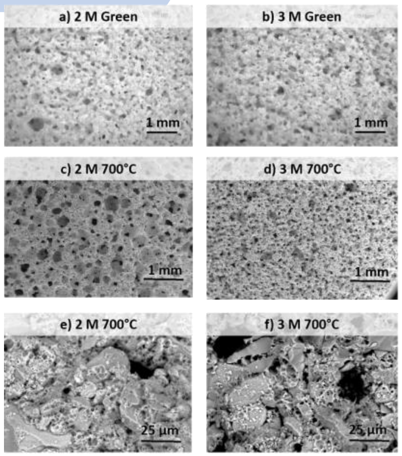
- EC standards
- Immobilization of polutants for **inert material** standards
- Corrosion tests& ICP-OES











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Inorganic Waste Upcycling (Examples)

Cullets

Fly/Bottom Ashes

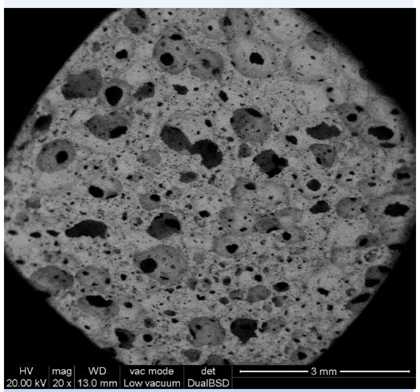
Slags

Mixed together

Alkali-activation (from 0 – 8 M NaOH solution)

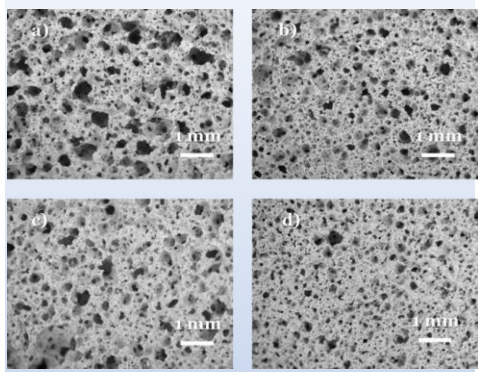
Cullets

- ✓ Mechanical properties
- ✓ **Safety&Durability**
- ✓ Low procesing T



Fly/Bottom Ashes

- ✓ Immobilization of polutants
- ✓ **Versatile utility** (from bulk to foams)

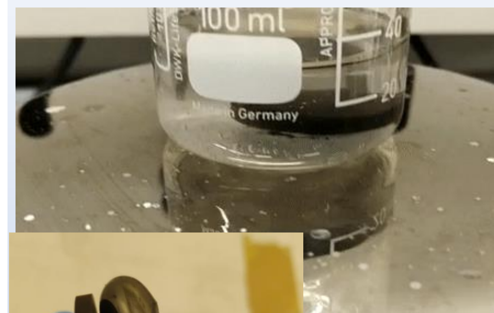


Slags

- ➢ Similar to **Portland Cement**
- ➢ Immediate curing/high speed of curing

Mixed together

- ➢ Vitrification utilization
- ➢ High amounts of Fe in some wastes = **Functionalization**



Glass-ceramic foams from cullets only

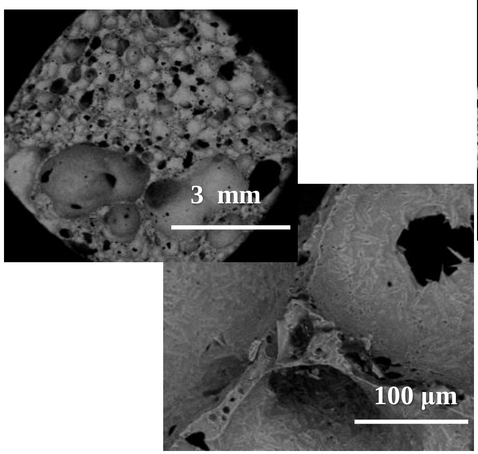
Secondary Foaming

- 2.5 M NaOH
- Soda-lime cullets
- T 850°C
- 0-6 wt.% of $CaCO_3$

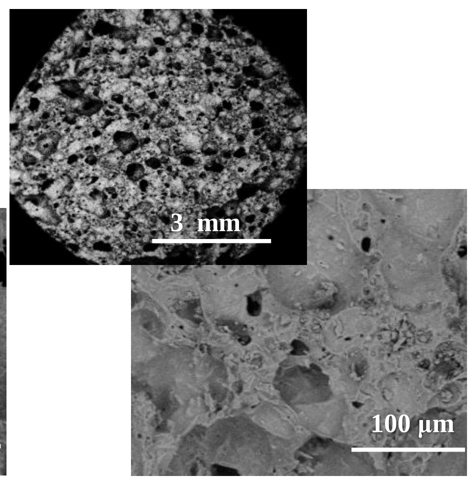
I.) What is **the best result**?
II.) Can we **replace activating solution**?

Can we make glass-ceramic foam based just on the **waste streams**?

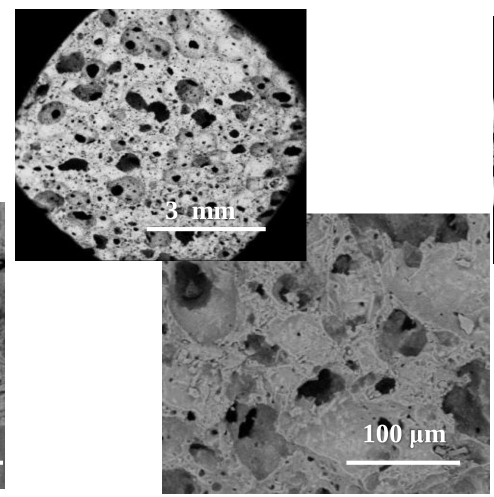
No $CaCO_3$



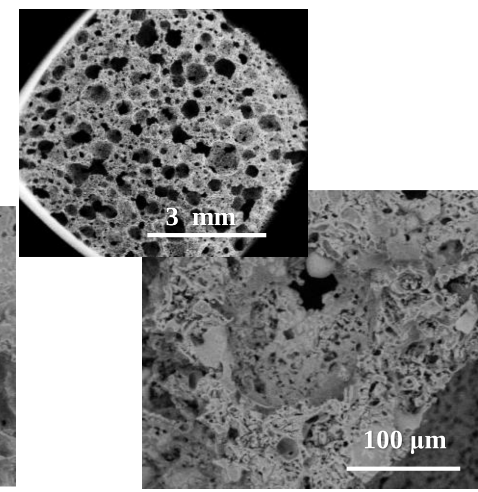
2wt.% $CaCO_3$



4wt.% $CaCO_3$



6wt.% $CaCO_3$



- ✓ Strongest foams @ 4wt.% (217 MPa in Crushing strength)
- ✓ Porosity up to 80% share of opened porosity grows with the addition of $CaCO_3$

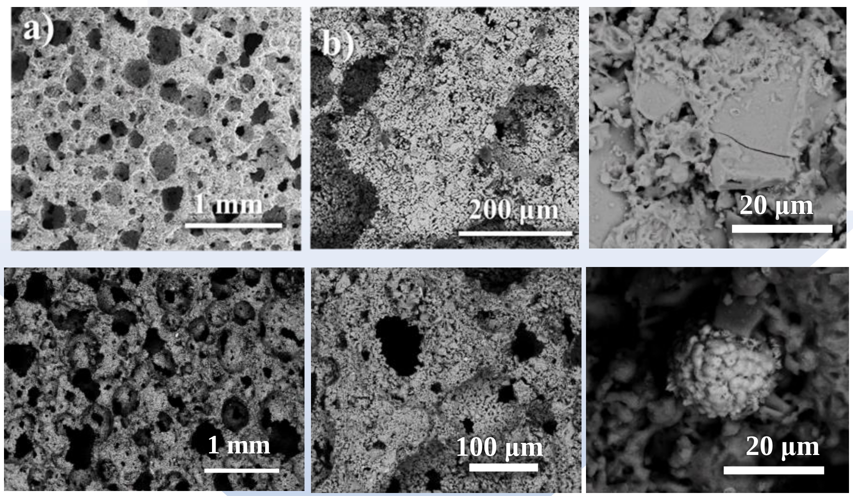
Glass-ceramic Foams from Vitrified Bottom Ash from Bratislava

- R 70/30
- 2.5 M NaOH
- T range 850-1000°C
- ↑10 K/min – ↓5 K/min

Soda-lime-silica glass

SLG 900 °C

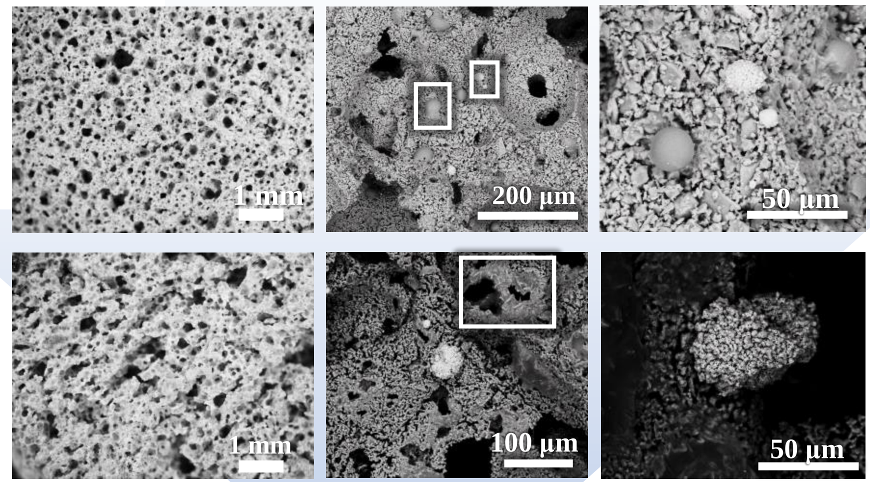
SLG 1000 °C



Alumina-Borosilicate glass

BSG 850 °C

BSG 950 °C

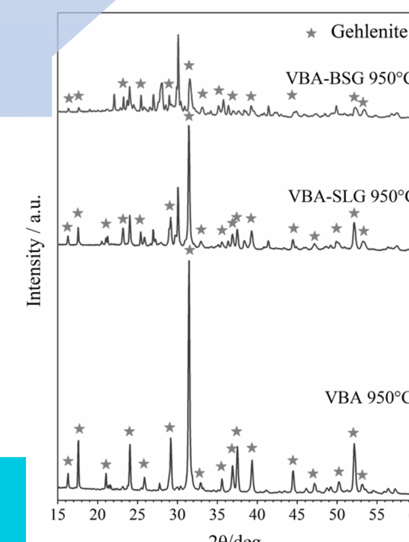


Leaching tests

- ✓ **Inert** except VBASLG @ 900°C
- ✓ Increasing temperatures supported **inclusion of Cr^{3+}** into gehlenite s-s
- ✓ At lower temperatures Cr^{3+} remains in amorphous phase

Mechanical tests

- ✓ Bending strength **exceeds 100 Mpa**
- ✓ SLG foams were weaker
- ✓ Effect of **amorphous phase**?
- ✓ Different mineralogy for BSG: less gehlenite, more feldspathoids

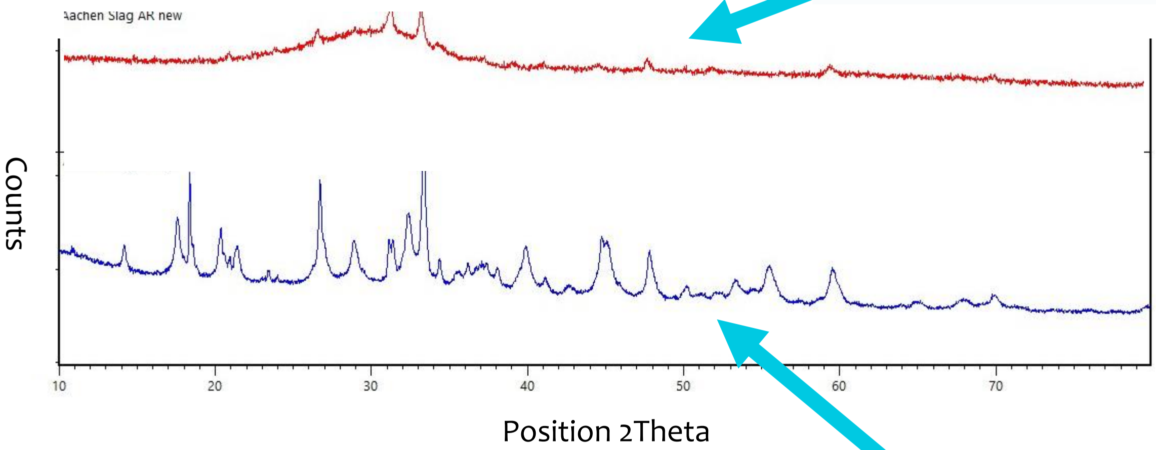


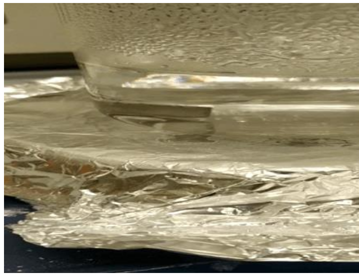
Smelting, Gehlenite glasses and possible solutions for fly ashes?

Smelting: separation of metals from a mineral slag

✓ Leftover: the mineral slag

Slag as received





? Leaching of Cr and Mo

? Mechanical properties (material is fairly weak) around 7-9MPa in flexural strength

Slag activated with water after 7 Days

- ✓ CaSH phase: Vertumite; Katoite; Gismondine
- ✓ Perovskite; Quartz
- ✓ Mechanism similar to that of amorphous gehlenite – like glasses in the reaction with water (Corning Patent)

Possible extraction of other toxic and heavy metals (Cr, other volatiles such as Se?)[4] into ferrous melts

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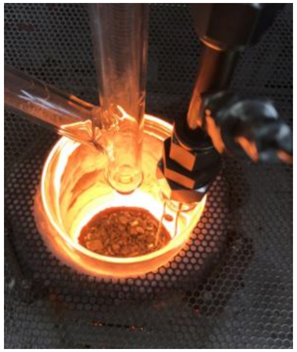
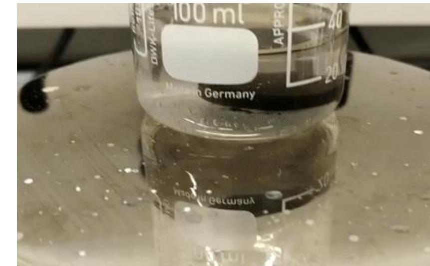
Vitrification – possible solutions for non-nuclears?



Safest and (probably) most expensive strategy

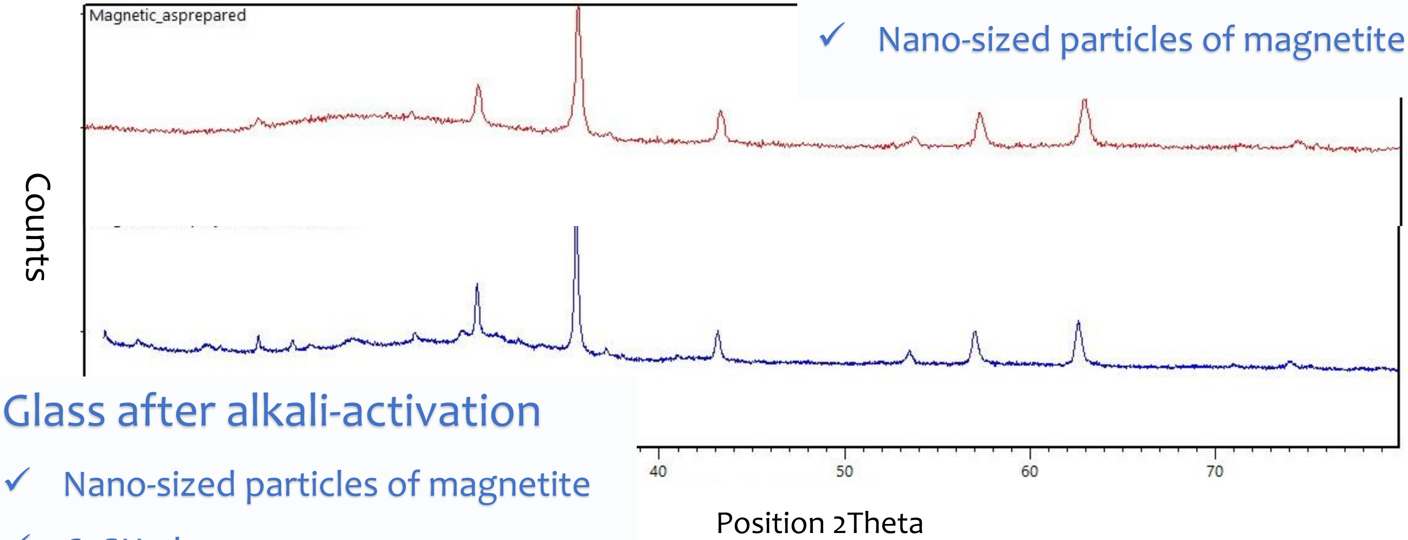
Fly Ash + Red Mud + SLG cullets

1. Step: simulation of composition + alkali-activation (8M NaOH)
2. Actual wastes melting + alkali activation (8M NaOH)



Glass after melting

- ✓ Nano-sized particles of magnetite



Glass after alkali-activation

- ✓ Nano-sized particles of magnetite
- ✓ CaSH phases

- Good flexural strength (up to 15 Mpa)
- Leachability? Mo remains above treshold for inert materials
- Functionalization? Shielding? Magnetic properties?

- ✓ Hard Work?
- ✓ Broken samples?
- ✓ Polishing to precision?
- ✓ Burns from caustics?

It is worth it for a decent publication.

But

Should we stop there?

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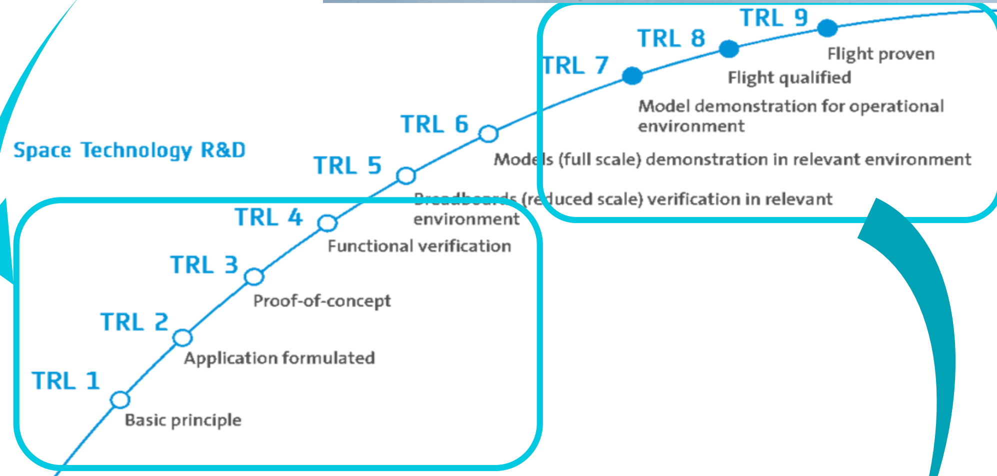
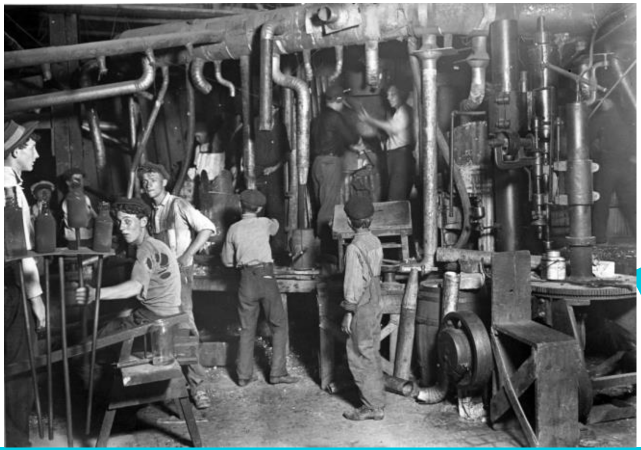
Where to go from here?

- Results either were or are about to be published in good journals
- Strategies we found are promising for further elaboration/extension to other inorganic wastes
- But how do we move on the TRL scale?
- Is maximization of waste implementation in upcycled product having only benefits?
- LCA? Game models? Sustainabilty via MFA?





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Lets talk!

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