Steel slag wastes to fight the climate change

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BALTIC CARBON FORUM

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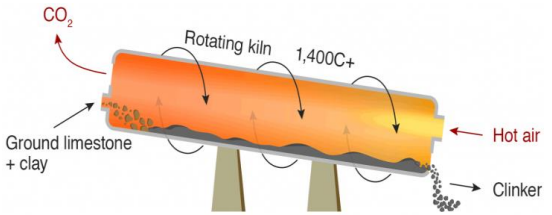
Overview

- Current problem in this field
- Summary of ongoing funded project
- Progress so far
- Outcomes
- Way Forward

Production of cement – problem & solution

- The cement industry continues to have a large impact on industrial development.
- Cement production are responsible for the *CO_2 emission* worldwide (5-8%).
- Example: Ordinary Portland Cement (OPC)



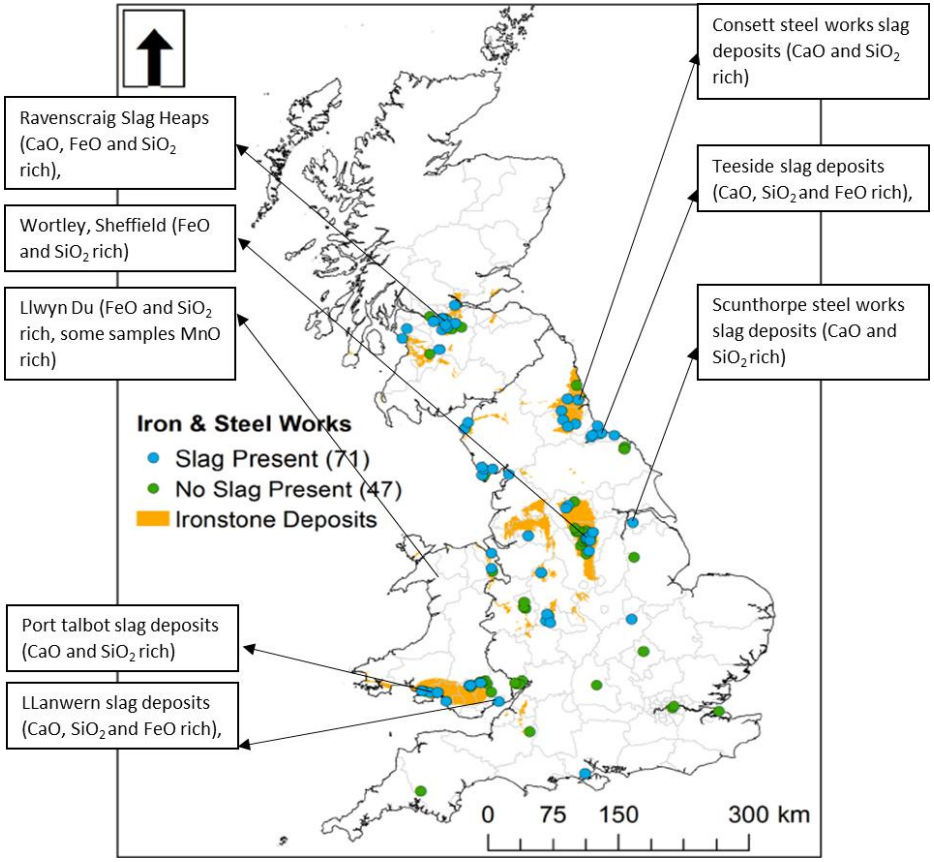
$$5CaCO3 + 2SiO2 \rightarrow (3CaO,SiO2)(2CaO,SiO2) + 5CO2$$

Problem !!

- Solution:
  - ✓ *Geopolymer technology*
    - *No heat requirement*
    - *Cost effective*
    - Reducing CO_2 emissions

Project summary

- **Project name:** Mevocrete
- **Funding body :** Innovate UK
- **Partners :** 10 Industrial partners + TU
- **Total Fund :** £7.6 M
- **Project duration :** 2 Years
- **Aim:** up-scaled on-site facility for geopolymer cement production from historical steel slag waste (85% lower CO_2 emissions of OPC - Ordinary Portland Cement).



Availability of Steel slag in the UK

Innovate UK
MATERIAL EVOLUTION
Teesside University
Geocast ltd
Playfair Capital LLP
LKAB
ZTL TECH manufacturing your ideas
Materials Processing Institute
CELSA GROUP
CELSA STEEL UK
Enursan ltd
NANOMOX
retaining ltd

Overall plan

600 kg slag/ ton of steel

Characterisation of raw materials

Selected samples based on geopolymer/CO_2 sequestration/heavy metal aspects

- ✓ Geopolymer: Al, Si
- ✓ CO_2 sequestration: Ca, Mg

Production of geopolymer cement

- ✓ Selected materials
- ✓ Alkaline solution: silicate & hydroxide

Geopolymer cement curing

- ✓ Injection of water and carbon dioxide

Chemical and physical properties of concrete

- ✓ Strength and durability properties

CO_2 absorption in concrete

Material Evolution innovation

Geopolymer

Metal Recovery

CO_2 sequestration

Raw materials + alkaline activator = Geopolymer cement

Geopolymer cement

Drying/Grinding geopolymer cement to powder form

Verified Carbon Unit Generation

Fundamental info about steel slags

Sample ID	CO2 Sequestration (kg CO2/Ton of Slag)
Blast Furnace Slag (BFS)	473.9592987
Electric Arc Furnace Slag (EAF)	471.5718789
Basic Oxygen Furnace Slag (BOF)	407.4192221
Ladle Furnace (LF) Slag	403.4953633
Stainless Steel Slag	317.667038
Converter Slag	450.416146
Granulated Blast Furnace Slag (GBFS)	226.9217185
Steel Slag Aggregates	383.8760695
Steel Slag Fines	282.3523091
Slag Wool	356.9056258

$$R_{CO2} = \frac{M_{CO2}}{100}\left(\frac{\%CaO}{M_{CaO}} + \frac{\%MgO}{M_{MgO}}\right) \times \omega$$

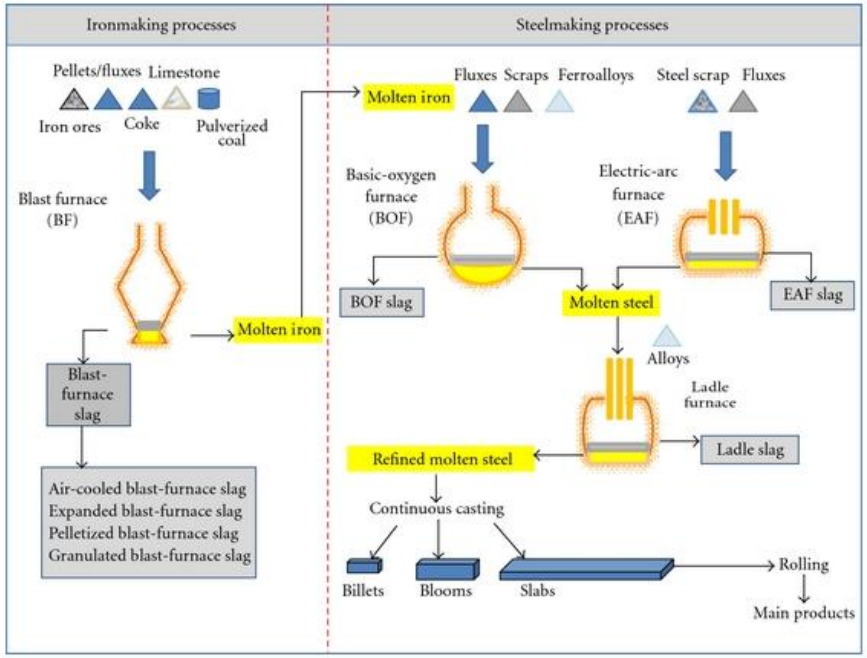


Fig.1 Iron and Steel Making Processes and Steel Slag Types (Yildirim and Prezzi, 2011).

Slag Type /Components	CaO	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	MnO	P_2O_5
BOFs	45-60	10-15	1-5	3-9	7-20	3-13	2-6	1-4
EAFS	30-50	11-20	10-18	5-6	8-22	8-13	5-10	2-5
LS	30-60	2-35	5-35	–	0-15	1-10	0-5	0.1-0.4

Table 1. Chemical Composition of Steel Slags (Cheng et al, 2012 and Shi, 2004)

Current State of steel slag wastes

- The **global production of steelmaking slag** is estimated to be in the order of **170 million to 250 million tonnes per annum.**

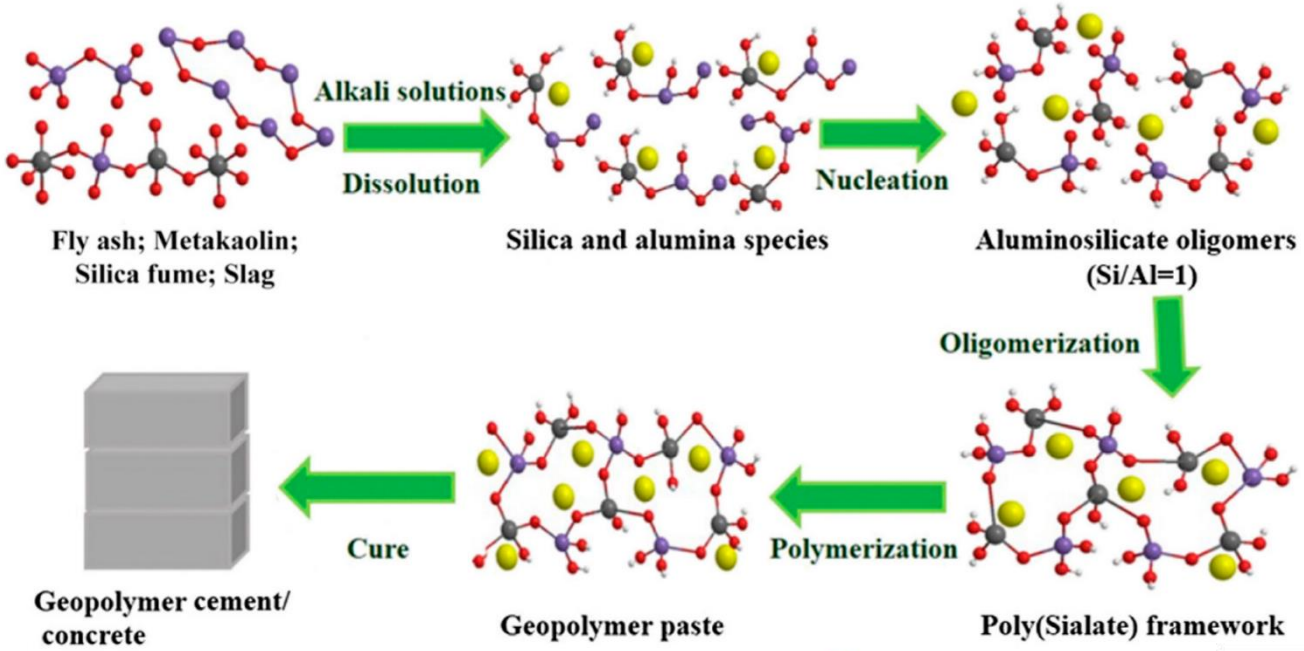
- Low quality GGBS, BOS (Basic Oxygen Furnace) etc.) and much of it ends up in lagoons, slag piles or landfill. It is estimated that there are 190million tonnes of legacy slag in the UK alone.

- PFA (Pulverised Fuel Ash) and only high-quality GGBS (Ground Granulated Blast-furnace Slag) can be used in the production of hybrid cement (OPC mixed with slag) and geopolymers (slag mixed with alkaline activators),

- A CO2 sequestration capacity of 0.27 to 0.43 kg CO2 per kilogram of slag stored as a mineral carbonate is achievable

What is Geopolymer technology/ feedstock and requirement

- Geopolymers are essentially a family of alumino-silicate materials.
- Geopolymers make it possible to produce ceramic-like materials without the need for high-temperature techniques as a replacement material for cement.
- Waste materials like steel slag, fly ash,… - as replacement material for the production of cement.

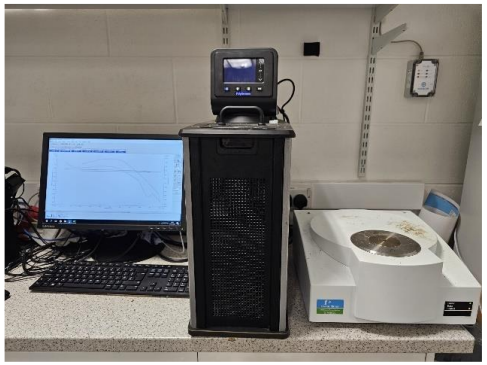


Laboratory work – methods

- Quantitative analysis (indicating CO_2 sequestration)

Calcimeter

TGA



- Qualitative analysis

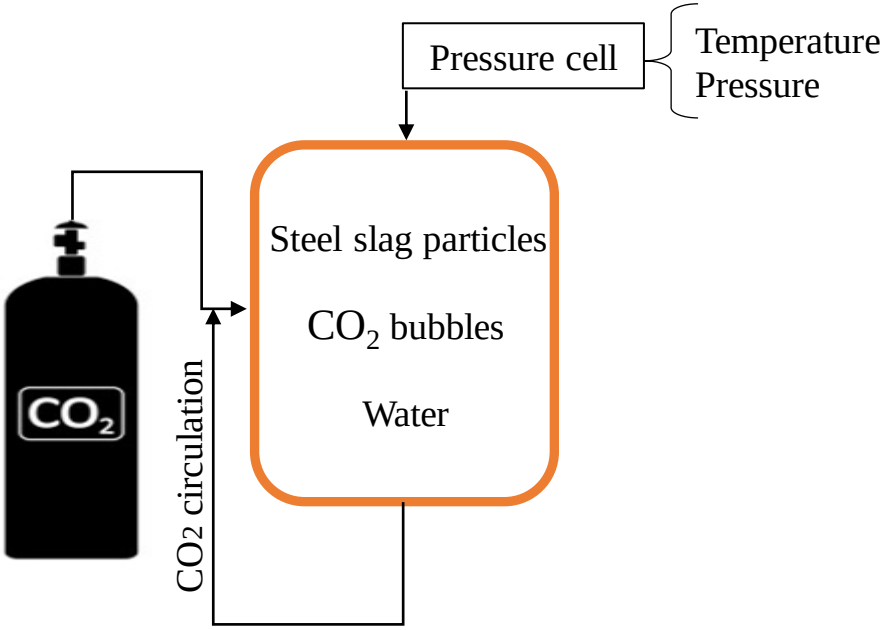
SEM

FT-IR

XRD

Carbonation setup for CO_2 sequestration!

- Mixing the steel slag waste with water in the presence of CO_2
- Analysing the effects of different conditions (Temperature, pressure, particle size, and etc)
  - ✓ Optimal condition for maximising CO_2 sequestration

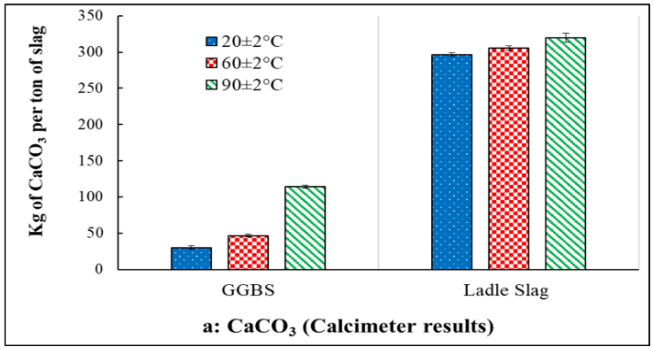


https://www.cemnet.com/Articles/story/175525/geopolymer-cements-to-address-the-ghg-challenge.html

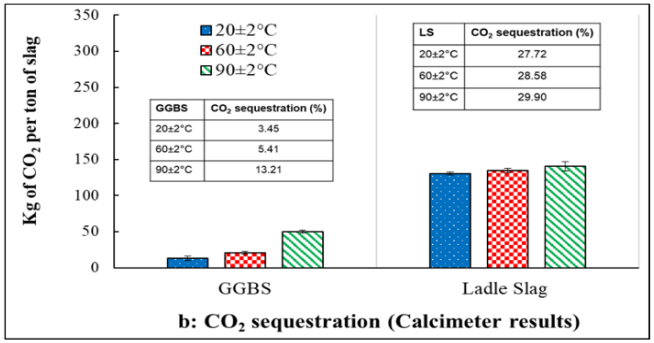
(https://www.iom3.org/resource/holding-the-fort-the-potential-for-mineral-carbonation.html)

Main outcomes

Quantitative analysis



Calcimeter results



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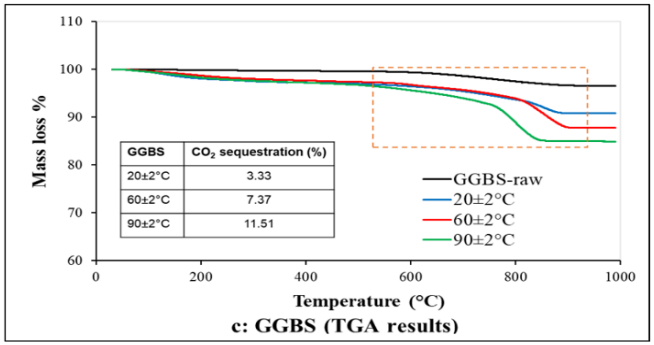
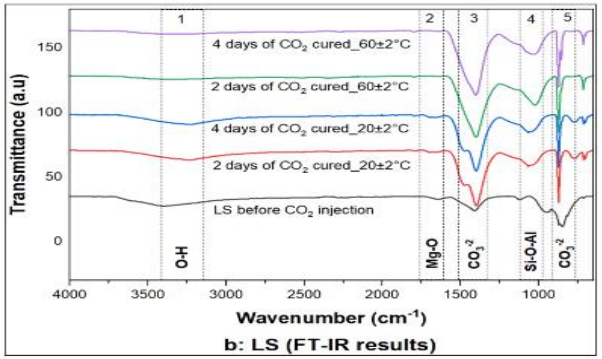
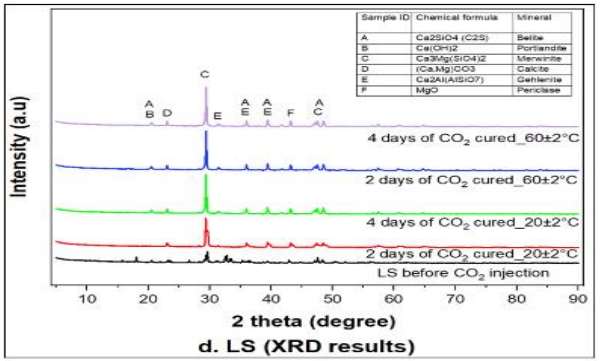


TGA results

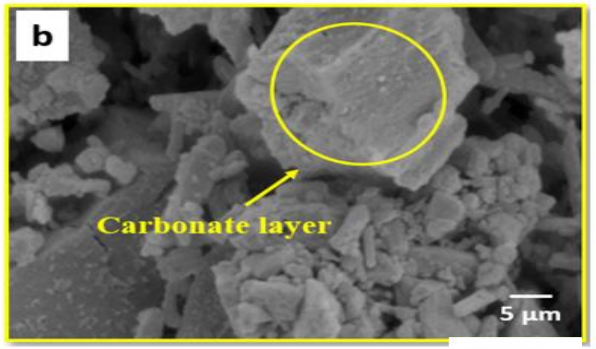
Qualitative analysis



FT-IR results

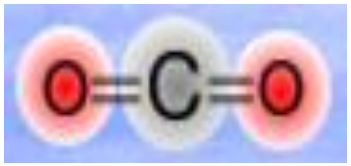


XRD results

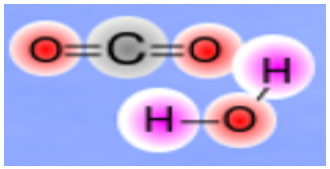


SEM results

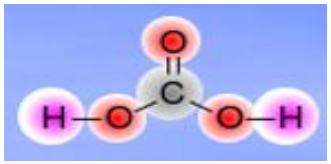
Proposed mechanism of the carbonation process for geopolymer cement



Carbon dioxide



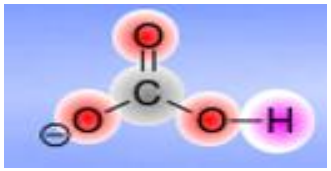
Water and Carbon dioxide



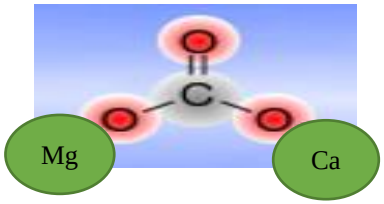
Carbonic acid

Mg
Ca
Fe

Steel slag



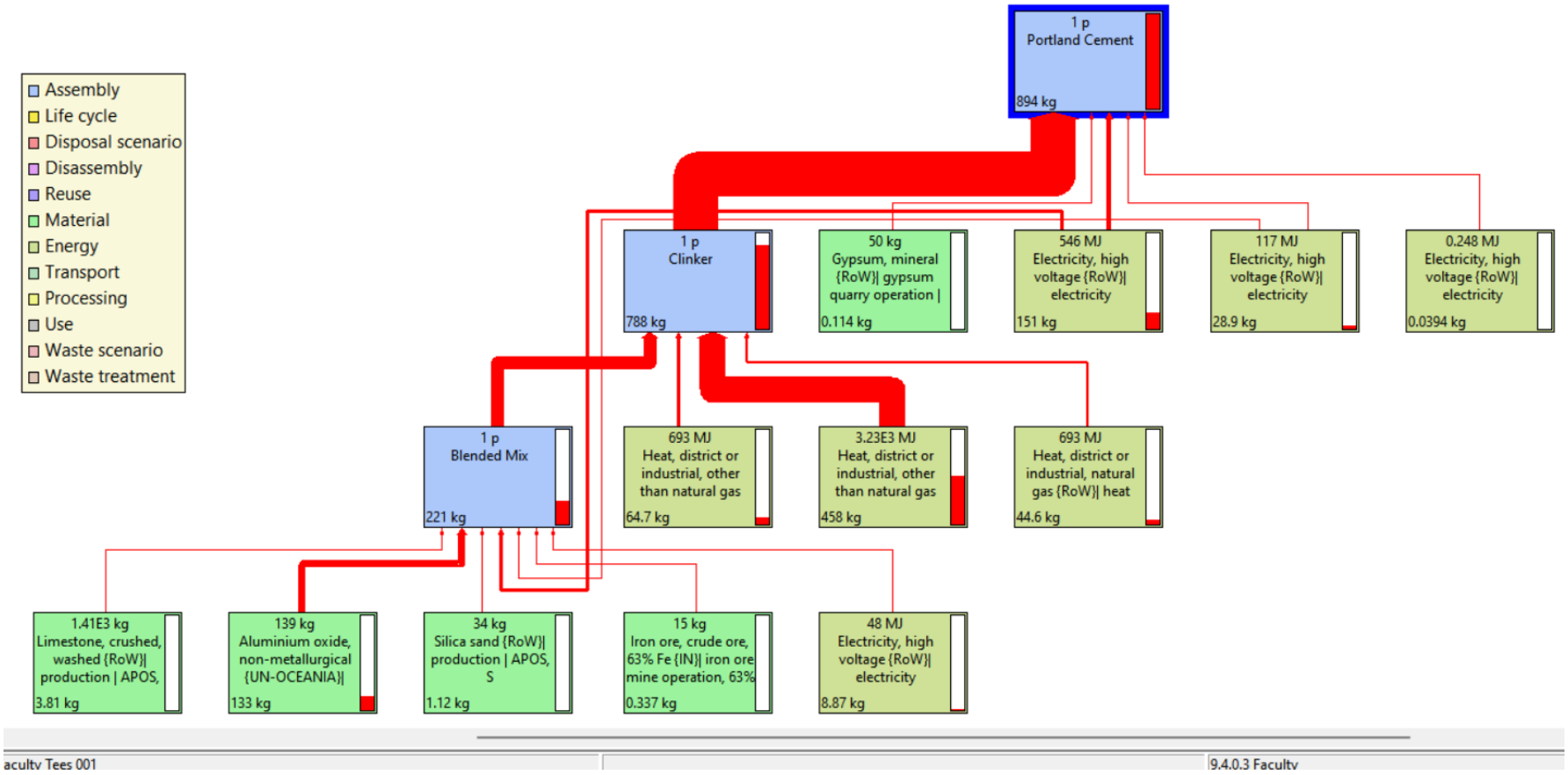
Biocarbonate



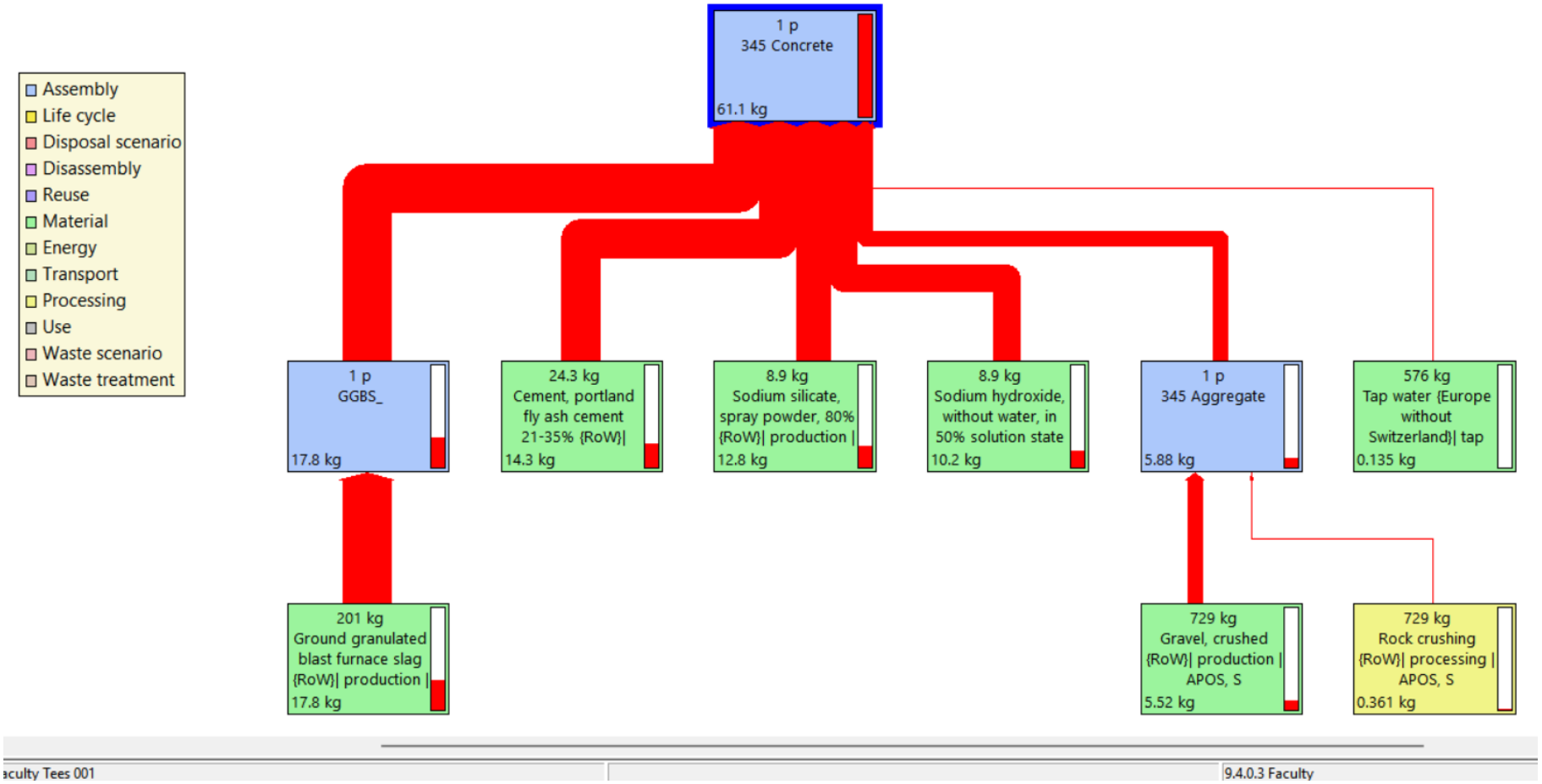
Carbonate mineral

$CaCO_3$
$MgCO_3$
$FeCO_3$

Early stage , LCA – OP - Cement



Early stage - LCA – GP Concert



Innovate UK

MATERIAL EVOLUTION

Teesside University

Geocast ltd

Playfair Capital LLP

LKAB

ZTL TECH manufacturing your ideas

Materials Processing Institute

CELSA GROUP

CELSA STEEL UK

Enursan ltd

NANOMOX

retaining ltd

Way Forward

- Using steel slag waste materials for CO_2 sequestration / Demonstration plant with 96 t/day by 2025
- Optimal conditions for maximizing CO_2 capture (Mineral mix + curing conditions)
- Capturing **300-400kg** of CO_2 per tonne of steel slag (Required sophisticated technique to reach to this ideal CO2 capture and storage)
  - ✓ Quantitative analysis: Calcimeter, TGA
  - ✓ Qualitative analysis: SEM, FT-IR, XRD
  - ✓ Stress-strain for innovated Geopolymer (with steel slags)
- Product Accreditation by British Standard for Final product

Acknowledgment - Contact Information

- This work was supported by the Mevocrete project through UK Research and Innovation (**UKRI**), which was a collaboration with nine other industrial partners. We thank to **Material Evolution** for providing the samples that were used in this study.
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Thank
you