

# Reclaiming Mining and Industrial Waste for Use in Green Building and Metal Recovery

Annual Baltic Carbon Forum 2025

Mai Uibu (Tallinn University of Technology, R-S OSA Service OÜ)

Can Rüstü Yörük, Adheena Thomas, Ademola Michael Adegbile  
(Tallinn University of Technology)

# Layout

- TEM-TA87
- Waste-based and carbonate-based building materials
  - Motivation
  - Objectives
  - Results
- Deposited oil shale ash as a raw material for precipitated calcium carbonate - OSA project
  - Objectives
  - Raw material crisis
  - Laboratory testing
- Main challenges
- Acknowledgements

## TEM-TA87

# Complex recovery of mineral mining and industrial waste as secondary raw material in the context of eco-conscious building materials and hydrometallurgy

Societal and economic pressure for new waste-free and CO<sub>2</sub>-neutral technologies remains high.

**In the context of modern raw material security, the landfills of the past must become the resource deposits of the future.**

**The aim** - comprehensive valorization of mineral waste streams, which will be achieved through the development of waste-based construction materials and critical raw material resources, as well as the reduction of carbon footprint using carbonation technologies.

**Expected outcomes include foundational and applied knowledge for:**

- Valorizing local mineral industrial waste into lightweight construction materials based on required technical properties such as strength, thermal insulation, soundproofing, durability, environmental indicators, and CO<sub>2</sub> binding.
- Integrating optimized extraction solutions for low-Mg content (4–6% MgO) raw materials into a potentially waste-free valorization complex for ash hills, in the context of critical raw material resources.



**Kaasrahanud  
Euroopa Liit**



**Eesti  
tuleviku heaks**



# Waste-based and carbonate-based building materials

## 🗑️ Waste-Based Building Materials

These are materials made by repurposing industrial, agricultural, or municipal waste. The goal is to reduce landfill use and environmental impact while creating useful products.

### Benefits:

- Reduces raw material consumption.
- Diverts waste from landfills.
- Often lighter and more insulating.

## 🗑️ Carbonate-Based Building Materials

These materials incorporate **carbonation processes**—where CO<sub>2</sub> reacts with calcium or magnesium compounds to form stable carbonates. This can either:

1. **Capture CO<sub>2</sub>** during production (carbon-negative or carbon-neutral).
2. Use naturally occurring carbonates or **carbonated materials**.

### Benefits:

- Reduces carbon footprint.
- Can sequester CO<sub>2</sub> permanently.
- Enhances durability and strength in some cases.

# Motivation

- ~600 million tons of landfilled oil shale ash<sup>2</sup>
- Illite-dominant and mineralogically heterogeneous clays (2:1) have underexplored and often considered limited.<sup>1</sup>



- $\text{CaCO}_3$  -  $\text{CaMg}(\text{CO})_3$
- $\text{CaO}$  - Portlandite
- $\text{C}_2\text{S}$  and other Ca-Mg silicates
- $\text{CaSO}_4$  - Ettringite - Anhydrite



1- Ragn-Sells' Way of Solving the Oil Shale Ash Quest in Estonia. Ragnsells.com. Published 2019. <https://www.ragnsells.com/about-us/press-media/articles/oil-shale-ash-in-estonia/>

2- Msinjili et al. Comparison of calcined illitic clays (brick clays) and low-grade kaolinitic clays as supplementary cementitious materials, Materials and Structures (2019) 52:94 <https://doi.org/10.1617/s11527-019-1393-2>

# Objectives

---

**Resource evaluation and material selection:** Assess the potential of locally available secondary materials for sustainable alternative binders and develop thermal treatment methods (landfilled oil shale ash, Arumetsa, Kunda, Aseri clays).

---

Pozzolanic reactivity assessments

---

**Activation and co-calcination effects:** Investigate the effects of mechanochemical and thermal activation on clay performance, as well as its co-calcination in cement blends.

---

Isothermal calorimetry

---

The role of **accelerated carbonation curing (ACC)**: Evaluate the impact of ACC on sustainable aerated /cellular building blocks.

---

Landfilled ash as cement replacer

---



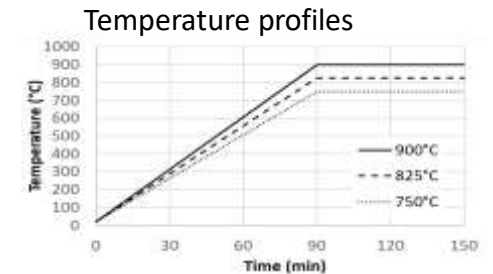
# Pozzolanic reactivity assessment

## Characterisation

List of samples	
Aseri clay (ASC)	Wienerberger AS, Aseri
Arumetsa clay (ARC)	LECA EESTI, Pärnu
Kunda clay	Heidelberg Materials Kunda AS, Kunda
Slaked lime, Ca(OH) <sub>2</sub>	Unikaks AS



Characterisation methods	
Physical characterisation	PSD, SSA (before and after calcination)
Chemical and mineralogical characterisation	XRF, XRD (before and after calcination)
Residual Ca(OH) <sub>2</sub>	TGA



## Pre-treatment and calcination



Natural clay as received



Drying at 105°C for 24 hours



Initial ball milling



Grinding with desintegrator



Nabertherm Rotary Tube Furnace



750/825/900°C (20rpm)



Calcination at 900°C

# Pozzolanic reactivity assessment

## Mortar preparation

Curing at  $22 \pm 2$  °C for 24h and at  $55 \pm 2$  °C for 6 d

EN 1015-3:2004+A2:2007

EN 196-1

Samples	Slaked lime (g)	Clay (g)	Sand (g)	Water (g)
ASC/750-825-900	150	365	1350	390
ARC/750-825-900	150	365	1350	402



Mortars were cast into prismatic molds ( $40 \times 40 \times 160$  mm)

# Density, Compressive and Flexural Strength

- All investigated clays (Arumetsa, Aseri, and Kunda) exhibit pozzolanic behavior following thermal activation, with mortars achieving optimal compressive strengths at 825 °C (7.4, 6.6, and 6.9 MPa, respectively).
- Owing to its higher kaolin content, Arumetsa clay demonstrates enhanced performance.
- In accordance with pozzolanic activity requirements, the 7-day compressive strength should exceed 4 MPa.<sup>4-5</sup>



Mortars were cast into prismatic molds (40 × 40 × 160 mm)



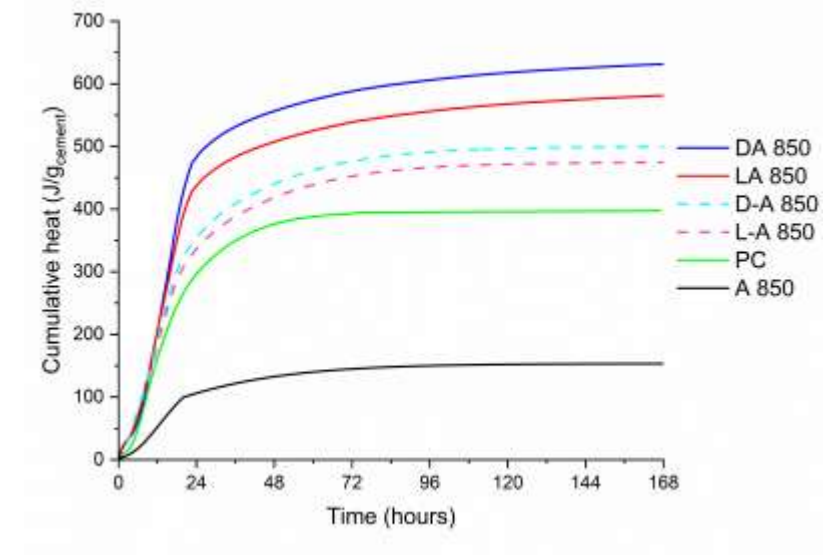
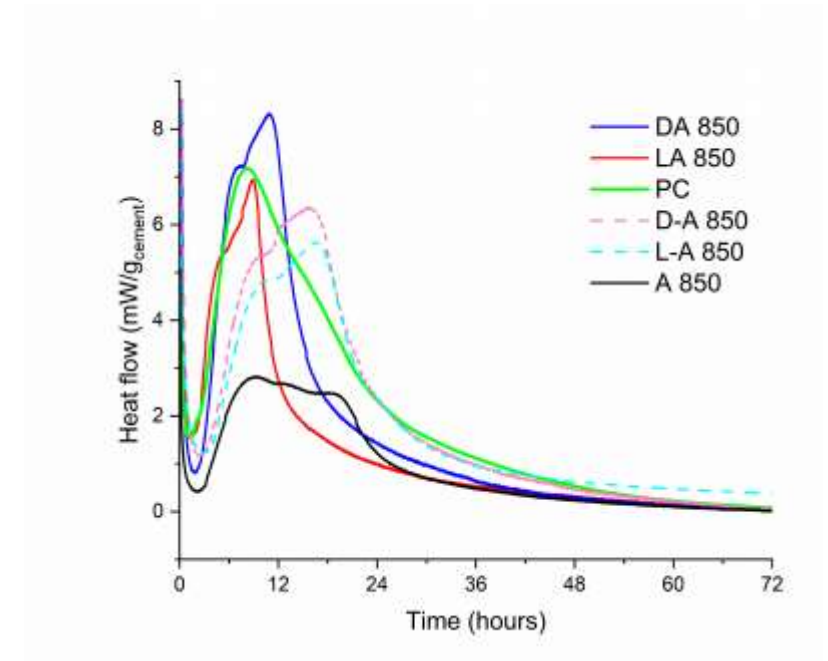
4-Baki, V.A. et al. Determination of the Pozzolanic Activities of Trachyte and Rhyolite and Comparison of the Test Methods Implemented. Int J Civ Eng 18, 1053–1066 (2020). <https://doi.org/10.1007/s40999-020-00516-5>

5-TS 25 (2008) Natural pozzolan (trass) for use in cement and concrete- definitions, requirements and conformity criteria. Turkish Standards Institute, Ankara

# Co-Calcination of dolomite (D) or landfilled ash (L)/clay (A-Arumetsa)

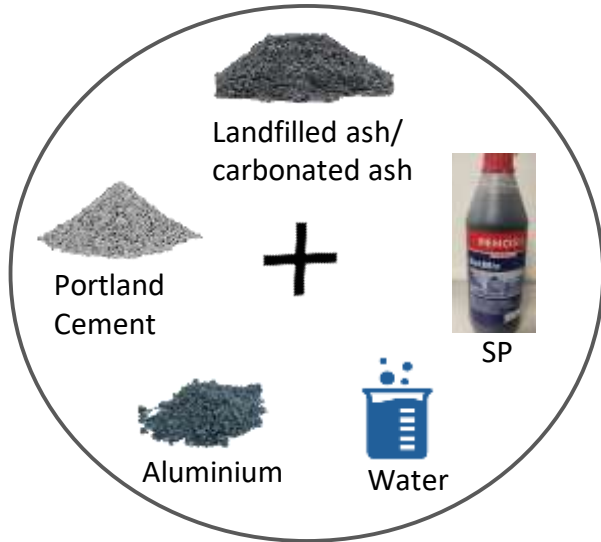
Isothermal calorimetry heat curves of samples calcined at 850°C

- Dashed lines represent separately calcined mixtures (e.g., D-A 850: Dolomite and Clay calcined separately)
- Solid lines indicate co-calcined mixtures (e.g., LA 750: Landfilled Ash–Clay co-calcined blend)
  
- **The hydraulic reactivity of illite-rich clays can be further improved through co-calcination with dolomite and landfilled ash.**
- **Co-calcination presents a synergistic approach that facilitates a broader and more efficient utilization of LFA and heterogeneous clay resources.**



# Cellular blocks

## Mixing



## Casting



Mould: 40x40x40mm



Demoulded samples (after 24hrs)

## Curing

CO<sub>2</sub>



Carbonation Chamber



Humidity Chamber

## Testing



- **Landfilled ash:** oven-dried @ 60 °C - 48 hours, Grounded - Retch four-ball planetary mill (≤2mm), grinding in disintegrator at 100Hz
- **Carbonated landfilled ash:** carbonated with flue gas containing 16% CO<sub>2</sub>, 6% O<sub>2</sub>/N<sub>2</sub>, at 2 bar pressure, ~70% RH, room temperature

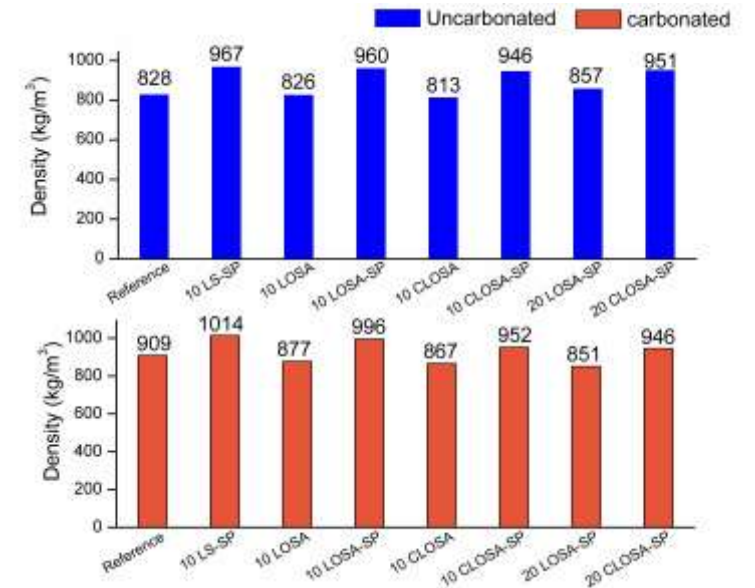
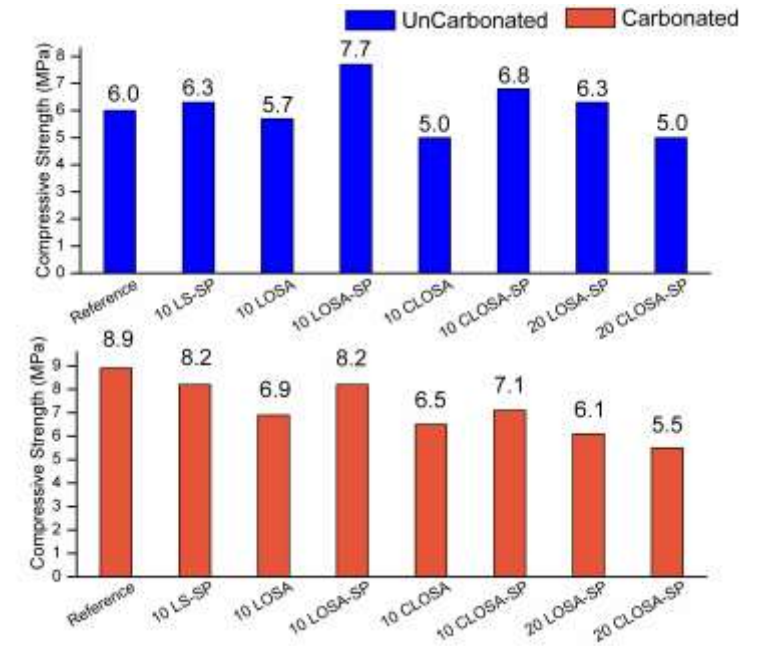


Expansion due to H<sub>2</sub> gas

# Compressive Strength and Density

- LOSA – landfilled ash (10-20%)
- CLOSA – carbonated landfilled ash (10-20%)
- Carbonation curing has been found to significantly enhance the mechanical performance of blocks within cementitious systems, simultaneously improving their environmental friendliness by promoting CO<sub>2</sub> uptake and reducing the overall carbon footprint.

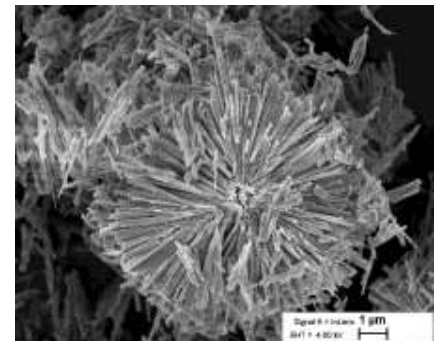
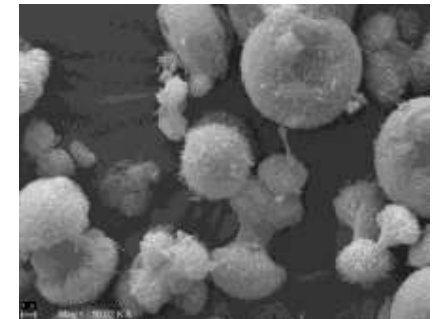
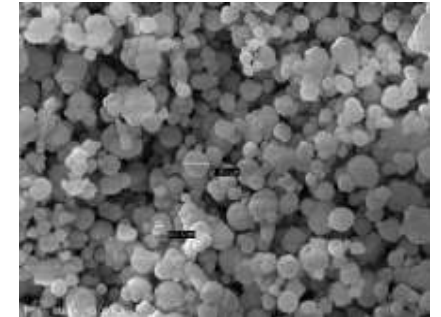
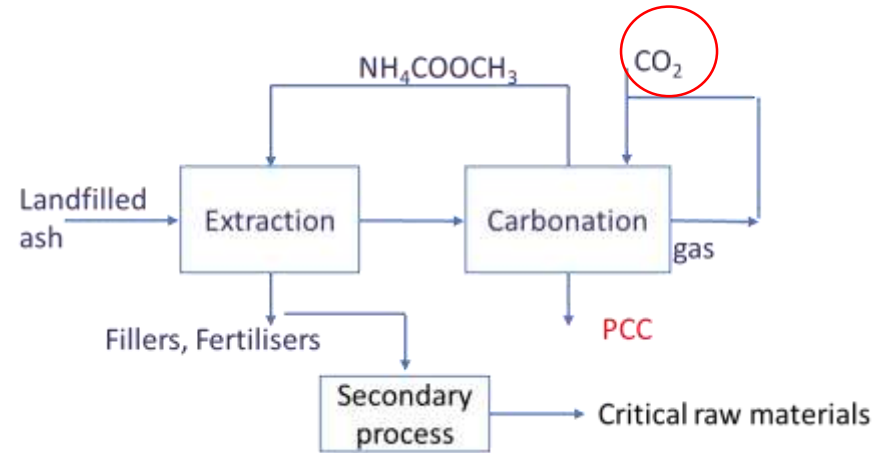
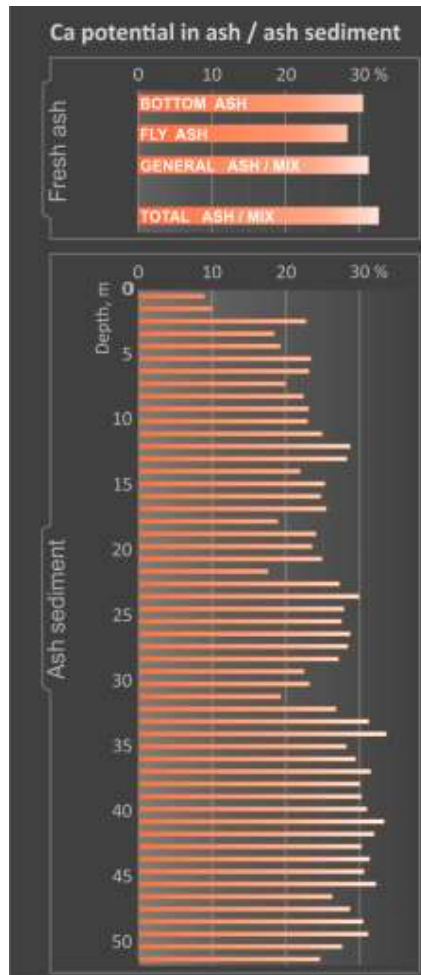
Samples	Density kg/m <sup>3</sup>	Strength MPa	CO <sub>2</sub> uptake %
Pressed bricks	1500-2000	15-30	10-15
Low-weight blocks	600-900	2-5	10-15



Landfilled oil shale ash as a raw material for precipitated calcium carbonate



# Valorization of ash mountains for obtaining precipitated $\text{CaCO}_3$ (PCC) using the $\text{CO}_2$ mineralization process



- The calcium potential of oil shale ash varies between 10–30% depending on its chemical and phase composition, being higher in deeper layers.
- PCC produced from core samples was characterized by high purity – 98%  $\text{CaCO}_3$ .
- By varying the carbonation conditions, it is possible to obtain crystals with different particle sizes and morphologies.
- A two stages extraction method for synthesizing precipitated calcium carbonate; Omanikud: R-S OSA SERVICE OÜ; Autorid: Hussain Azeez MOHAMED, Anders KIHIL, Alar Saluste, Mai Uibu, Andres Triikkel, Rein Kuusik, Kadriann Tamm, Ae Leier, Riho Mõtlep, Kalle Kirsimäe; Prioriteedi number: EP2020065108; Prioriteedi kuupäev: 1.06.2020.

RAGN  SELLS

# WHAT A WASTE!

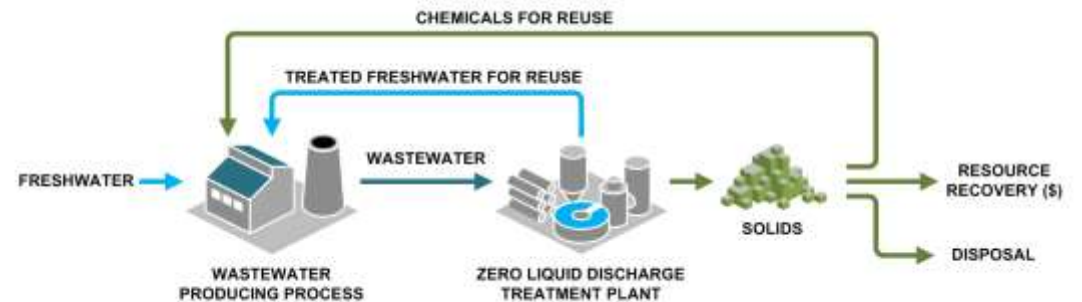
Mõtle ringlusele

## OSA: Northern Europe's Largest Circular Economy Project

[OSA – Põhja-Euroopa suurim ringmajanduse projekt](#)

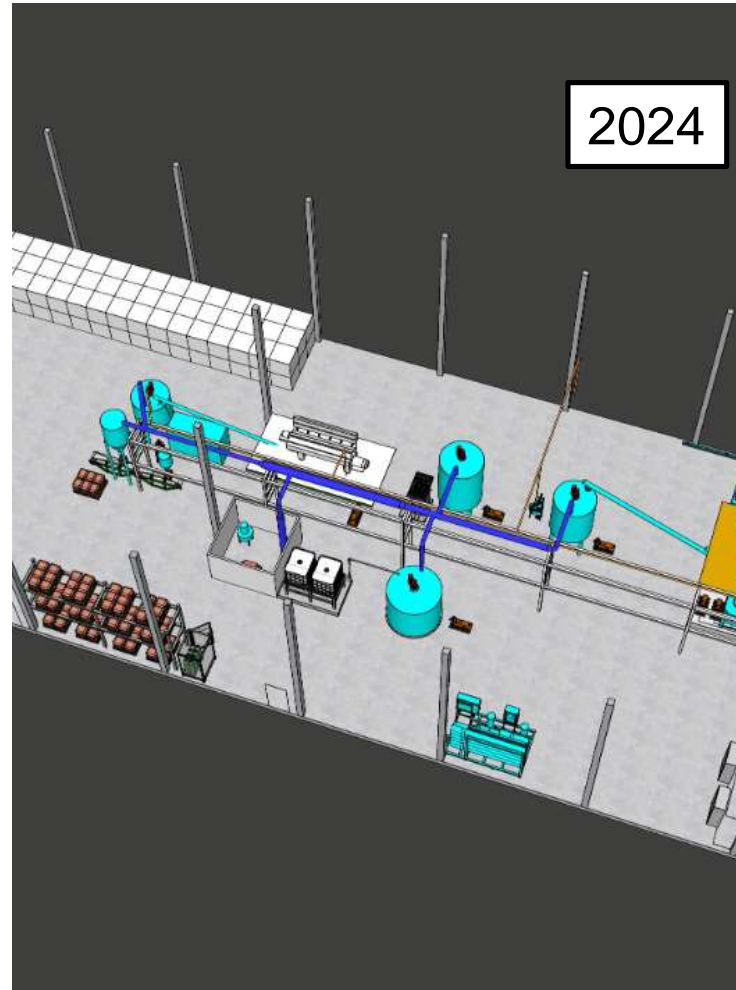
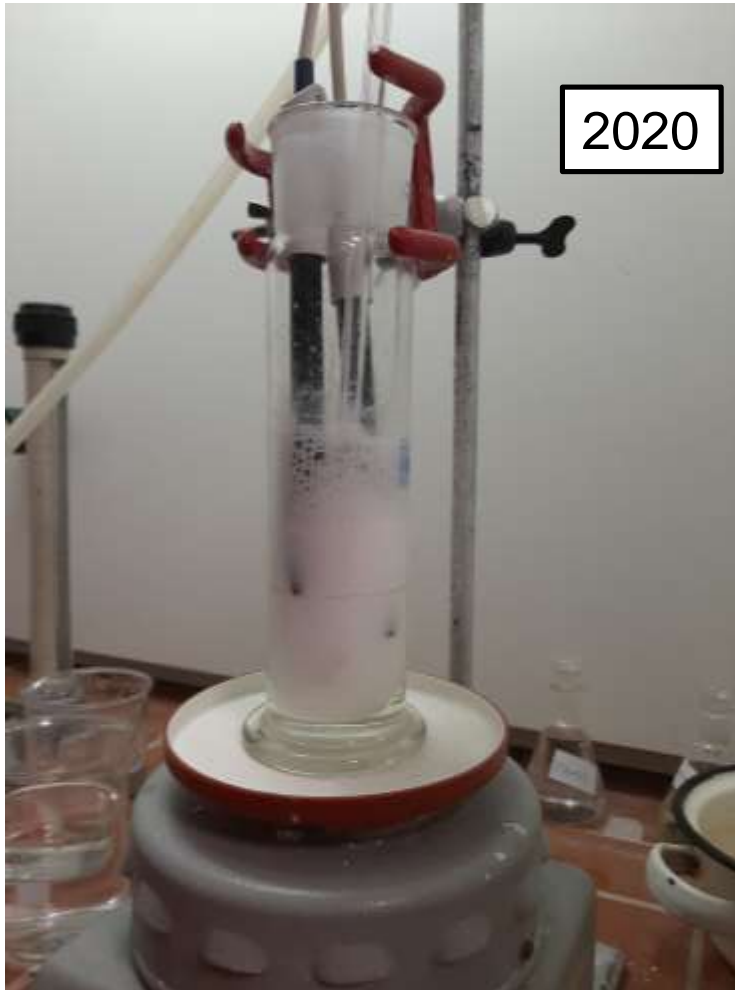
# Objective

- To produce a commercial product—precipitated calcium carbonate—from deposited oil shale ash
  - Emission-free CCUS (**Carbon Capture, Utilization, and Storage**) solution
  - A waste recycling-based approach
  - Solvent-based zero liquid discharge (ZLD) solution
  - Economically viable solution





# Laboratory testing: From concept to execution

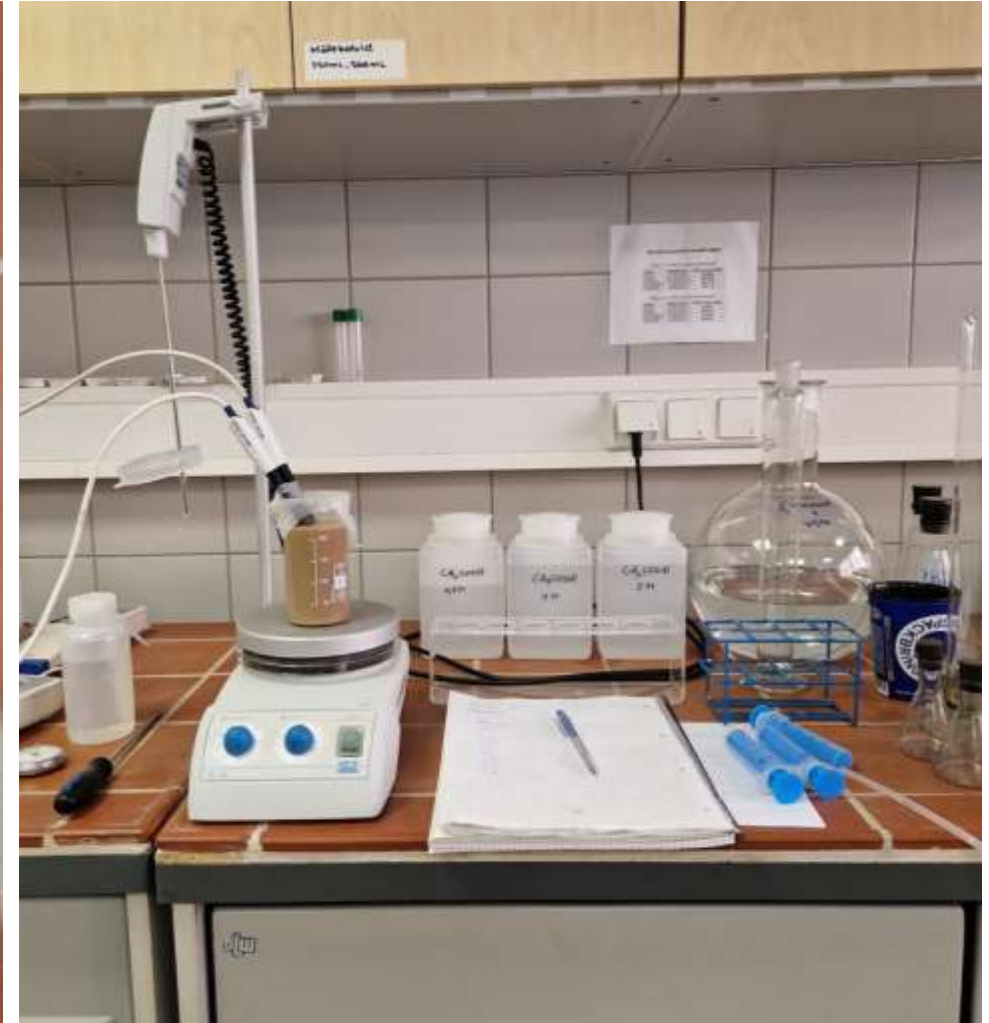
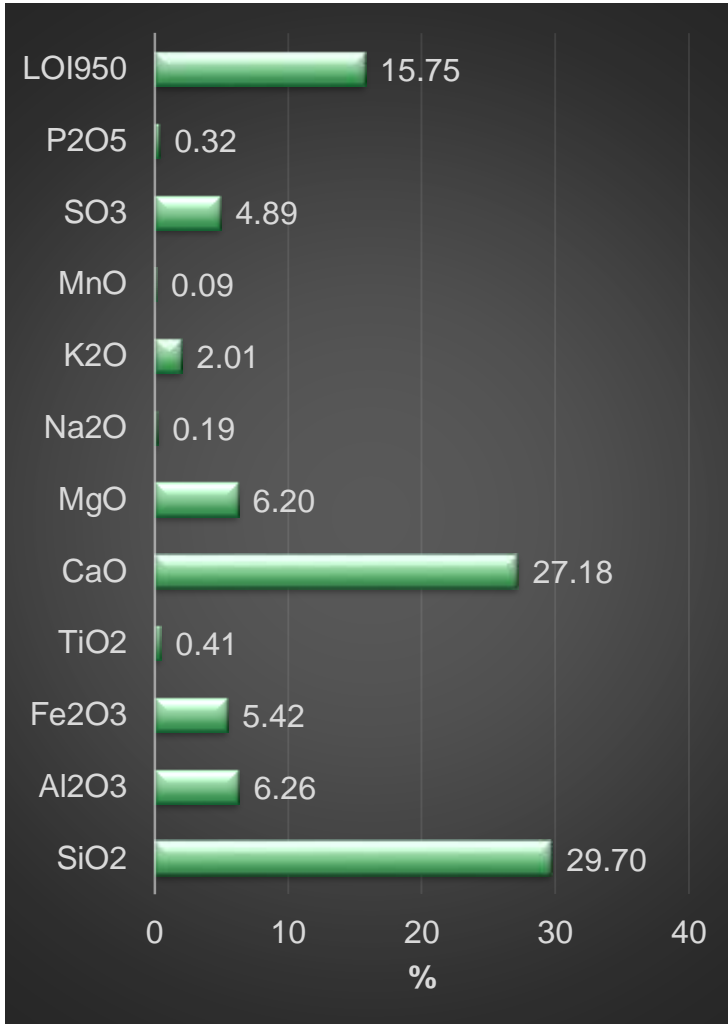


- What to do next?
- Continue ash valorization!
- PCC production residue can be valorised further to produce more PCC, but also  $\text{Mg}(\text{OH})_2$
- $\text{Fe}(\text{OH})_3$
- nano- $\text{SiO}_2$ .



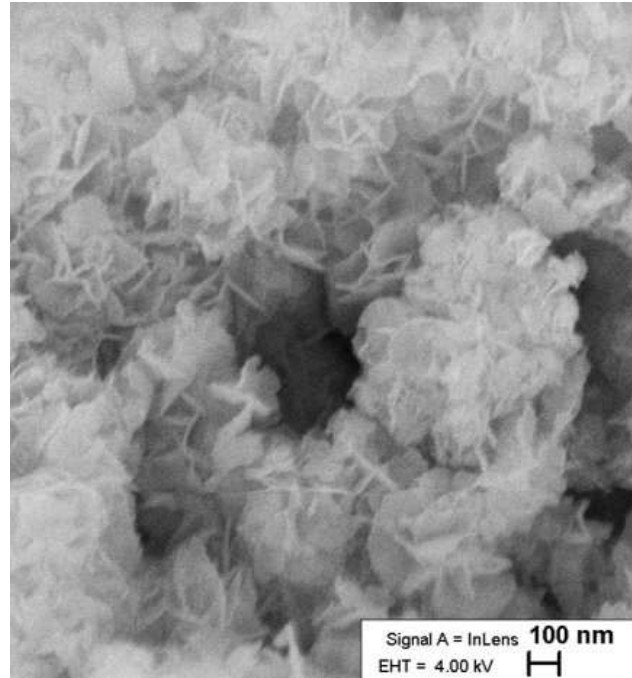
Annual Baltic Carbon Forum 2025

# Laboratory testing continues: Mg, Al, Ca, Fe, Si



Annual Baltic Carbon Forum 2025

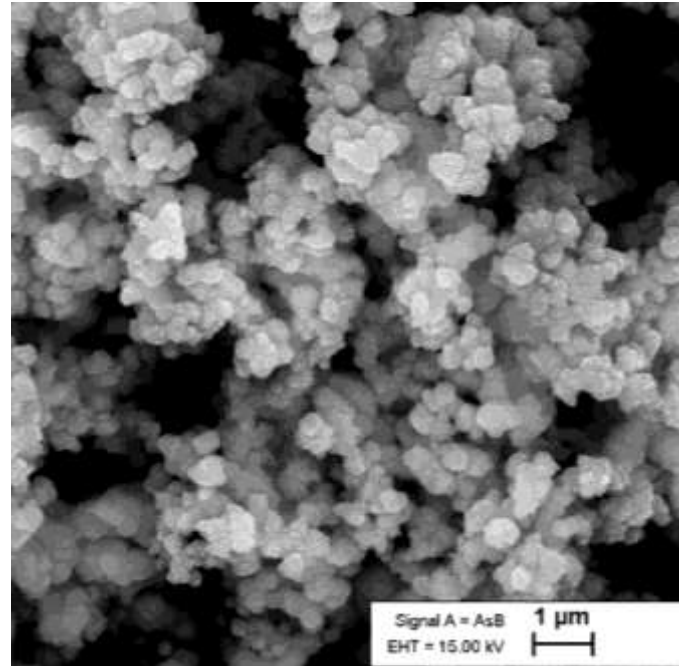
# By-product of PCC production as Mg feedstock



- **First, three potential products were separated:**
- **Fe(OH)<sub>3</sub>**
- **Al precipitate** (mainly contains Al<sub>2</sub>O<sub>3</sub>, but also other phases)
- **Mg(OH)<sub>2</sub>**
  
- **Mg(OH)<sub>2</sub> / brucite with 98% purity**  
78 g of Mg(OH)<sub>2</sub> per 1 kg of PCC production residue

Annual Baltic Carbon Forum 2025

# By-product of PCC production as nano-SiO<sub>2</sub> feedstock



<sup>6</sup>Hossain, S. S., Bae, C.-J., & Roy, P. K. 2022. Recent progress of wastes derived nano-silica: Synthesis, properties, and applications. Journal of Cleaner Production, 377: 134418.

# Main Challenges

- The EU is gradually recognizing CCU as a key technology for carbon neutrality, but regulatory clarity is still evolving, especially around the permanence of carbon storage in CCU products.
- The EU Emissions Trading System (ETS) has been amended to include CCU, but criteria for permanent storage are still being defined.
- In Estonia, while there is a national circular economy strategy, implementation is slow, and regulatory and administrative barriers continue to delay technology deployment.
- The accessibility and price of landfilled oil shale ash.



# Acknowledgements

**TEM-TA87 "Complex recovery of mineral mining and industrial waste as secondary raw material in the context of eco-conscious building materials and hydrometallurgy"** (01.06.2024–31.05.2028); Principal Investigator: Mai Uibu; Tallinn University of Technology, School of Engineering, Department of Materials and Environmental Technology (coordinator), University of Tartu (partner); Financier: Estonian Research Council; Financing: 601 744 EUR.

## SCIENTIFIC WORK AND APPLIED RESEARCH



## PARTNERS



Product testing  
Europe leading window and doors  
profile manufacturer  
[www.gealan.de](http://www.gealan.de)

## FUNDING

**ARCHIMEDES**

