Near Zero-waste and Near Break-even: A Path towards Sustainable Bauxite Processing

Efthymios Balomenos

Mytilineos S.A.- Metallurgy BU

About the Presenter

Efthymios Balomenos, Ph.D.
Research & Sustainable Development
AoG | METALLURGY BUSINESS UNIT
MYTILINEOS S.A.
Plant: Ag. Nikolaos, 320 03, Viotia, Greece
D: +30 2267049334 +30 6977859589
E: efthymios.balomenos-external@alhellas.gr
W: http://www.mytilineos.gr/

Short CV

- *Metallurgical Engineer - NTU Athens*
- *PhD in thermodynamics (2005)*
- *Senior Researcher at NTU Athens: Sustainable metallurgy, processing, exergy*
- *Research manager / coordinator in numerous collaborative EU RTD projects*
- *Recipient of the TMS Light Metals Subject Award – Alumina & Bauxite in 2017.*
- *60 publications, +600 citations, h-index 14*

Other Members of the Research and Sustainable Development team

Panagiotis Davris, Ph.D.
Research and Sustainable Development Activity
AoG | METALLURGY BUSINESS UNIT
MYTILINEOS S.A.
A: Agios Nikolaos Plant, 320 03 Viotia, Greece
T: +30 2267049209 +30 6983871724
E: panagiotis.davris@alhellas.gr
W: www.mytilineos.gr

Aikaterini Pagkle
Research and Sustainable Development
AoG | METALLURGY BUSINESS UNIT
MYTILINEOS S.A.
A: Agios Nikolaos Plant, 320 03 Viotia, Greece
T: +30 22670 49228
E: aikaterini.pagkle@alhellas.gr
W: www.mytilineos.gr

MYTILINEOS - Aluminium of Greece Plant

Mining 650,000 tons of Greek bauxite ore, processing each year more than **1.4 million tons of Greek bauxite ore** and 0.4 million tons of tropical bauxite ore.

Producing **835,000 tons of alumina** (out of which 475,000 tons are exported)

Producing **190,000 tons of aluminium** (out of which 105,000 tons are exported)

The leading industrial producer of alumina and aluminium in S.E. Europe and **the only vertically integrated bauxite, alumina and aluminium production plant in Europe**

MYTILINEOS

What is the Bauxite Residue?

Bauxite Ore

1,800,000 t/year

Digestion

The ore is digested under high temperature and pressure in alkaline solution

Precipitation

Alumina precipitates from the alkaline "pregnant" solution

Alumina

800,000 t/year

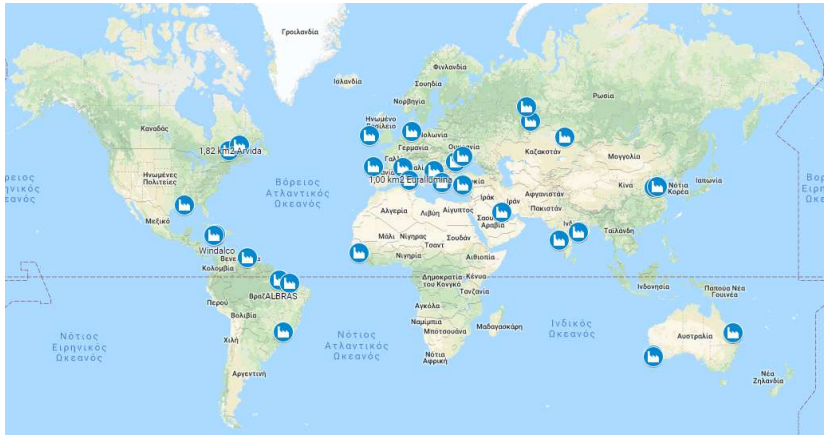
Filtration

The undissolved portion of the ore, forms a pulp known as 'red mud' or Bauxite Residue (BR)

Bauxite Residue (BR)

750,000 t/year

Worldwide in 2017 only 3% from the **140,000,000 t of Bauxite Residue** produced annually are utilized in cement and iron production



Bauxite Residue Handling Practices

Today there are three main options for BR handling

Slurry / pulp [red mud] in tailings damns

BR might be processed in deep thickeners or drum filters to partially remove water before pumped to the BRDA

Moisture: 40 – 55%.

Mud Farming / Dry Stacking

BR is pumped as thick pulp at the BRDA

At the BRDA BR is 'farmed' / is placed in step inclines and naturally dried and carbonated.

Moisture after time 30-35%.

Solid filtercake

BR is filterpressed at the plant and transferred as a solid filtercake to the BRDA

Moisture 24 – 28 %

5

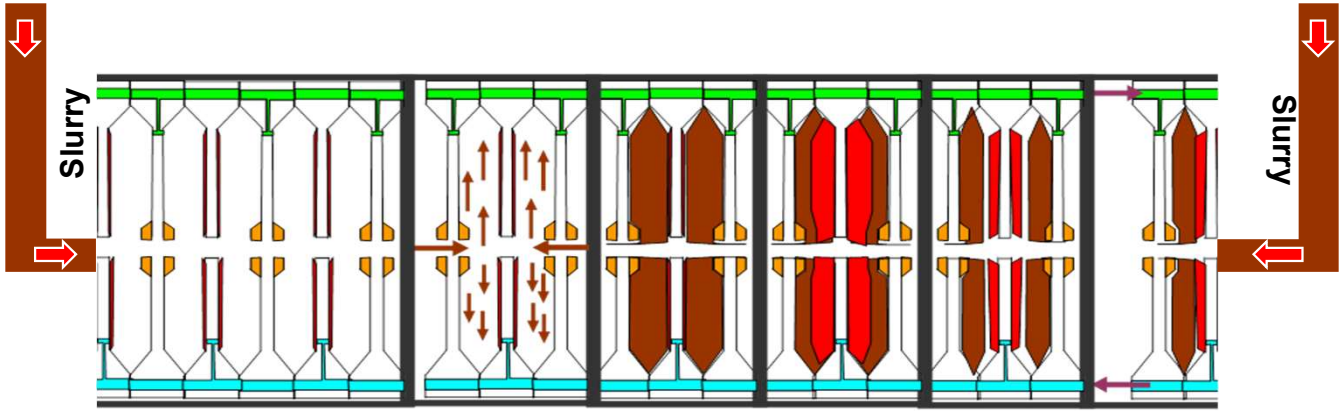
Our Vision

Use Filterpress to remove the water content from the slurry so:

- ❑ It can be safely deposited in-land in full accordance with EC waste directives.
- ❑ It can be easily transported in other industrial facilities for re-use.

MYTILINEOS

- 2006: Installation of 1st Filterpress .
- 2007: Pilot tests- Automation and improvements.
- 2008: Installation of 2nd Filterpress, storage site.
- 2009: Installation of 3rd and 4th Filterpress - gradual increase of operations.
- 2012 - today: 100% dry disposal of all bauxite residue produced from the alumina refinery.



Bauxite Residue discharged with moisture between 24-28%

Filtrate is returned to washers, and re-introduced to the Bayer cycle

The BR storage site is located just behind the plant

- Storage takes place in accordance to geotechnical study
- Currently 7 active plateaus with heights 9-15 m.
- The site contains over 7 million tons of BR already.
- Estimated to be in operation for another 20 years.
- Rehabilitation is done in parallel

MYTILINEOS

But our goal is not to make new mountains…

MYTILINEOS

Since 1991, AoG BR has focused on reusing BR.

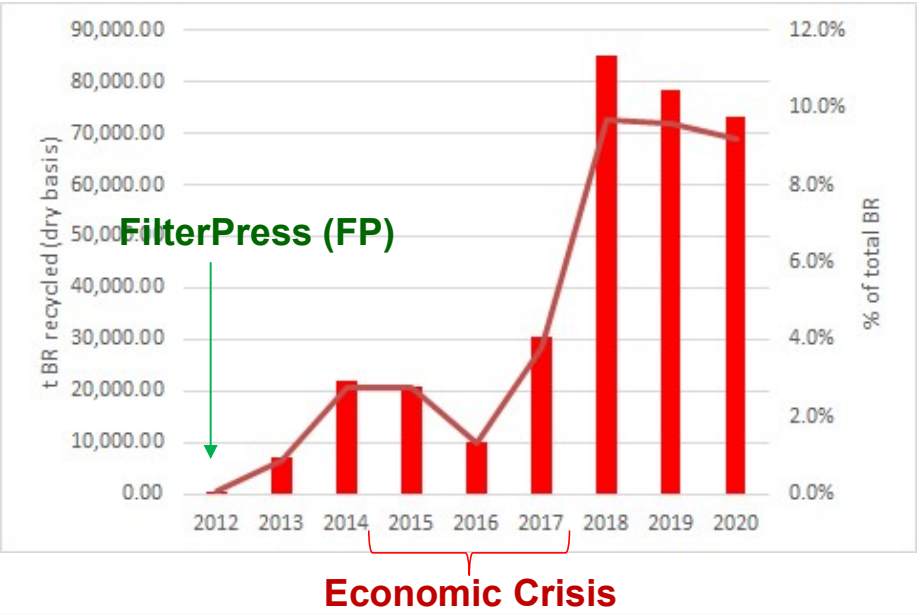
So far Greek BR has been tested for use in:

- ***Cement Industry (iron/alumina source in clinker)***
- ***Iron production***
- ***Brick/Tile Industry (substitution of clay)***
- ***Geopolymer bricks***
- ***Soil Remediation/ Vegetation cover***
- ***Road Base Construction***
- ***Landfill barrier / cover***
- ***Backfilling of closed Mines***
- ***Cement tiles***

MYTILINEOS

BR can be used as an iron/alumina source in OPC clinker

- ✓ **Since 2012 Mytilineos has recycled more than 330,000 t of BR**
- ✓ **This practice is also performed in Ukraine, more recently in India, and is being investigated in USA, Canada, Emirates and Brazil**

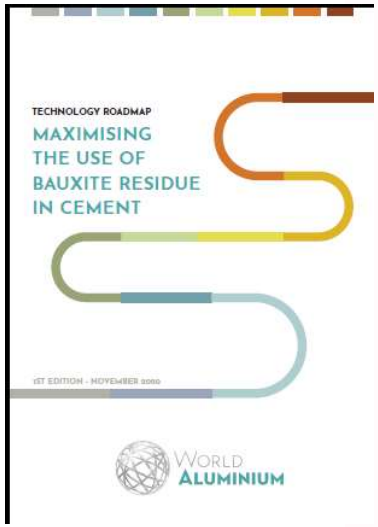


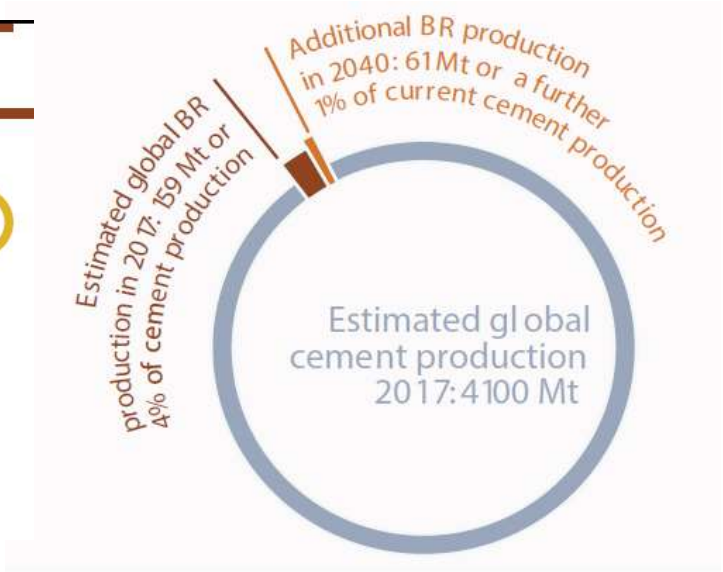
- ❑ AoG's BR bas been used at rates of 1.5 - 3% substitution in the clinker.
- ❑ BR is transferred by ship to nearby cement plants
- ❑ In 2018 BR was shipped for the first time outside of the Greece, to Cyprus

Filter-pressed BR loaded on ship @ MYTILINEOS

BR can be used as an iron/alumina source in OPC clinker

- ✓ **Theoretically up to 4-5% substitution is feasible**
- ✓ **Theoretically the worldwide cement production could reuse all the worldwide BR production**





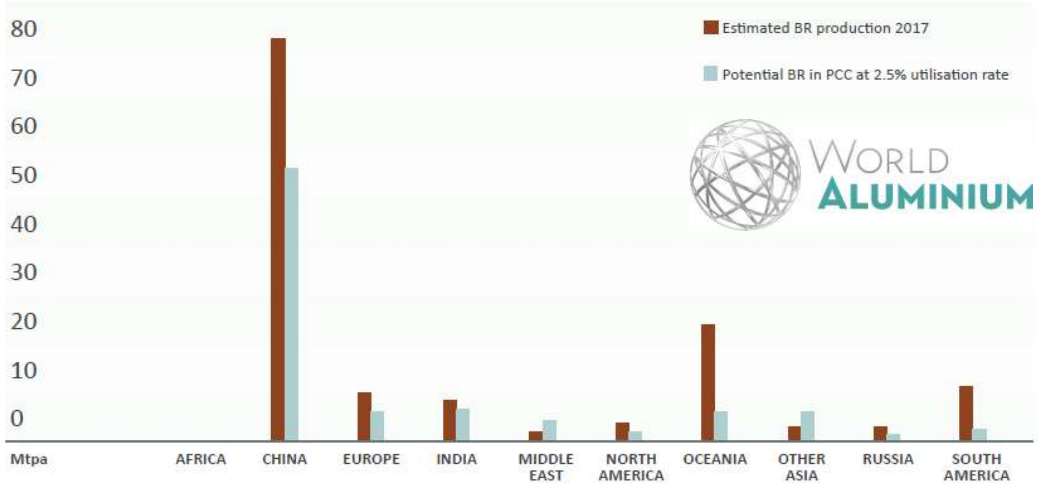
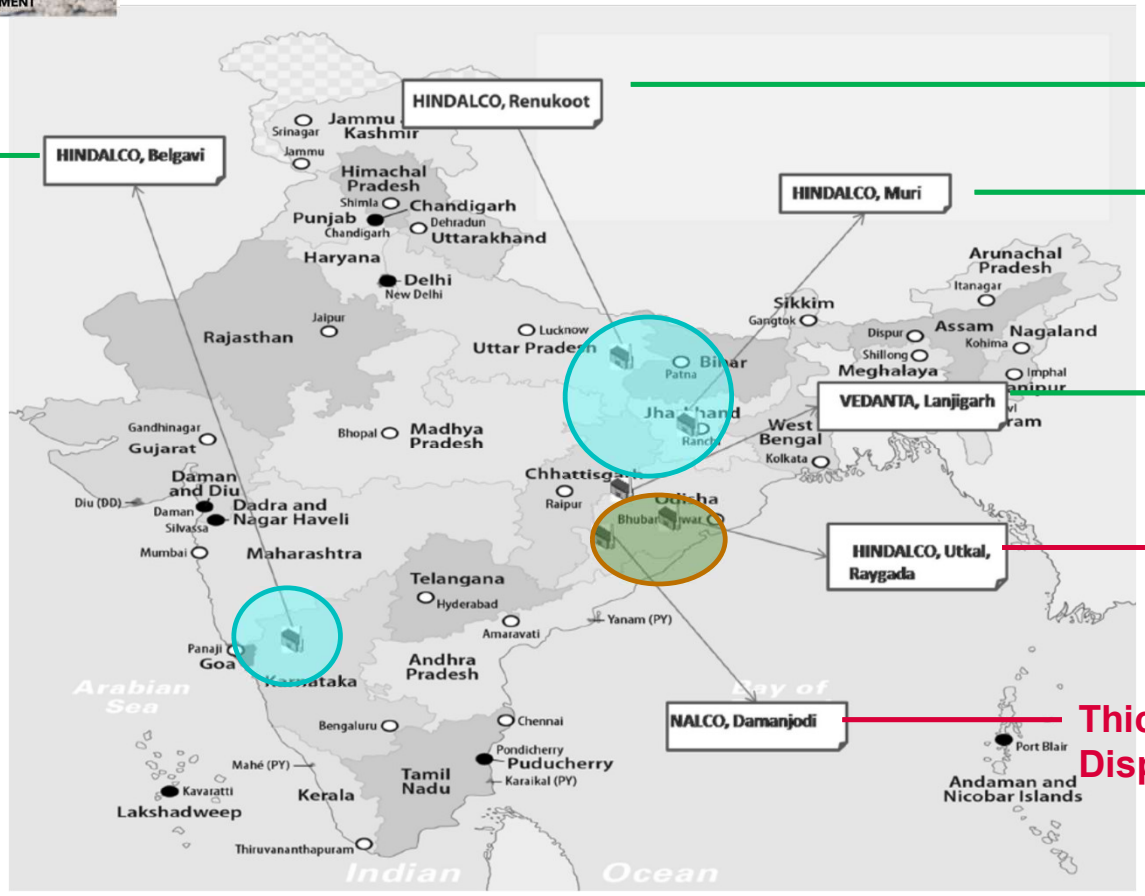


Figure 11: Potential utilisation of BR in PCC by region. Sources: USGS[9], Cembureau[10], IAI[1]

https://www.world-aluminium.org/media/filer_public/2020/11/15/technology_roadmap_-_br_use_in_cement_2020.pdf

BR reuse in India



FilterPress (FP)

FilterPress (FP)

Dry Stacking disposal

FilterPress (FP)

Thickened Tailings Disposal (TTD)

Cement plant region

No-Cement plant region

- India is 4th largest alumina producer with ~9 mio tpa capacity
- This year HINDALCO announced that it expects to achieve 2,000,000 tpa BR reuse in OPC
- In total 4 Indian alumina plants recycle BR into cement plants
- BR Transport is done via railroad

Why not more ? – Key Barriers

Technical Barriers

- ❑ **Having dry (transportable) BR is essential prerequisite**
- ❑ Soda content, Cr content, moisture are the most common technical barriers, yet none of them is crucial for additions up to **1% -1.5%**

Legislative Barriers

- ❑ European Community waste transport legislation is a complicated process requiring specific permits from all parties involved.
- ❑ **Cross-boarder transport even more complicated. (Basel convention**).

Financial Barriers

- ❑ **Logistics is the key issue (Distance, means of transport).**
- ❑ Cement plants are willing to utilize BR only as long at is a cheaper alternative to other iron and alumina sources.
- ❑ Gate fees may also come into play.
- ❑ Reuse depends also on cement production levels (external factor)

Social Barriers

- ❑ **Local Societies are always eager to protest against cement plants treating wastes 'in their backyard**'.
- ❑ BR handling during unloading and mill feeding is the biggest issue as any potential dusting of the BR would create significant protests by local societies.

Our Vision

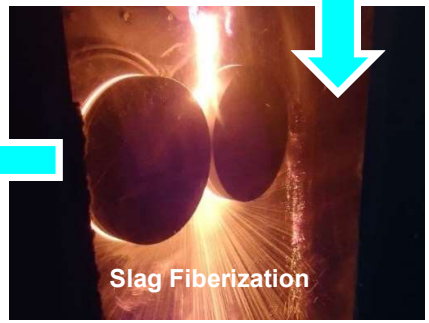
BR in OPC is a good starting point, still:

- ❑ Multiple solutions / customers are needed to recycle the full BR produced
- ❑ BR centric recycling processes are need for added value products.

MYTILINEOS

The ENEXAL Project [2010-2014]: BR Treatment Process

- 2012: Electric Arc Furnace and Melt Fiberizing unit installed in AoG Pilot Plant
- During a two-year long experimental campaigns treated more than 30 t of BR
- More than 5 t of Pig Iron produced and tested in secondary steel production as scrap substitute
- High Quality mineral wool product produced from the slag



ZERO WASTE

- ✓ Smelting energy 14.5% in excess of thermodynamic requirement
- ✓ Overall pilot plant consumption 2 MWh/t BR
- ✓ Exergy Utilization efficiency 32%
- ✓ Increase of alumina refinery exergy utilization by 8 percentile points

The ENEXAL Project [2010-2014]: BR Treatment Process

White Iron grinding balls produced from BR iron (21%wt scrap substitution)

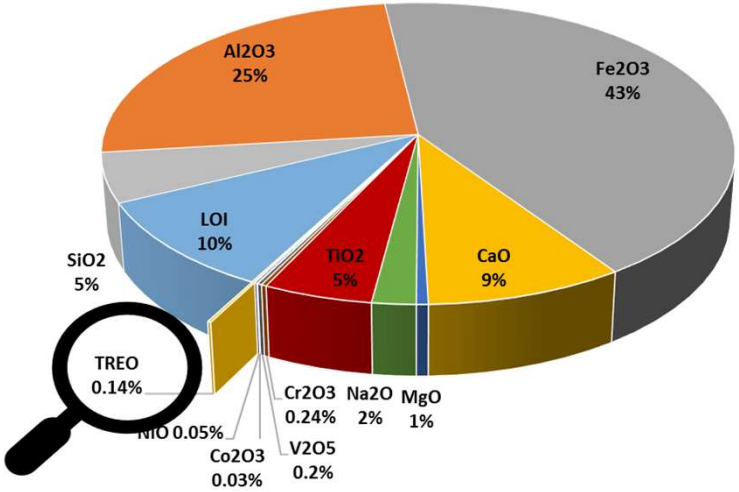
Mineral wool used inside the plant

Techno-economic Evaluation

- ☑ The revenues of pig iron and mineral wool could match and exceed the operational cost of the unit
- ☒ Pig iron revenues alone would only cover up to 35% of operational costs
- ☒ The mineral wool market is limited in size (60,000 -100,000 t) and could not absorb the mineral wool that would be produced from a full BR processing (>300,000 t of slag)

Next Steps

- Produce more products to achieve a flexible and viable process
- Combine low value –high volume products with high value – small volume niche products



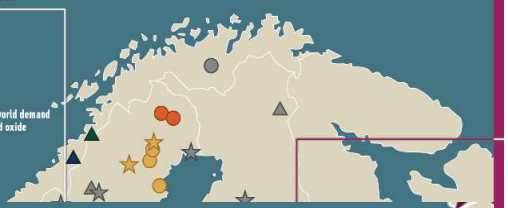
ES IN EUROPE

NORRA KÄRR DEPOSIT, SWEDEN

TASMAN METALS LTD

Unique HREE/LREE % ratio: 49/51
331Kt of TREO, (0.44% TREO grade)
40 Year Mine Life
No radioactivity
Simple magnetic concentration
Potential to supply 14% of the projected world demand in Dy oxide, 7% in Tb oxide and 2.2% of Nd oxide
Exploitable Zr content
Geological Setting: Peralkaline nepheline
Major REE mineral: Eudialite

Status: Mining Licence



BAUXITE RESIDUE, GREECE

ALUMINIUM OF GREECE

Industrial by-product of primary aluminium industry
More than 700,000 t produced annually in Greece and stored near the plant
0.14% TREO including Sc (Potential global Sc resource)

The amount of REE present in the Bauxite Residue produced annually in Greece, amounts to nearly the 10% of the annual European demand

eposits (Greenland,
n analysis performed
roduced for 5 samples
nal, 1 placer deposit)

$_{0.3}Y_{0.7}ZrSi_8O_{22}(OH)_{1.5}Cl_{0.5}$

THE KVANEFJELD DEMONSTRATION LINE:

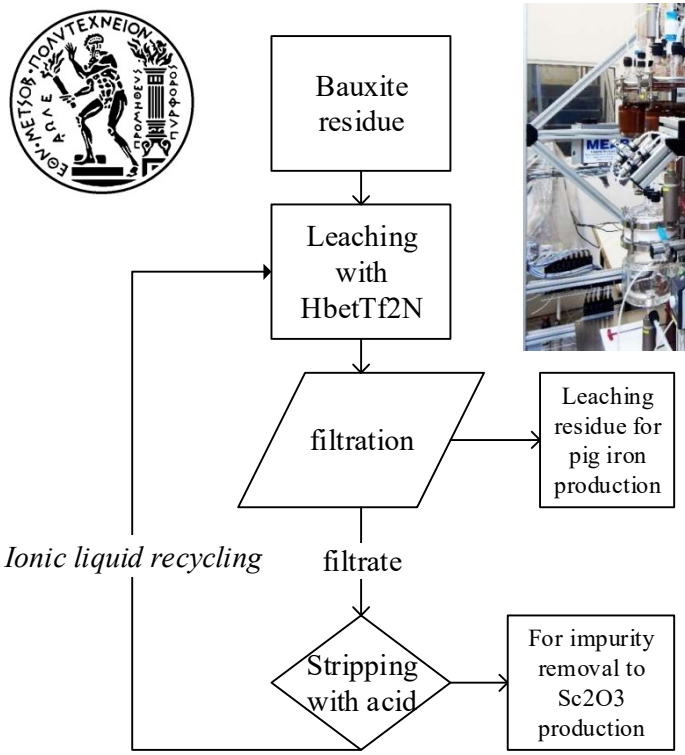
KVANEFJELD SAMPLE
GME, GREENLAND
4 t ORE
1.3% REO

BENEFICIATION PILOT PLANT
GTK, FINLAND
250 kg
Mineral Concentrate
15% REO

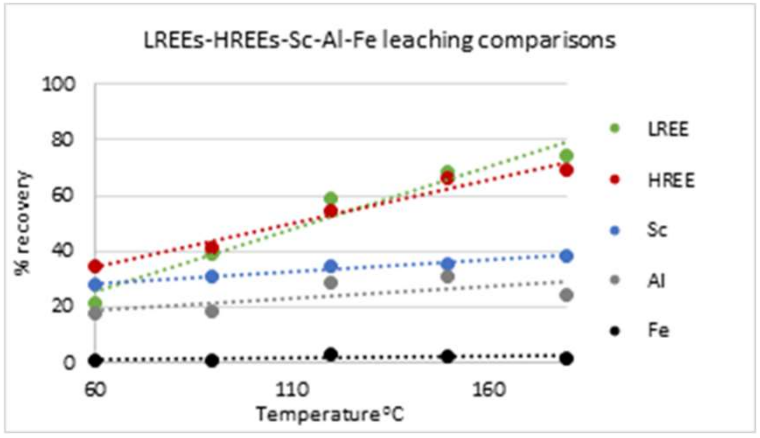
LEACHING PILOT PLANT
OUTOTEC, FINLAND
25 kg Mixed
REE Carbonate
50% REO

SOLVENT EX

EURARE Project [2013-2017]: REE Leaching from BR



SiO_2	6.54%
Al_2O_3	12.27%
Fe_2O_3	56.11%
CaO	0.06%
TiO_2	7.51%
LOI	7.82%



Developing New Process for Selective Extraction of Rare Earth Elements from Bauxite Residue Based on Functionalized Ionic Liquids

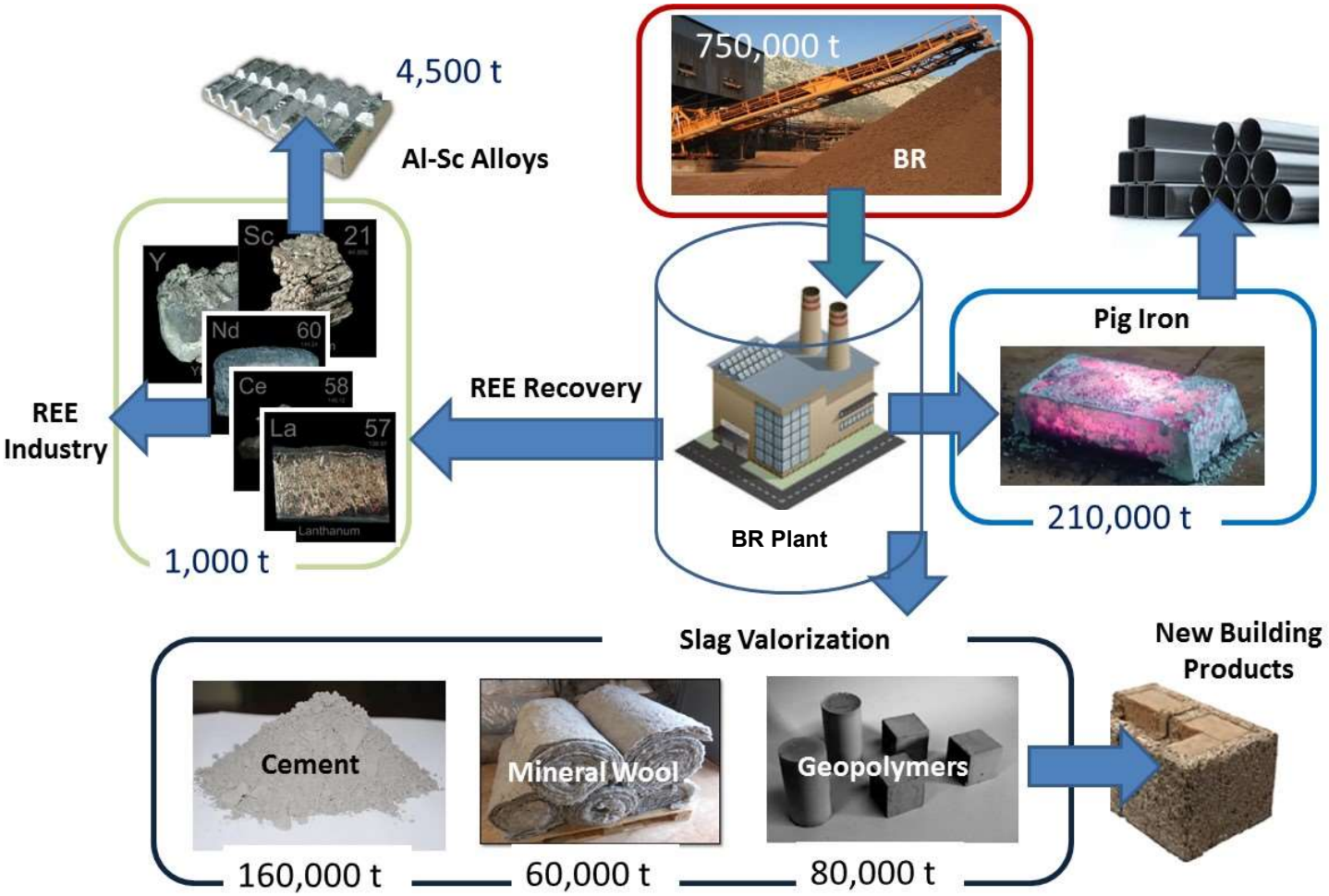
Panagiotis Davris, Efthymios Balomenos, Dimitrios Panias, and Ioannis Paspaliaris

Abstract

Ionic liquids (IL's) are versatile solvents consisting solely of ions and can be utilized to dissolve selectively rare earth elements (REE) from bauxite residue. The leaching process that developed is based on the hydrophobic ionic liquid betainium bis(trifluoromethylsulfonyl)imide [Hbet][Tf2N] and other similar ionic liquid derivatives. Leaching bauxite residue with HbetTf2N selectively dissolves REE (>70%) against Fe, Al, Ti and Si generating a solid residue to be utilized in cement or iron industry. Scandium appear to have different leaching behavior attention [1, 2] since REE are critical metals used in advanced applications and for applying greener technology [3–5]. Studies have shown that Greek BR contains ~1 kg REEs/ton (incl. Sc) [6, 7] and that this concentration is fairly constant, with a small variation over several years. REE market is found to be volatile with unpredictable fluctuation of their prices, yet scandium has steadily increasing its price over the years. Scandium can be produced as a byproduct of the U, Th, Al, W, Sn, Ta, Zr, Ti and REE's metallurgical production [8], yet it has been pointed out that bauxite and laterite ores are the most promising future source for a long

Light Metals Subject Award - Alumina/Bauxite

Mud2Metal: Holistic Valorization of BR



Our Vision

100% reuse of BR through multiple products/process:

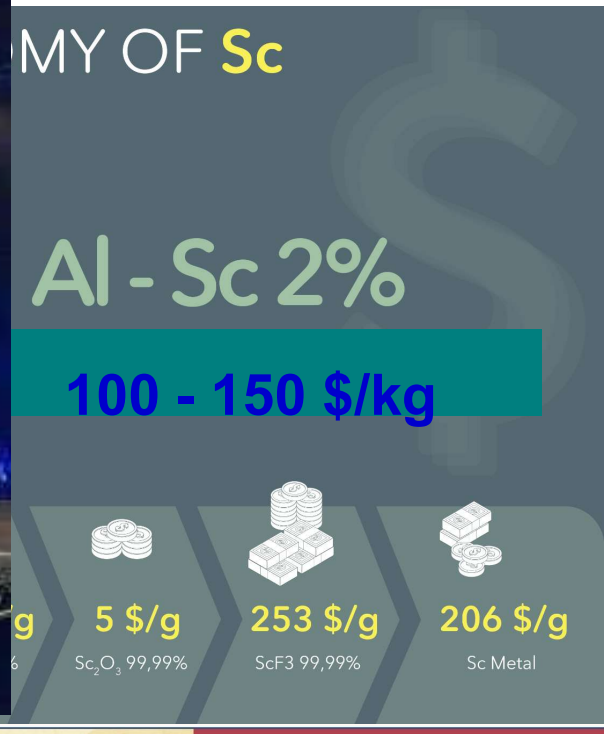
- ❑ Near Zero-Waste
- ❑ Near break-even
- ❑ Symbiotic with other industries

MYTILINEOS

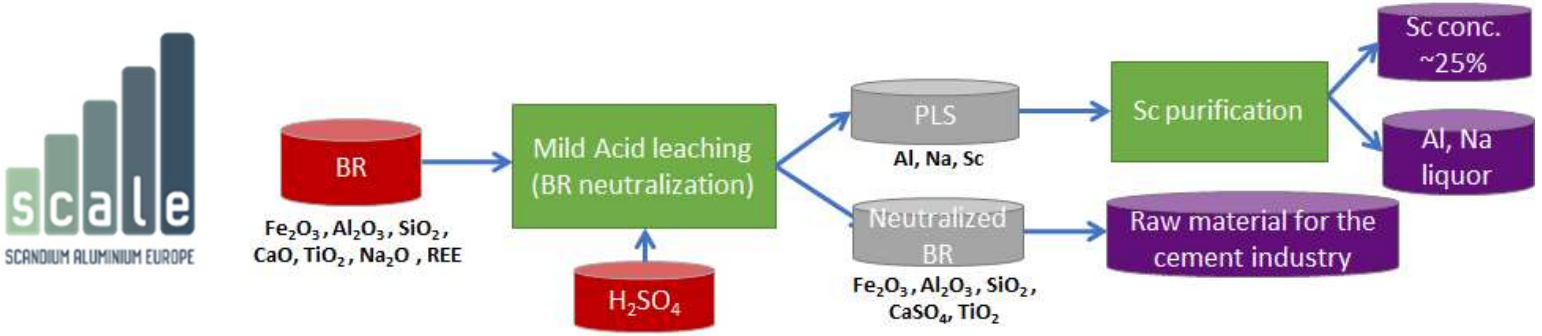
The SCALE project [2016-2021]: Extracting Sc from BR

The SCALE project [2016-2021]: Extracting Sc from BR

- **Sc is an “exotic” REE produced in minor quantities –not traded as a commodity**
- **Sc can ‘substitute’ Y in many material applications achieving superior results:**
  - **In SOFC Sc-stabilized Zirconia has lowered operational temperatures leading to commercialization of the technology**
  - **Sc drastically improves Aluminium alloy properties increasing strength, corrosion resistance, allowing welding and others**
- **The Al-Sc-Mg alloy powder is used in additive layer manufacturing (3D printing) by AIRBUS –its use can result in 45% weight reduction of an A320 partition.**



The SCALE project [2016-2021]: Extracting Sc from BR



BR Sc < 0.1 gr/kg → **X 2500** → Scale Concentrate Sc 250 gr/kg

With the SCALE processes (leaching, IX, purification, calcination, metal production) 1.4t of BR would yield 1 kg AlSc2% master alloy with processing costs ~40 EUR (estimation).

The RemovAl project [2018-2022]: Combining Flowsheets

removAL

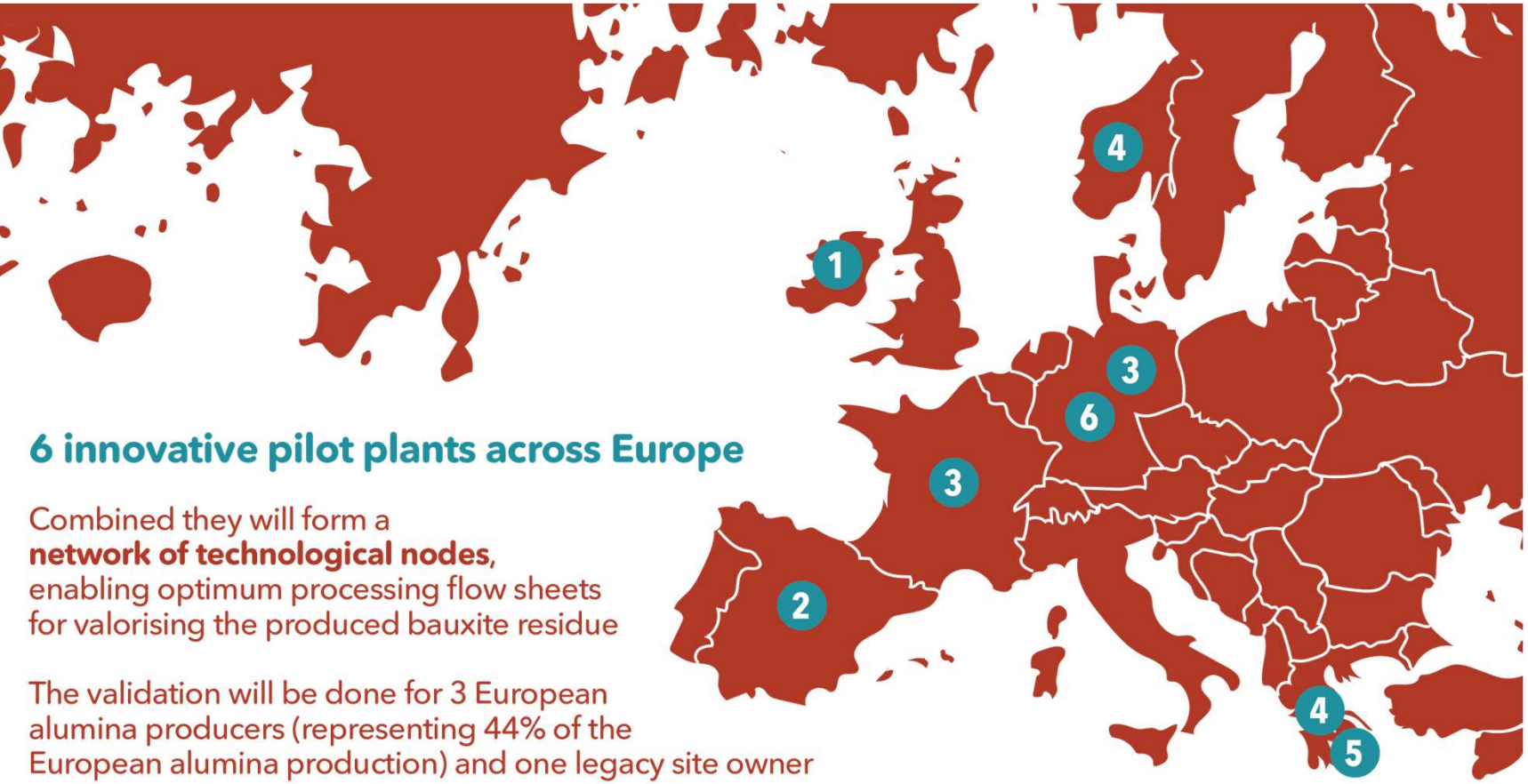
removing waste from alumina production

RemovAL overcomes the barriers of economic viability by pooling together and integrating proposed stand-alone solutions, while adhering to the following principles:

- treat waste with waste
- recover valuable critical metals
- develop marketable products
- customise the solution to the industrial ecostystem of each alumina plant

near zero-waste processing, near break-even flowsheets

The RemovAI project [2018-2022]: Combining Flowsheets

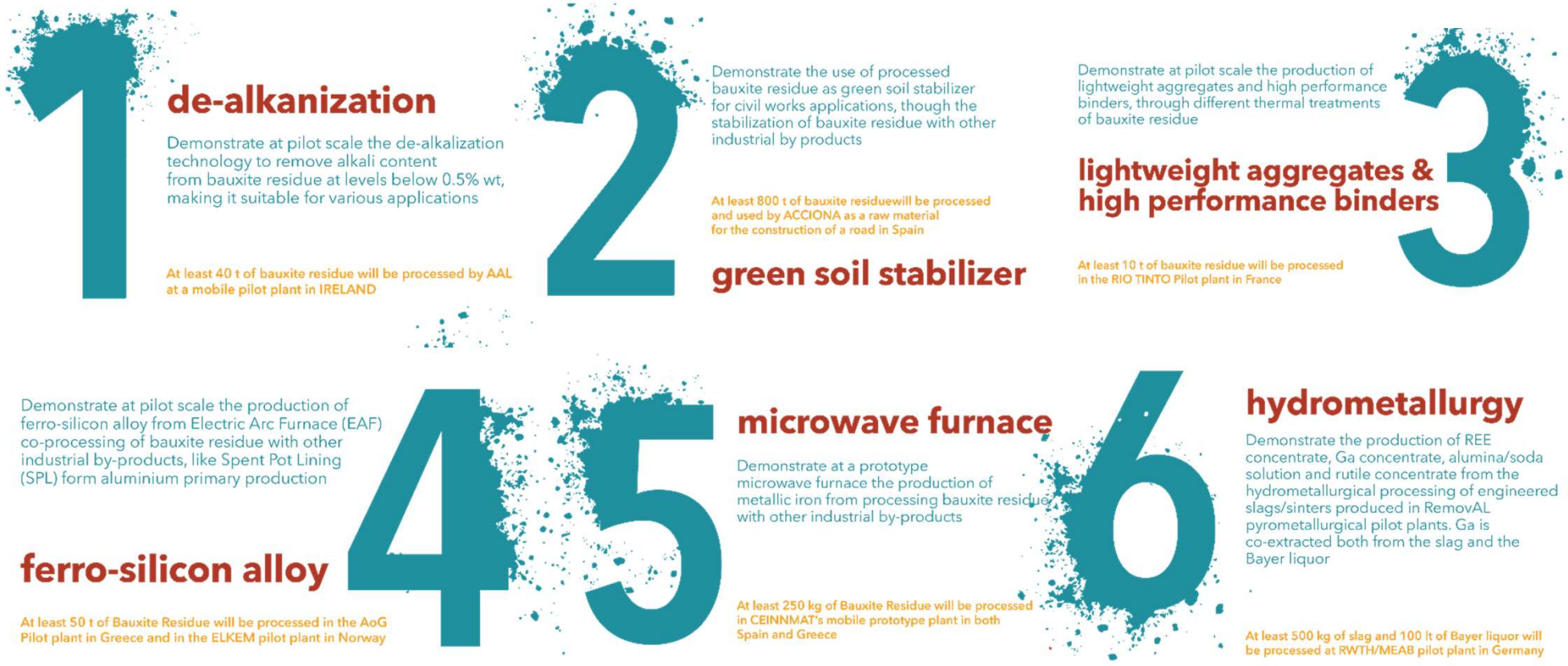


6 innovative pilot plants across Europe

Combined they will form a
network of technological nodes,
enabling optimum processing flow sheets
for valorising the produced bauxite residue

The validation will be done for 3 European alumina producers (representing 44% of the European alumina production) and one legacy site owner

The RemovAl project [2018-2022]: Combining Flowsheets



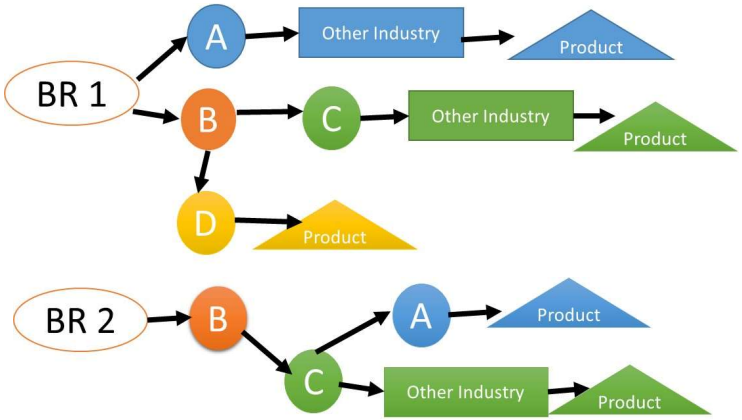
The RemovAl project [2018-2022]: Combining Flowsheets

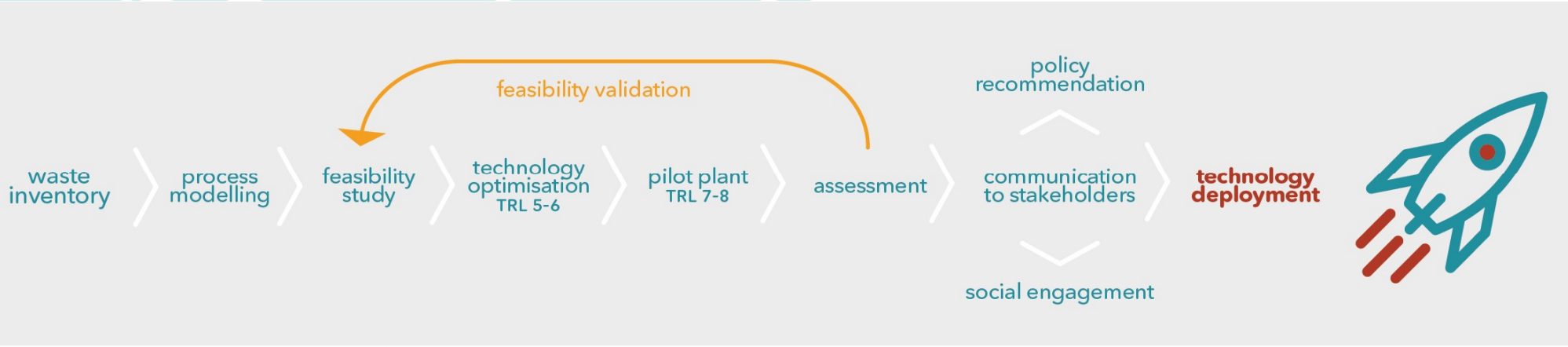
feasibility studies

for each of the 3 alumina producers and the 1 legacy site owner, detailing the optimum processing flow sheet for valorising the produced bauxite residue along with other industrial by-products, taking into consideration:

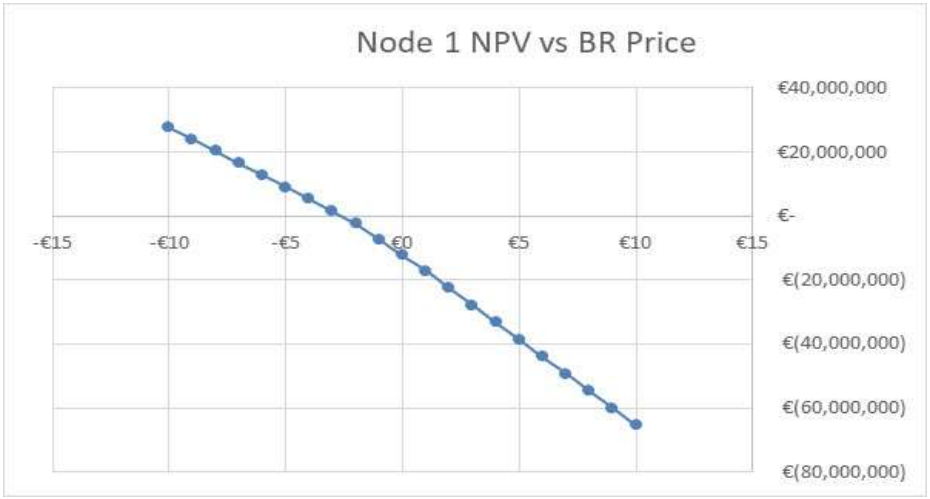
- waste characteristics
- logistics and
- symbiosis with other plants in the geographical vicinity

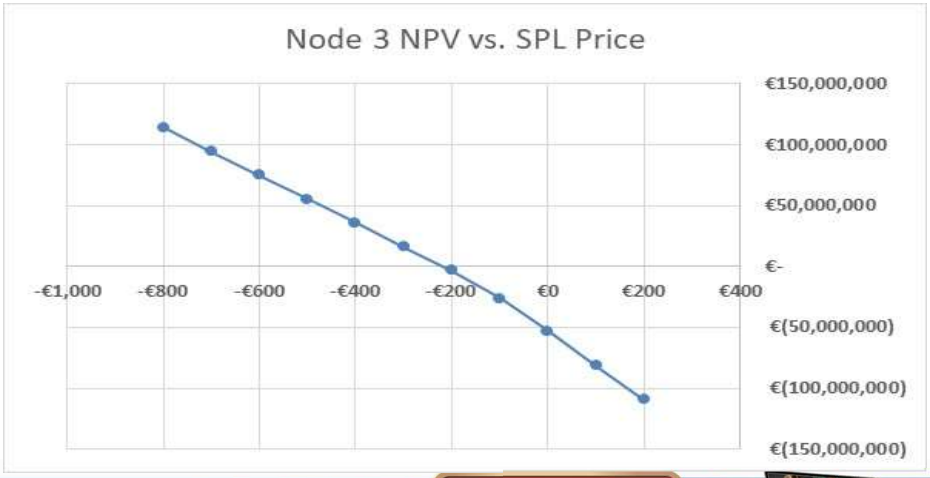
customise the solution to the industrial ecostystem of each alumina plant





The RemovAl project [2018-2022]: Combining Flowsheets





treat waste with waste

RemovAL business plans become more and more sustainable as the cost for landfilling of by-products becomes higher (or not an option at all) and industrial symbiosis becomes more and more necessary

The RemovAl project [2018-2022]: Combining Flowsheets

Demonstrate the production of new, marketable building products from the building materials produced in the pilot demonstrations

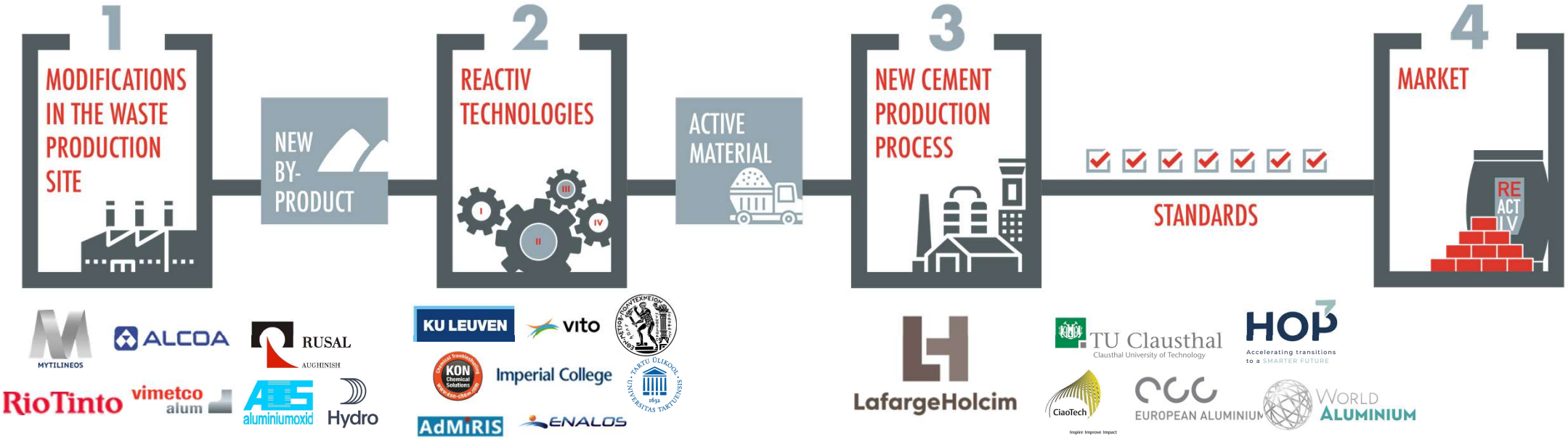
A demo house 25 m² will be built exclusively with bauxite residue building products in the housing settlement next to the AoG alumina plant

www.removal-project.com

+ Build Social Acceptance

The research leading to these results has been performed within the REMOVAL project and received funding from the European Community's Horizon 2020 Programme (H2020/2014-2020) under grant agreement n° 776469.

The ReActiv project [2020-2024]: Symbiosis with cement



RE ACT IV — INDUSTRIAL RESIDUE ACTIVATION FOR SUSTAINABLE CEMENT PRODUCTION

- Solve 2 problems in 2 sectors: waste disposal in alumina & CO_2 footprint in cement, through symbiosis
- Process BR to produce a new Supplementary Cementious Material (SCM) for novel low CO_2 cement products

Thank you for your attention

The research leading to these results has been performed within the EURARE, SCALE, REMOVAL, REACTIV projects and has received funding from the European Community's FP7 and Horizon 2020 Programme.