Bauxite Residue Handling Practice and Valorisation research in Aluminium of Greece

Efthymios Balomenos
Residue Valorization
Mytilineos S.A.- Metallurgy Business Unit
Aluminium of Greece

➢ 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

➢ 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 820,000 tons of alumina (out of which 480,000 tons are exported)

➢ Producing 185,000 tons of aluminium (out of which 125,000 tons are exported)
Activities for Residue Valorization

The AoG Alumina Refinery

Bauxite Ore

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

Alumina

Alumina precipitates from the alkaline "pregnant" solution

1,800,000 t/year
AoG processes (mainly) Greek Bauxite

800,000 t/year

750,000 t/year

Bauxite Residue (BR)
The undissolved portion of the ore, forms the Bauxite Residue (BR) by-product

Digestion

Precipitation

Filtration

Bauxite Ore

60% \( \text{Al}_2\text{O}_3 \)
20% \( \text{Fe}_2\text{O}_3 \)
15% \( \text{H}_2\text{O} \)
5% Other oxides

Alumina

99% \( \text{Al}_2\text{O}_3 \)

45% \( \text{Fe}_2\text{O}_3 \)
25% \( \text{Al}_2\text{O}_3 \)
9% \( \text{CaO} \)
5% \( \text{SiO}_2 \)
5% \( \text{TiO}_2 \)
Activities for Residue Valorization

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

...and this takes place mainly in China and India.
Activities for Residue Valorization

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**.

**AoG Vision for Red Mud**

- **2006**: Installation of 1\(^{st}\) Filterpress.
- **2007**: Pilot tests- Automation and improvements.
- **2008**: Installation of 2\(^{nd}\) Filterpress, storage site.
- **2009**: Installation of 3rd and 4\(^{th}\) Filterpress - gradual increase of operations.
- **2012 - today**: 100% dry disposal of all bauxite residue produced from the alumina refinery.
Activities for Residue Valorization

The Filter-Press Process

Bauxite Residue discharged with moisture between 26-28%

Filtrate is returned to washers, and re-introduced to the Bayer cycle
Activities for Residue Valorization

- Each filterpress carries 156 frames/filters
- Dewatering takes place in 30 min cycles
Activities for Residue Valorization

Filtrate ~ 1.200 km$^3$/y

To storage site
BR 750 kt/y (dry basis)

Recycled to the alumina plant
Activities for Residue Valorization

The BR storage site is located just behind the plant (St. Athanasios).

Storage takes place in accordance to obtained environmental permit and geotechnical study.
Activities for Residue Valorization

Geofabric and gravel introduced at specific height intervals to enhance stability
Activities for Residue Valorization

- Currently 7 plateau active with heights 9-15 m.
- The site contains over 4,5 million tons of BR already.
- Estimated to be in operation for another 20 years.
But our goal is not to make new mountains...
RESEARCH ACTIVITIES IN RESIDUE VALORIZATION

Aluminium

Alumina

Iron

Scandium

Bauxite

EU Rare

Sustainable Exploitation

REDMUD EU-REE-INN

ENEX-AL

Scale

SUREAL

Scandium Aluminium Europe

Removing waste from alumina production
Activities for Residue Valorization

Since 1991, AoG BR was been tested for use in

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

- BR can substitute up to 5-10% of the cement raw material feed as iron and alumina sources.
- The installed production capacity of the Greek cement industry could utilize all 750,000 t of BR produced in AoG with a 5% substitution in the raw meal.
- Up till now AoG BR bas been used at rates of 1.5 - 3% substitution.
- The past 5 years, 10-30 kt of BR were used in Greek cement plants annually.

This year
- the TITAN plant in Patra,
- the AGET plant in Volos,
- the VASILIKO plant in Cyprus
will utilize in total **110,000 t of BR or 15% of the annual BR produced in AoG**

Next year we will reach 20%
## Activities for Residue Valorization

### Why not more? – Key Barriers

<table>
<thead>
<tr>
<th>Barriers</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Technical Barriers</strong></td>
<td>Soda content, Cr content, moisture are the most common technical barriers, yet none of them is crucial.</td>
</tr>
<tr>
<td><strong>Legislative Barriers</strong></td>
<td>EC waste transport legislation is a complicated process requiring specific permits from all parties involved. Cross boarder transport even more complicated. <strong>There is no classification for BR only for red mud.</strong></td>
</tr>
<tr>
<td><strong>Financial Barriers</strong></td>
<td><strong>Logistics is a key issue.</strong> Cement plants are willing to utilize BR only as long as it is a cheaper alternative to other iron and alumina sources.</td>
</tr>
<tr>
<td><strong>Social Barriers</strong></td>
<td>Local Societies are always eager to protest against cement plants treating wastes ‘in their backyard’. <strong>BR handling during unloading and mill feeding is the biggest issue</strong> as any potential dusting of the BR would create significant protests by local societies.</td>
</tr>
</tbody>
</table>
## Activities for Residue Valorization

### Why not more? – Lifting Barriers

#### Technical Barriers
Air drying to further reduce moisture, De-alkalization of BR, …

#### Legislative Barriers
*EWC code 01 03 09 = waste/non-hazardous*
Once there is an ‘industrial-use’ for a waste it could be classified as a by-product, simplifying the transfer process. **Waste Declassification is a central policy decision.**

#### Financial Barriers
**Incentives** should be provided to the cement and other plants for utilizing BR and similar wastes. **Gate fees do not promote industrial symbiosis.**

#### Social Barriers
More effort should be placed on increasing social awareness – reducing NIMBYSM. **‘Popularizing science’ through RTD projects** could be a key.
Activities for Residue Valorization

In all these cases BR:

- Are used as substitutes of cheap and available raw materials (soil, clay, iron oxide…)
- Are not the main component but rather an additive in small amounts (1-30% wt)

There is need for new BR-centered processes that can be technically and financially viable
Activities for Residue Valorization

The ENEXAL 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
- **High Quality mineral wool product** produced from the slag (zero waste process)
Activities for Residue Valorization

Conclusions from ENEXAL

☑ 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 viable process
Activities for Residue Valorization

Research for a Sustainable European Exploitation Industry

FP7 2013 -
Coordinator NTUA

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
Activities for Residue Valorization

EURARE Project: REE Leaching from BR (NTUA)

Bauxite residue → Leaching with HbetTf2N → filtration → Leaching residue for pig iron production

Ionic liquid recycling → filtrate → Stripping with acid → For impurity removal to Sc2O3 production

Bauxite Residue

<table>
<thead>
<tr>
<th></th>
<th>%</th>
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<tbody>
<tr>
<td>SiO₂</td>
<td>6.54%</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>12.27%</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>56.11%</td>
</tr>
<tr>
<td>CaO</td>
<td>0.06%</td>
</tr>
<tr>
<td>TiO₂</td>
<td>7.51%</td>
</tr>
<tr>
<td>LOI</td>
<td>7.82%</td>
</tr>
</tbody>
</table>

LREEs-HREEs-Sc-Al-Fe leaching comparisons

% recovery vs Temperature (°C)

- LREE
- HREE
- Sc
- Al
- Fe
Activities for Residue Valorization

Mud2Metal: Holistic Valorization of BR

- 100% utilization of the BR stream
- Economically Viable
- Near Zero-Waste
- Industrial Symbiosis

BR Plant

Al-Sc Alloys
REE Recovery

REE Industry

1,000 t

750,000 t

Pig Iron

210,000 t

Slag Valorization

Cement

160,000 t

Mineral Wool

60,000 t

Geopolymers

80,000 t

New Building Products
Activities for Residue Valorization

H2020 2016-2020 Coordinator AoG
THE ECONOMY OF Sc

100 - 150 $/kg

Sc VALUE CHAIN:

- 0.9 $/g $\text{Sc}_2\text{O}_3$ 99%
- 5 $/g $\text{Sc}_2\text{O}_3$ 99.99%
- 253 $/g \text{ScF}_3$ 99.99%
- 206 $/g \text{Sc Metal}

Al - Sc 2%
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

"We did produce 122 out of the 162 parts on our M400 out of SCALMALLOY®. The partition weights a massive 45% less than current Airbus A320 partition designs"
Activities for Residue Valorization

**SCALE:** AN RTD PROJECT DEDICATED IN DEVELOPING A NOVEL Sc SUPPLY CHAIN

- **Horizon 2020**
- **4 year project**
- **€ 7,000,000.00**
- **AoG demo plant**

**EU MARKET POTENTIAL**

- **Alumina Sector:**
  up to 500 t/y of Sc

- **Titania Sector:**
  up to 140 t/y of Sc

**SCALE RAW MATERIAL SOURCES**

- **AoG Bauxite Residue:**
  130 g/t Sc; 750,000 t/y

- **AOS Bauxite Residue:**
  93 g/t Sc; 900,000 t/y

- **TRONOX acid waste filter cake:**
  150 g/t Sc; 50,000 t/y

*Newsflash: Sc now included on the 2017 list of Critical Raw Materials for the EU*

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The research leading to these results has been performed within the SCALE project and received funding from the European Community’s Horizon 2020 Programme (H2020/2014-2020) under grant agreement n° 730105.
Activities for Residue Valorization

SCALE:
Production of Sc compounds & Sc-Al alloys from European metallurgical by-products
Activities for Residue Valorization

CRITICAL TECHNOLOGICAL BARRIER
- extracting Sc from low grade and complicated resources/by-products

ESTABLISHED TECHNOLOGIES
- Multi stage S-X processing
- Use of HF(g)

CRITICAL MARKET BARRIER
- High processing costs
- Small production scales

mg/kg

g/kg

Sc Metal / Alloy production

99.999%
Activities for Residue Valorization

Our results so far - 18 months

- Leaching of up to 85% of Sc from Greek Bauxite Residue
- Positive results from SIR ion-exchange resin to extract Sc from dilute solutions produced
- Positive results in producing ScF$_3$ without use of HF gas
- Direct molten salt electrolytic production of Al-Sc Alloy from Sc$_2$O$_3$ – Al$_2$O$_3$ mixtures
- Room temperature electrowinning of Sc in ionic liquids from ScCl$_3$
Activities for Residue Valorization

UpScaling ULCOWIN Technology for CO$_2$-Free Steel production

SPIRE, 2017-2022, Coordinator ArceloMittal
Activities for Residue Valorization

- Iron metal electrolytically produced from iron oxide without direct involvement of carbon or fossil fuels.
- Powered by RES - cell with expert system to operate non-continuous according to RES real time availability
- Ambient temperature operation
- Soda as electrolyte
- Study for use low grade/alternative iron ores like Bauxite residue and Bauxite ore

SPIRE, 2017-2022, Coordinator ArcelorMittal
Activities for Residue Valorization

BR Electrolysis experiments @ NTUA

NaOH/H2O + BR
T = 110 °C
Duration = 2h
RE : Pt pseudoreference
Cathode: Stainless Steel
Anodes: Nickel
Current: 1A

Cathode after electrolysis

<table>
<thead>
<tr>
<th>Element</th>
<th>Weight%</th>
<th>Atomic%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe K</td>
<td>100.00</td>
<td>100.00</td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td>100.00</td>
</tr>
</tbody>
</table>

SEM-EDS
Revisit the ‘Pedersen’ process for extracting Al and Fe from lower grade bauxites and BR

Pilot Scale tests at AoG

SPIRE 2017-2021, Coordinator SINTEF
Activities for Residue Valorization

Bauxite/BR + Coke + Lime → Leachable slag → Pig iron → Alumina

M: Mayenite Ca_{12}Al_{14}O_{33}
CA: Calcium Aluminum Oxide CaAl_{2}O_{4}
S: Quartz SiO_{2}
Removing the waste streams from the primary Aluminum production in Europe

Project began on May 1\textsuperscript{st} 2018
Aluminum production in Europe creates 6,850kt of bauxite residue (red mud) yearly.

is Europe stuck in the mud
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 ecosystem of each alumina plant

**near zero-waste processing, near break-even flowsheets**

RemovAL builds on the results of **9 recent research projects**
Activities for Residue Valorization

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.

RemovAL is a consortium of 27 partners from 12 European countries.
Activities for Residue Valorization

**1. de-alkanization**

Demonstrate at pilot scale the de-alkalization technology to remove alkali content from bauxite residue at levels below 0.5% wt, making it suitable for various applications.

At least 40 t of bauxite residue will be processed by AAL at a mobile pilot plant in IRELAND.
Activities for Residue Valorization

Demonstrate the use of processed bauxite residue as green soil stabilizer for civil works applications, though the stabilization of bauxite residue with other industrial by products

At least 800 t of bauxite residue will be processed and used by ACCIONA as a raw material for the construction of a road in Spain
Demonstrate at pilot scale the production of lightweight aggregates and high performance binders, through different thermal treatments of bauxite residue.

lightweight aggregates & high performance binders

At least 10 t of bauxite residue will be processed in the RIO TINTO Pilot plant in France.
Activities for Residue Valorization

Demonstrate at pilot scale the production of ferro-silicon alloy from Electric Arc Furnace (EAF) co-processing of bauxite residue with other industrial by-products, like Spent Pot Lining (SPL) form aluminium primary production.

At least 50 t of Bauxite Residue will be processed in the AoG Pilot plant in Greece and in the ELKEM pilot plant in Norway.
Activities for Residue Valorization

microwave furnace

Demonstrate at a prototype microwave furnace the production of metallic iron from processing bauxite residue with other industrial by-products

At least 250 kg of Bauxite Residue will be processed in CEINNMAT's mobile prototype plant in both Spain and Greece
Activities for Residue Valorization

6. Hydrometallurgy

Demonstrate the production of REE concentrate, Ga concentrate, alumina/soda solution and rutile concentrate from the hydrometallurgical processing of engineered slags/sinters produced in RemovAL pyrometallurgical pilot plants. Ga is co-extracted both from the slag and the Bayer liquor.

At least 500 kg of slag and 100 lt of Bayer liquor will be processed at RWTH/MEAB pilot plant in Germany.
Activities for Residue Valorization

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

A demo house $25 \text{ m}^2$ will be built exclusively with bauxite residue building products in the housing settlement next to the AoG alumina plant.
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
Activities for Residue Valorization

the method

1. waste inventory
2. process modelling
3. feasibility study
4. technology optimisation TRL 5-6
5. pilot plant TRL 7-8
6. assessment
7. feasibility validation
8. policy recommendation
9. communication to stakeholders
10. social engagement
11. technology deployment
Activities for Residue Valorization

RemovAL is will co-organize the next BR conference, in 2021 in Ireland.
Activities for Residue Valorization

Bauxite Residue
A future valuable mineral resource

The research leading to these results has received funding from the European Union Seventh Framework Programme and H2020
Activities for Residue Valorization

Thank you for your attention

Deep Sea Port

Combined Heat and Power Plant

Aluminium Smelter

ENEXAL Pilot plant

Alumina Refinery

The AoG Plant in Ag. Nikolaos