Bauxite Residue (BR) valorization

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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 815,000 tons of alumina (out of which 480,000 tons are exported)
- Producing 175,000 tons of aluminium (out of which 125,000 tons are exported)
The AoG Alumina Refinery

Bauxite Ore

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

- 60% Al₂O₃
- 20% Fe₂O₃
- 15% H₂O
- 5% Other oxides

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

Alumina

Alumina precipitates from the alkaline "pregnant" solution.

- 99% Al₂O₃

800,000 t/year

Bauxite Residue (BR)

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

- 45% Fe₂O₃
- 25% Al₂O₃
- 9% CaO
- 5% SiO₂
- 5% TiO₂

750,000 t/year
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 Abandoned Bauxite Mines
In 2006 AoG is the first plant in Europe to install a high pressure filter to enable dry disposal of BR.

2006 - 2011 AoG invests in 4 filterpress, cost 10,000,000 €.

Since 1/1/2012 the 100% of the BR produced is deposited in AoG’s industrial landfill.

Landfill infrastructure cost 2,000,000 €.

Added annual production cost for dry BR inland management 3,500,000 €.
Since 2015 NTUA and AoG employ 2 PhD students each under the Marrie Currie project on “European Training Network for Zero-Waste Valorisation of Bauxite Residue (Red Mud)”

Starting December 1st 2016 AoG coordinates the H2020 SCALE project for Scandium extraction from industrial by-products.
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)
Mud2Metal

AoG’s BR contains REE

- More than 750,000 t produced annually in Greece and stored near the plant
- 0.14% TREO including Sc
- BR produced in AoG annually contains 10% of the European REE imports
- Potential global Sc resource
- No beneficiation methodology
- Low Th content.

REE in Bauxite residue

<table>
<thead>
<tr>
<th>REE</th>
<th>ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ce</td>
<td>483</td>
</tr>
<tr>
<td>La</td>
<td>156</td>
</tr>
<tr>
<td>Sc</td>
<td>134</td>
</tr>
<tr>
<td>Nd</td>
<td>125</td>
</tr>
<tr>
<td>Y</td>
<td>115</td>
</tr>
<tr>
<td>Pr</td>
<td>31.9</td>
</tr>
<tr>
<td>Sm</td>
<td>25.4</td>
</tr>
<tr>
<td>Dy</td>
<td>24.2</td>
</tr>
<tr>
<td>Gd</td>
<td>22.5</td>
</tr>
<tr>
<td>Yb</td>
<td>14.4</td>
</tr>
<tr>
<td>Er</td>
<td>13.7</td>
</tr>
<tr>
<td>Eu</td>
<td>5.31</td>
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</tbody>
</table>

Waste-to-resource

<table>
<thead>
<tr>
<th>Element</th>
<th>Atomic Number</th>
<th>Mass Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sc</td>
<td>21</td>
<td>44.956</td>
</tr>
<tr>
<td>Y</td>
<td>39</td>
<td>88.906</td>
</tr>
</tbody>
</table>
Under EURARE, NTUA and AoG worked on developing a method to selective leach the REE from the BR
Selective recovery of REEs against Fe, Si, Ti

The structure of the IL remains intact from the whole process of leaching and regeneration

Aqueous Strip solution produced is suitable for Sc extraction (Sc up-concentrates 8-12 times from the IL-PLS)

Pilot Scale tests under way for multiple cycles of IL regeneration

IL-PLS contains 60-80% BR's REE, 30% of Al and 4% of Fe, almost 100% Ca and Na

Solid Leach residue BR² contains 56% Iron oxides, 12% alumina, 7% titania and 6% silica
SCANDIUM (Sc)

- Global production 10-12 tpa / Demand 12-14 tpa
- Producers: Asia (China, Japan, Philippines), USA, Russia
- Current Sources:
  - TiO2 pigment product acid wastes streams
  - Uranium processing wastes (Soviet stockpiles)
  - Nickel-Cobalt Laterites (under development in Australia, Turkey, USA)
  - Bauxite Residues (Under development RUSAL, AoG)
- Mineral Resources: Bauxides and nickel laterite ores are proposed as the most promising scandium resources for future large scale Sc production; Parnassos/ Greece could well be a worldwide resource for Sc!

Sc value chain in 2013

- \( \text{Sc}_2\text{O}_3 \), 99%
  - 0.9 $/g
- \( \text{Sc}_2\text{O}_3 \), 99.9%
  - 5 $/g
- \( \text{ScF}_3 \), 99.9%
  - 253 $/g
- Sc metal
  - 206 $/g

Al-Sc2%
100-150 $/kg
**WHY IS Sc IMPORTANT?**

- 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
  - In lasers Sc garnets have 3 times higher efficiency than Y garnets
  - Sc compound is used as phosphors for high intensity “natural” light (close to solar optical spectrum)

- Sc drastically improves Aluminium alloy properties increasing strength, corrosion resistance, allowing welding and others

- $\text{Al}_{20}\text{Li}_{20}\text{Mg}_{10}\text{Sc}_{20}\text{Ti}_{30}$ has been shown to be as strong as titanium, light as aluminium, and hard as ceramic.

- The Al-Sc-Mg alloy powder is used in additive layer manufacturing (3D printing) by AIRBUS

**APWorks, 2 December 2015**

“We did produce 122 out of the 162 parts on our M400 out of SCALMALLOY®. The partition weighs a massive 45% less than current Airbus A320 partition designs”
SCALE: Production of Scandium compounds and Scandium Aluminum alloys from BR

New RTD project dedicated in developing a novel Sc supply chain

HORIZON 2020

SCALMALLOY ® 3D Printed components

Al-Sc Alloy

SOLID OXIDE FUEL CELLS: SSZ layer

LAZERS: YSG Garnets

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ALUMINIUM OF GREECE

Scandium Aluminum Europe

Bauxite Residues

TiO₂ Pigment acid wastes

Extracting Sc from waste

Sc Metal Production

Refining Sc concentrates

Metal Sc

99.996%

Sc₂O₃
- Coordinator AoG
- 4 year Project.
- 7,000,000 EUR EC funding.
- Includes industrial demo plant in AoG.
Mud2Metal

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

REE Recovery

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4,500 t Al-Sc Alloys

750,000 t BR

210,000 t Pig Iron

REE Industry

1,000 t

REE Recovery

Slag Valorization

New Building Products

Cement

Mineral Wool

Geopolymers

160,000 t

60,000 t

80,000 t

Aluminium of Greece
2ND CONFERENCE ON
EUROPEAN RARE EARTH RESOURCES
28-31 May 2017, Petros M. Nomikos Centre, Santorini, Greece

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Thank you for your attention

Deep Sea Port
Combined Heat and Power Plant
Aluminium Smelter
ENEXAL Pilot Plant
Alumina Refinery
Bauxite ore stock

The AoG Plant in Ag. Nikolaos
Mud2Metal

Bauxite Residue
A future valuable mineral resource

The research leading to these results has received funding from the European Union Seventh Framework Programme