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

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About the Presenter

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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

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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.
What is the Bauxite Residue?

Bauxite Ore

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

1,800,000 t/year

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

Alumina

99% Al2O3

800,000 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 (BR)

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

750,000 t/year

The undissolved portion of the ore forms a pulp known as ‘red mud’ or Bauxite Residue (BR).

Digestion

Precipitation

Alumina precipitates from the alkaline “pregnant” solution.

Filtration

What is the Bauxite Residue?
Bauxite Residue Handling Practices

Today there are three main options for BR handling:

**Slurry / pulp [red mud] in tailings dams**
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%*

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**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.
- 2006: Installation of 1st Filterpress.
- 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
But our goal is not to make new mountains...
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
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 has 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.
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.

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-border 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 as it 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 needed for added value products.
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

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

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

SiO$_2$ 6.54 %
Al$_2$O$_3$ 12.27 %
Fe$_2$O$_3$ 56.11 %
CaO 0.06 %
TiO$_2$ 7.51 %
LOI 7.82 %

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LREEs–HREEs–Sc–Al–Fe leaching comparisons

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

Paraskevi Davai, Efthymios Balomenos, Dimitrios Panias, and Ioannis Paspalakis

Evaluating the feasibility and the potential of using ionic liquids (ILs) as versatile solvents possessing selectively to dissolve rare earth elements (REEs) from bauxite residue. The leaching process is based on the ethylbis[2-methylphenyl]hexafluorophosphate ([Hbet] [Tf$_2$N]) and other similar ionic liquids in a series. Leaching bauxite residue with HbetTf$_2$N selectively dissolves HREEs (~3%) against LREs, Al, Fe, and Ti promoting a solid residue to be utilized as cement or iron industry. Scandium appears in four different building behaviour attention [1, 2]; since REE are critical metals used in advanced applications and for applying geothermal technology [3–5]. Studies have shown that China's REE contains ~1% Yttrium (Y), but this concentration is fairly constant. With a small variation over several years, the REE market is found to be volatile with unprecedented fluctuations of their prices, yet scandium has steadily increasing its prices over the years. Scandium can be produced as a byproduct of the Y, Th, Lu, W, Re, Ta, Ti, and Ti2O5's mechanical production [6], yet it has been pointed out that scandium and lanthanum are the two promising rare earths for a long term.
Mud2Metal: Holistic Valorization of BR

100% reuse of BR through multiple products/process:
- Near Zero-Waste
- Near break-even
- Symbiotic with other industries

Our Vision
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

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 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
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

1. **de-alkanization**
   - Demonstrate at pilot scale the de-alkanization 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.

2. **green soil stabilizer**
   - 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.

3. **lightweight aggregates & high performance binders**
   - Demonstrate at pilot scale the production of lightweight aggregates and high performance binders, through different thermal treatments of bauxite residue.
   - At least 10 t of bauxite residue will be processed in the RIO TINTO Pilot plant in France.

4. **ferro-silicon alloy**
   - 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.

5. **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 CERNAMAF’s mobile prototype plant in both Spain and Greece.

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 t of Bayer liquor will be processed at IWTH/MEAll pilot plant in Germany.
The RemovAI 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
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 ReActiv project [2020-2024]: Symbiosis with cement

- Solve 2 problems in 2 sectors: waste disposal in alumina & CO2 footprint in cement, through symbiosis
- Process BR to produce a new Supplementary Cementious Material (SCM) for novel low CO2 cement products
Thank you for your attention

The AoG Plant in Ag. Nikolaos

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