Bauxite Residue Handling Practice and Valorisation research in Aluminium of Greece

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Residue Valorization
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MYTILINEOS

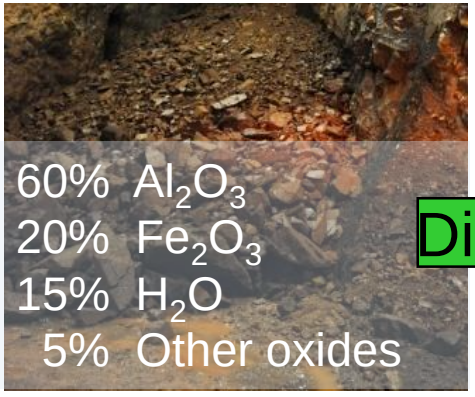
ALUMINIUM OF GREECE
METALLURGY BUSINESS UNIT

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)

The AoG Alumina Refinery

Bauxite Ore

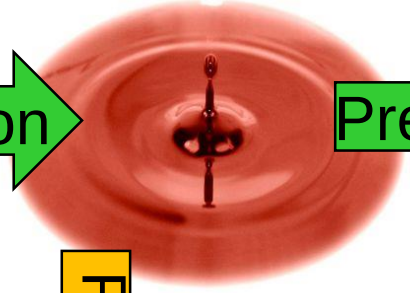


1,800,000 t/year

AoG processes (mainly) Greek Bauxite

Digestion

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



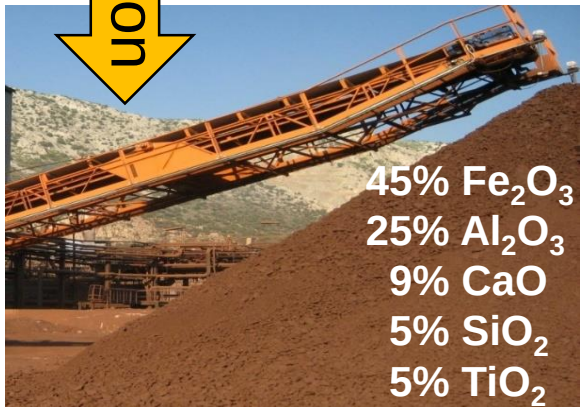
Precipitation

Alumina

800,000 t/year

Alumina precipitates from the alkaline "pregnant" solution

Filtration



Bauxite Residue (BR)

750,000 t/year

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

Activities for Residue Valorization

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

…and this takes place mainly in **China and India**

Activities for Residue Valorization

AoG Vision for Red Mud

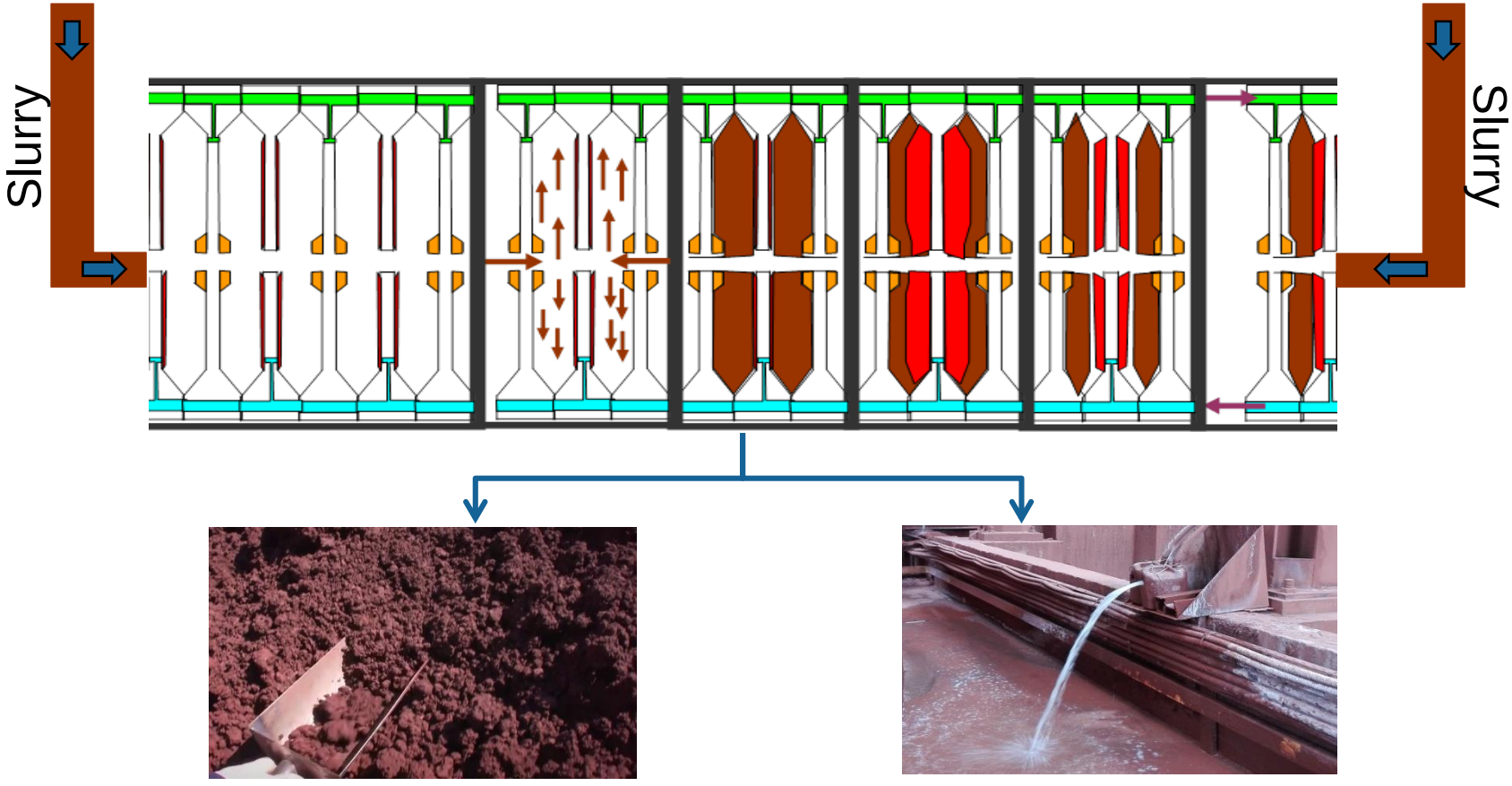
To remove the water content from the slurry so:

- 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 .
- 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.**



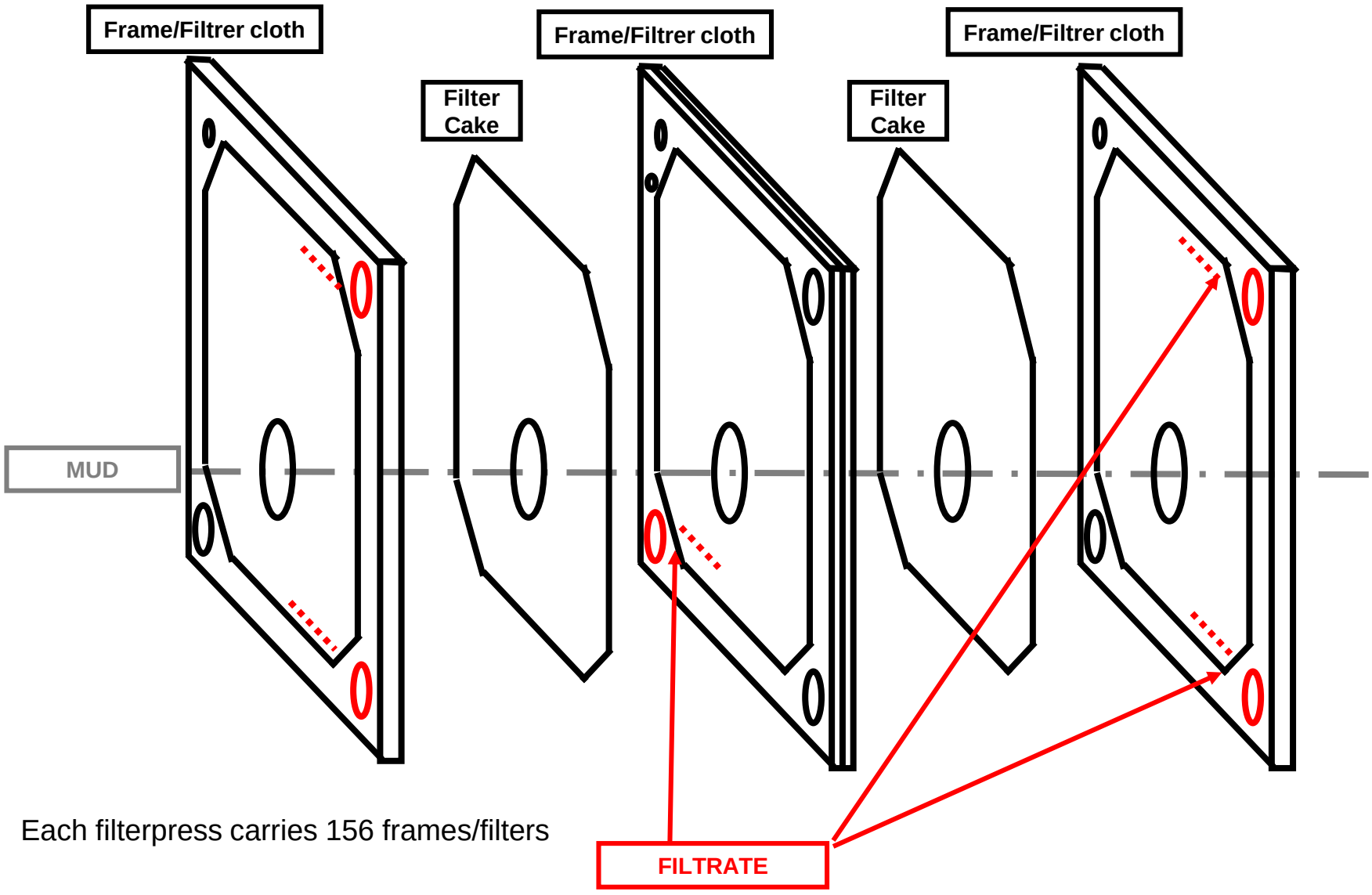

The Filter-Press Process



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

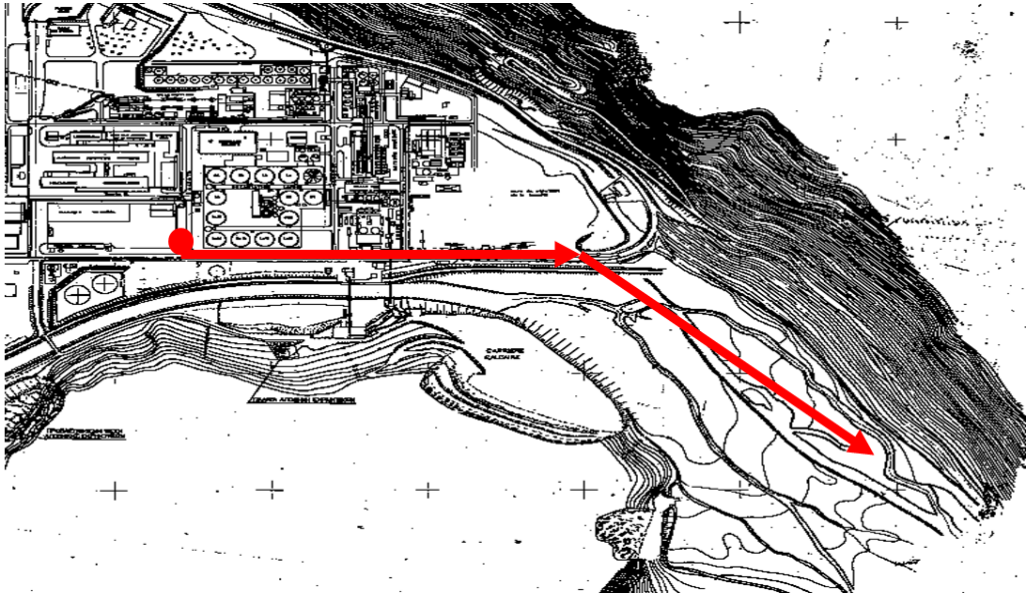
Filtrate ~ 1.200 km^3/y

Recycled to the alumina plant

BR 750 kt/y (dry basis)

To storage site

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

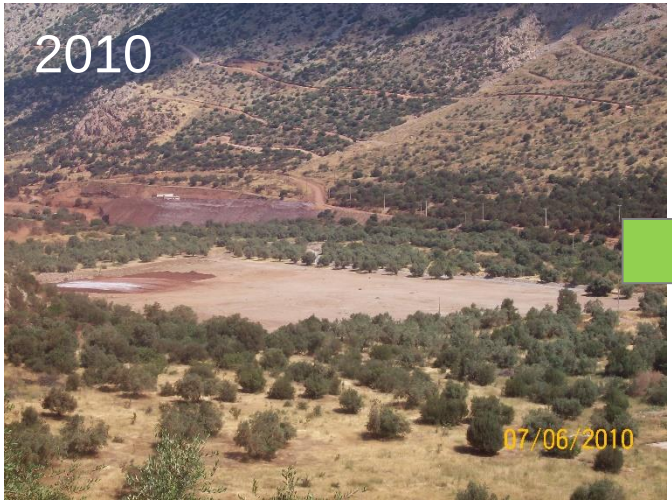
Activities for Residue Valorization

Central pipeline

Peripheral draining channels

Geofabric and gravel introduced at specific height intervals to enhance stability

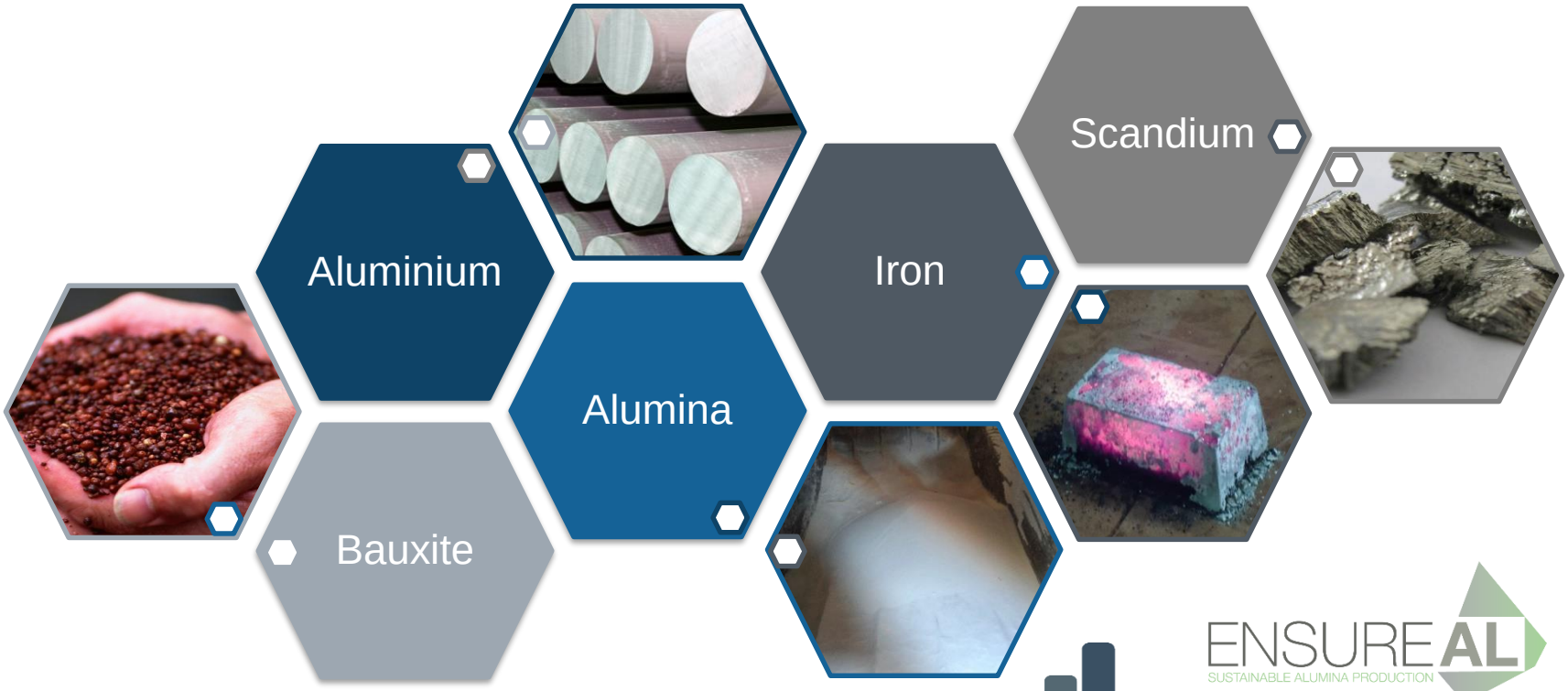
Activities for Residue Valorization



- 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



eu Rare 57-71 sustainable exploitation

REDMUD EU MSCA-ETN

EN Energy EX Energy AL Aluminium

scale SCANDIUM ALUMINIUM EUROPE

ENSURE AL SUSTAINABLE ALUMINA PRODUCTION

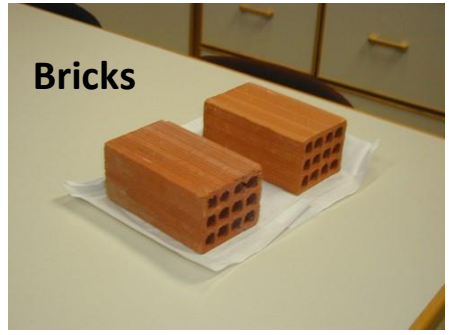
removAL removing waste from alumina production

Activities for Residue Valorization

CEMENT

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



Geopolymers

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

- theTITAN 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%

BR loading at AoG

Why not more ? – Key Barriers

Technical Barriers

Soda content, Cr content, moisture are the most common technical barriers, yet none of them is crucial.

Legislative Barriers

EWC code 01 03 09 = waste/non-hazardous

EC waste transport legislation is a complicated process requiring specific permits from all parties involved. Cross boarder transport even more complicated.
There is no classification for BR only for red mud.

Financial Barriers

Logistics is a key issue. Cement plants are willing to utilize BR only as long at is a cheaper alternative to other iron and alumina sources.

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.

Why not more ? – Lifting Barriers

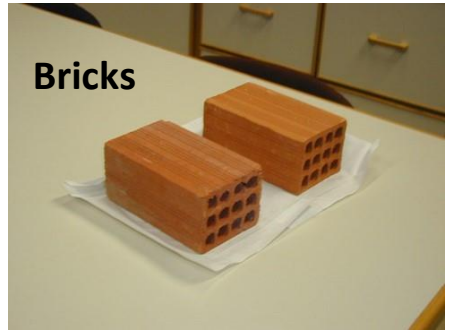
Technical Barriers	Air drying to further reduce moisture, De-alkalization of BR, …
Legislative Barriers **EWC code 01 03 09 = waste/non-hazardous**	Once there is an 'industrial- use' for a waste it could be classified as a by-product, simplifying the transfer process. **Waste Declassification is a central 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

CEMENT

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 ratter an additive in small amounts (1-30% wt)

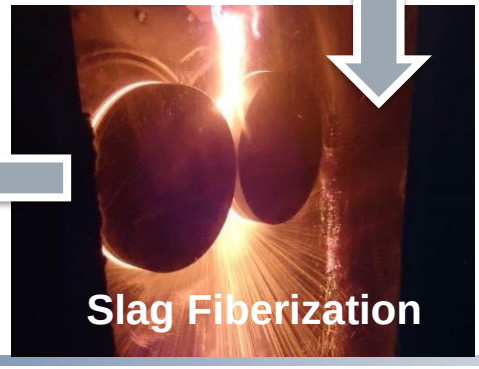


Geopolymers

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

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)



EN Energy EX Exergy AL Aluminium

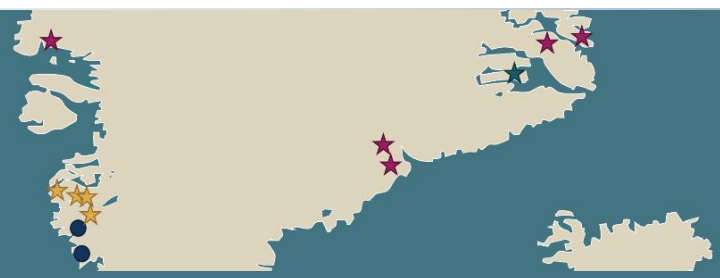
Conclusions from ENEXAL

- ☑ 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

ES IN EUROPE

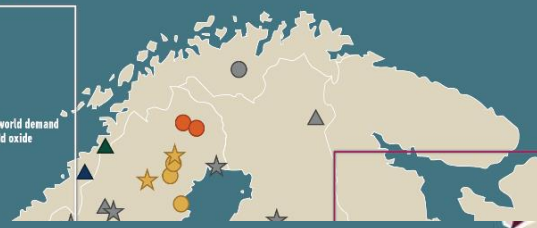


NORRA KÄRR DEPOSIT, SWEDEN

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: Eydialite

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

deposits (Greenland,

n analysis performed
produced for 5 samples
mal, 1 placer deposit)

$^{+}_{0.3}Y_{0.1}ZrSi_6O_{22}(OH)_{1.5}Cl_{0.5}$

THE KVANEFJELD DEMONSTRATION LINE:

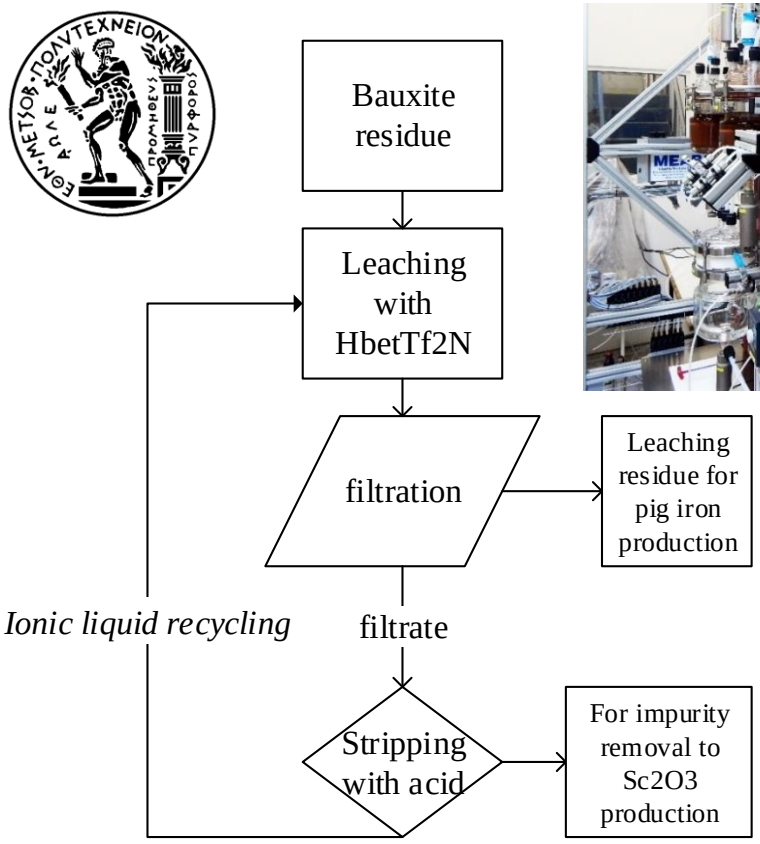
KVANEFJELD SAMPLE
GME, GREENLAND

4 T ORE
1.3% REO

BENEFICIATION PI
GTK, FINLAND

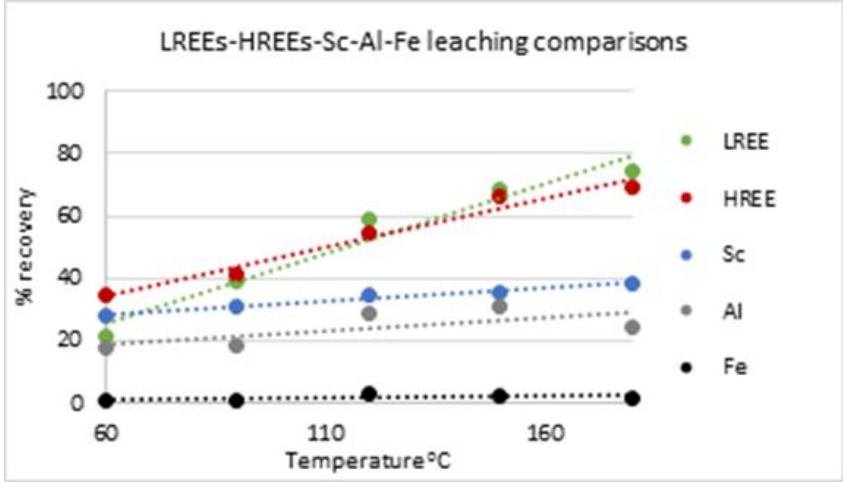
250 kg
Mineral Concentrati
15% REO

EURARE Project: REE Leaching from BR (NTUA)



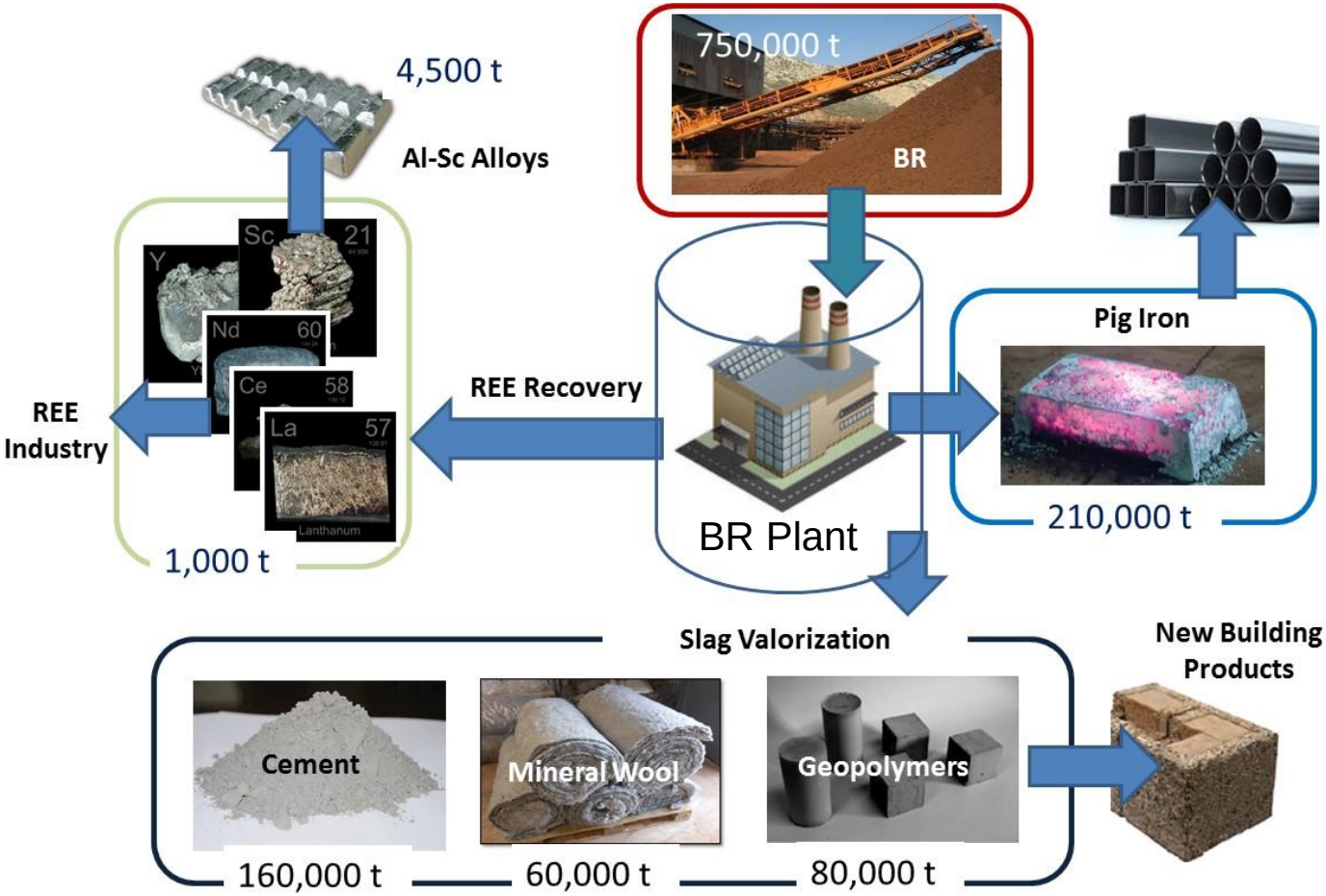
Bauxite Residue [2]

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



eu Rare 57-71 sustainable exploitation

Mud2Metal: Holistic Valorization of BR



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

Activities for Residue Valorization

ALUMINIUM OF GREECE
METALLURGY BUSINESS UNIT

scale
SCANDIUM ALUMINIUM EUROPE

what is scandium?

RARE EARTH
scandium
21
Sc
44.956

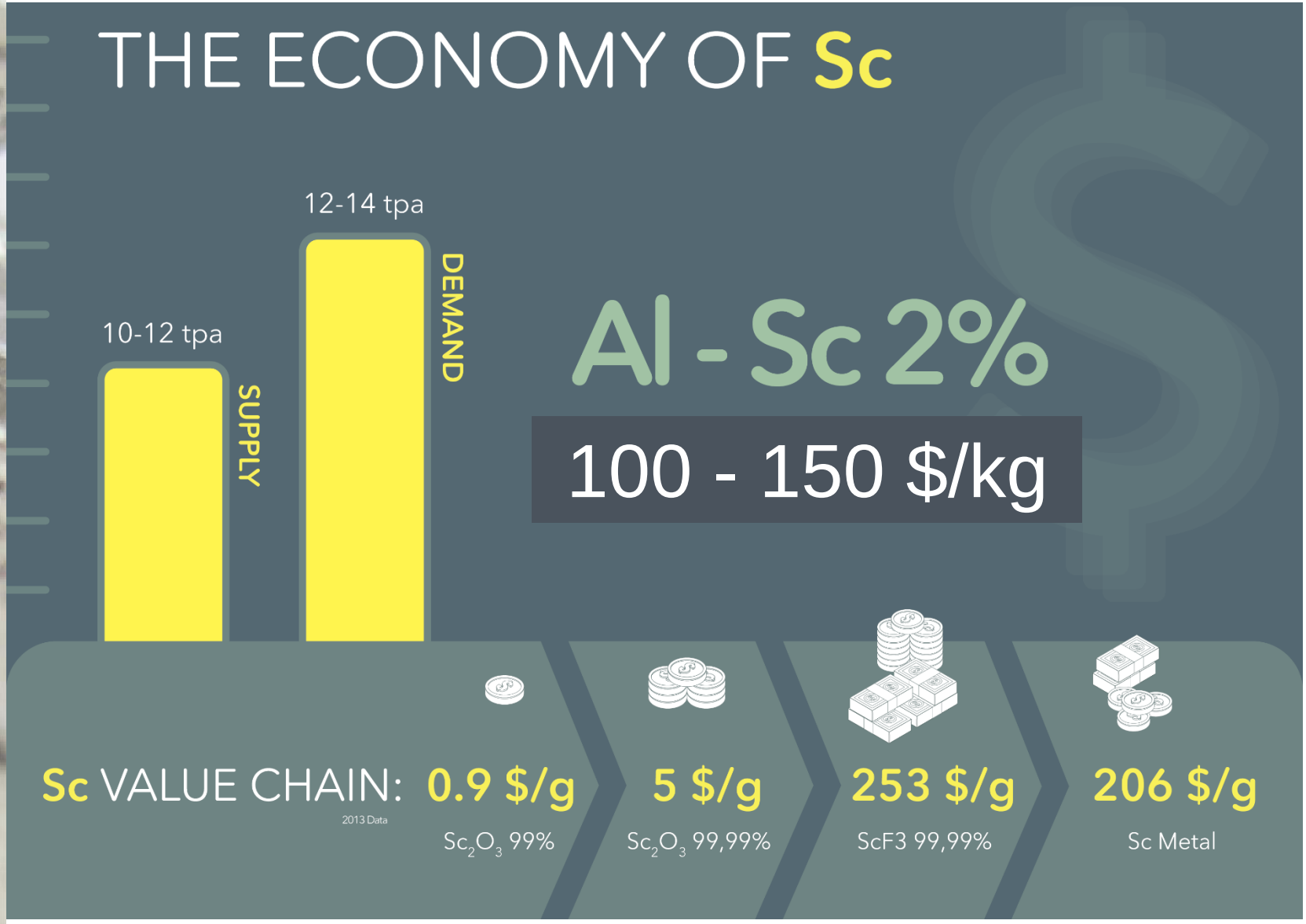
H2020 2016-2020
Coordinator AoG

Activities for Residue Valorization

ALUMINIUM OF GREECE
METALLURGY BUSINESS UNIT

MYTILINEOS

scale
SCANDIUM ALUMINIUM EUROPE



Activities for Residue Valorization

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METALLURGY BUSINESS UNIT

scale
SCANDIUM ALUMINIUM EUROPE

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

Sc+Al

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 weights a massive 45% less than current Airbus A320 partition designs”

Activities for Residue Valorization

MYTILINEOS

ALUMINIUM OF GREECE
METALLURGY BUSINESS UNIT

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

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

SCALE RAW MATERIAL SOURCES

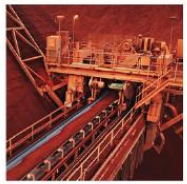
AoG Bauxite Residue:
130 g/t Sc; 750,000 t/y

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

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

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



Bauxite Residues
TiO_2 Pigment Acid Wastes

mg/kg

EXTRACTING

Sc from waste

g/kg

REFINING

Sc concentrates

PRODUCING

Sc Metal

Sc_2O_3

SCALE:

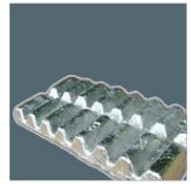
Production of Sc compounds & Sc-Al alloys from European metallugrical by-products

LASERS: YSG GARNETS

II-VI

SSZ LAYER SOLID OXIDE FUEL CELLS

AL-SC ALLOY



IKBM AFFILIPS MASTER ALLOYS

SCALMALLOY 3D PRINTING

AIRBUS

scale

SCANDIUM ALUMINIUM EUROPE

Activities for Residue Valorization

ALUMINIUM OF GREECE
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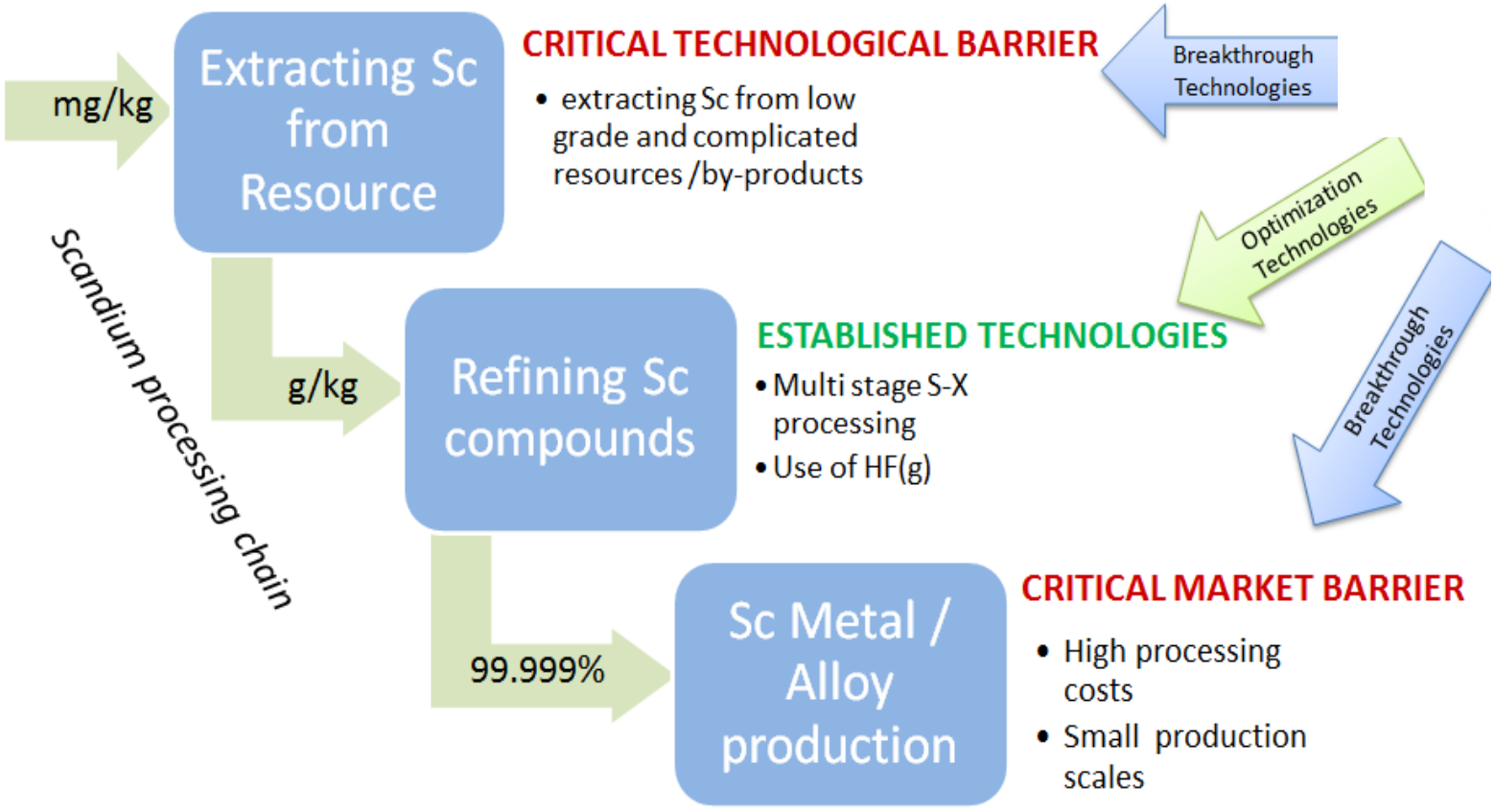
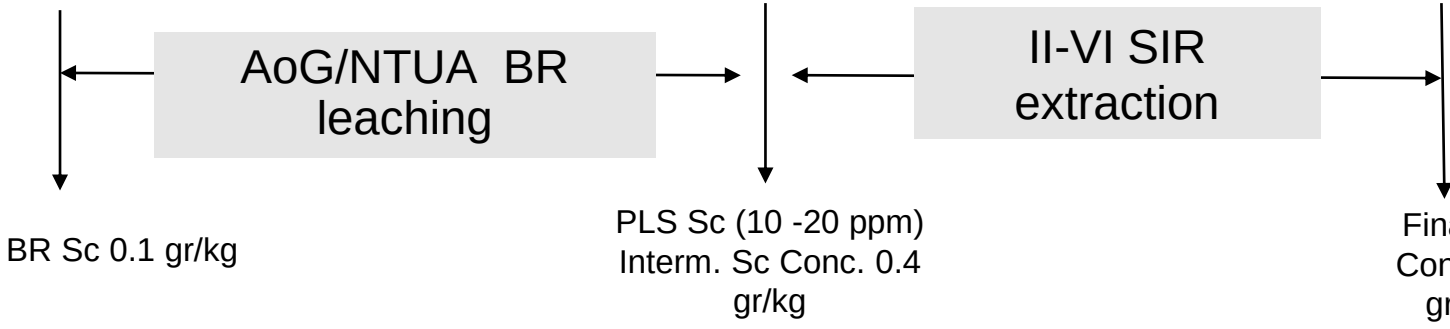


Our results so far - 18 months

- Leaching of up to 85% of Sc from Greek Bauxite Residue
- Positive resutls 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 $Sc_2O_3 – Al_2O_3$ mixtures
- Room temperature electrowining of Sc in ionic liquids from $ScCl_3$

Activities for Residue Valorization

Development of new methodologieS for InDustrial CO2-freE steel pRoduction by electroWINning

Upscaling ULCOWIN technology for CO_2–Free Steel production

SPIRE, 2017-2022, Coordinator ArceloMittal

Activities for Residue Valorization

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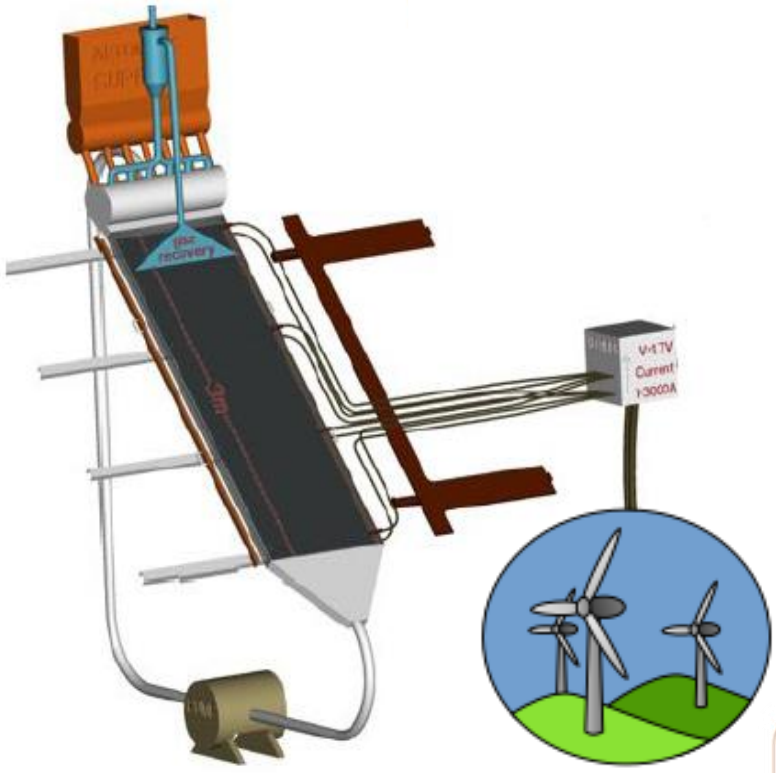
Siderwin

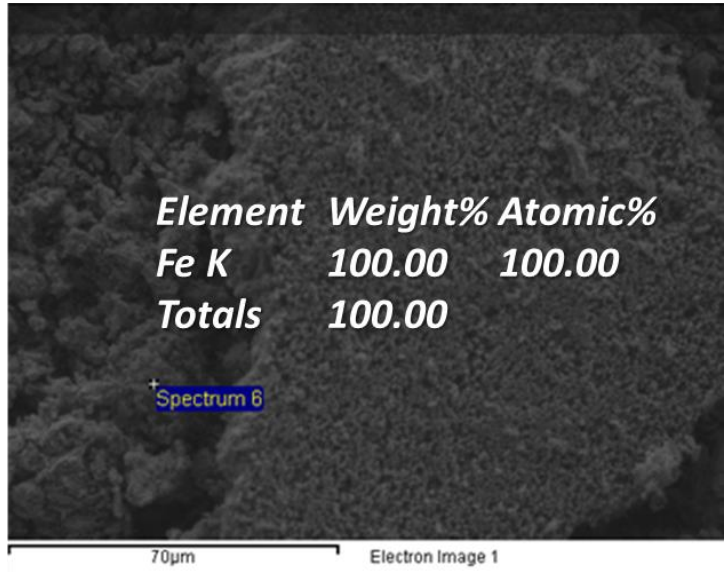
Development of new methodologies for InDustrial CO2-freE steel pRoduction by electroWINning



- 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

BR Electrolysis experiments @ NTUA



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

Cathode after electrolysis

SEM-EDS

Siderwin

Activities for Residue Valorization

ENSUREAL: Integrated cross-sectorial approach for environmentally sustainable and resource-efficient alumina production

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

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ENSUREAL
SUSTAINABLE ALUMINA PRODUCTION

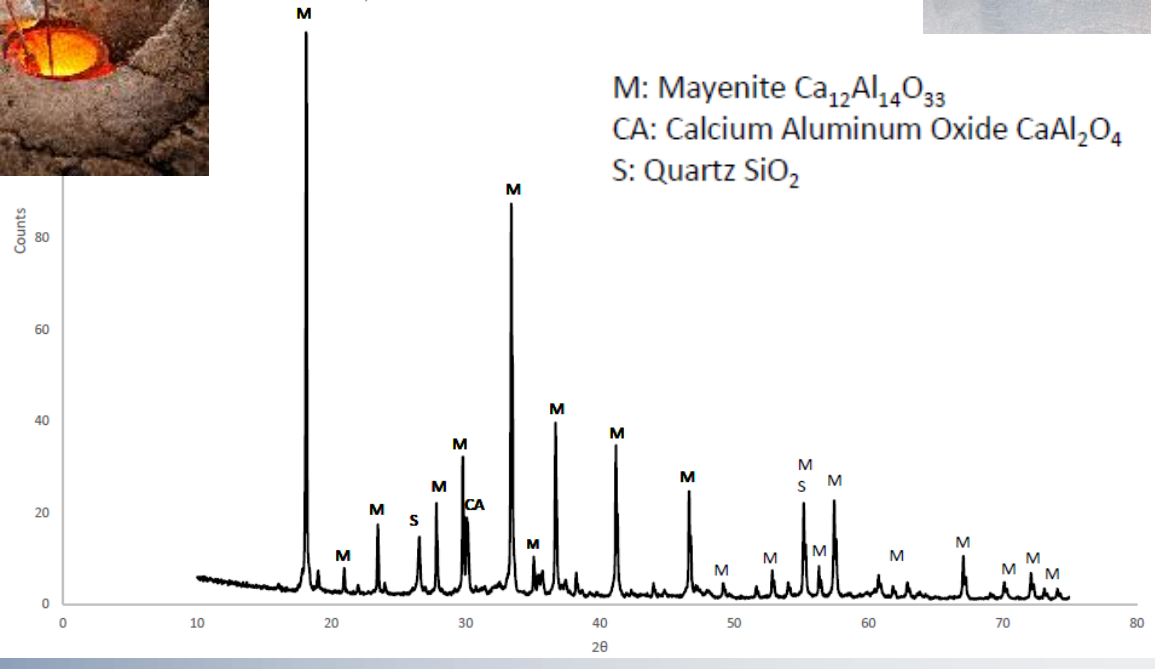
+

+

Pig iron

Alumina

Leachable slag



NTNU
Norwegian University of Science and Technology

Activities for Residue Valorization

removal

removing waste from alumina production

H2020 2018-2022, Coordinator AoG

Removing the waste streams from the primary Aluminum production in Europe

Project began on May 1st 2018


Aluminum production in Europe creates
6,850kt of bauxite residue (red mud) yearly
is Europe stuck in the mud

Activities for Residue Valorization

MYTILINEOS

ALUMINIUM OF GREECE
METALLURGY BUSINESS UNIT

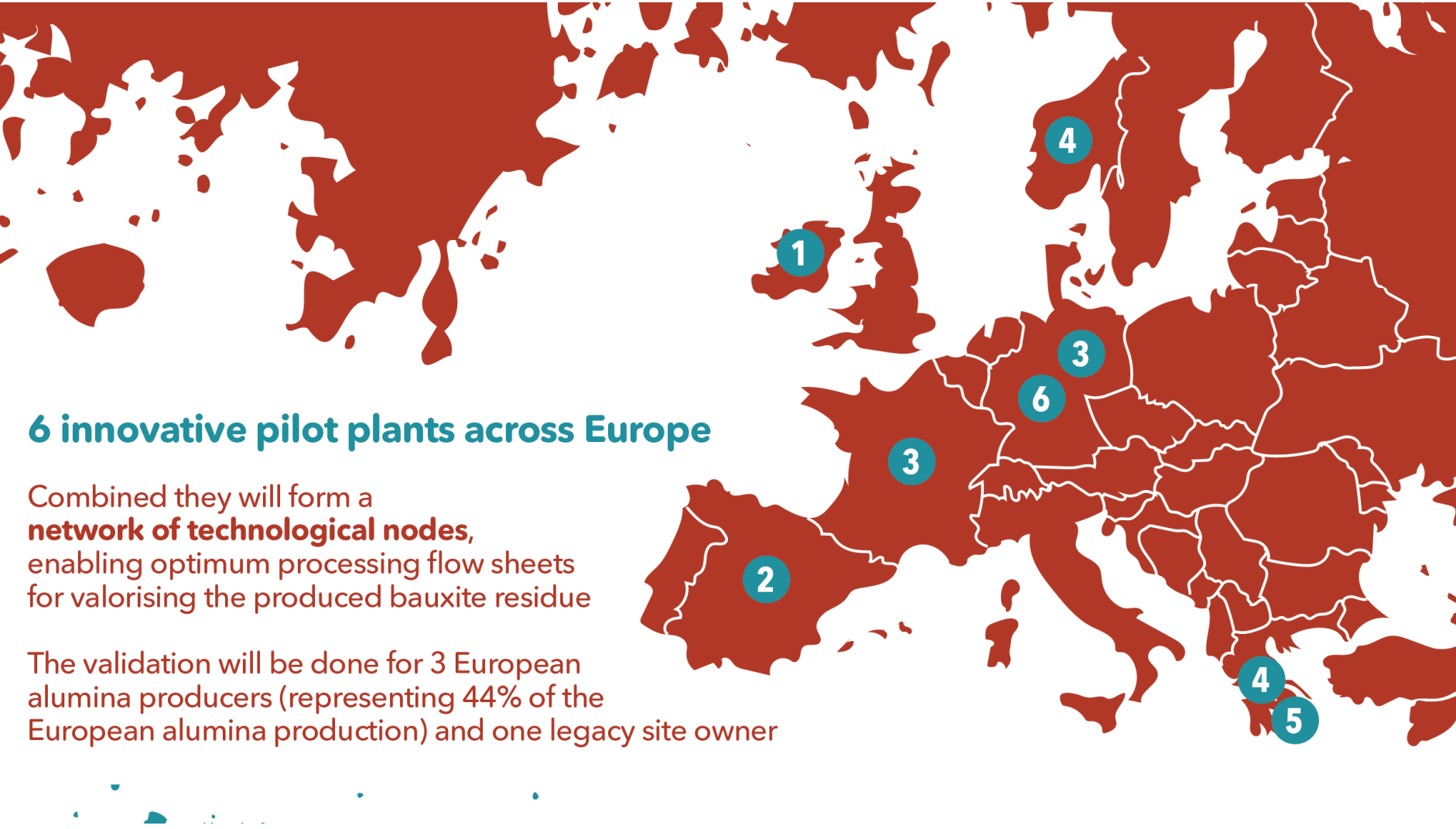
RemovAL overcomes the barriers of economic viability by pooling together and integrating proposed stand-alone solutions, while adhering to the following principles:

- 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

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

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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 residuewill be processed and used by ACCIONA as a raw material for the construction of a road in Spain

green soil stabilizer

Activities for Residue Valorization

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

4

ferro-silicon alloy

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

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

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

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Activities for Residue Valorization

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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

MYTILINEOS

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the method

Activities for Residue Valorization

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www.removal-project.com

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.

RemovAL is will co-organize **the next BR conference, in 2021 in Ireland**

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

Thank you for your attention