The Time has Come for Refractory Sustainability

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Topics to be Covered

- Definition
- Consumption/markets
- Circular economy
- Greenhouse gasses
- Raw materials
- Mining
- Waste management: recycling, re-application

NOT presented: water use, transportation, social impact

For the refractory industry to truly achieve sustainability on a large scale, manufacturers need a more comprehensive way of measuring their environmental impact.

("Why Refractory Manufacturers Should Embrace Sustainability and See Net Zero as an Opportunity", July, 2022, www.worldrefractories.org)

Definition

- UN defined **sustainability** as "meeting the needs of the present without compromising the ability of future generations to meet their own needs." (Brundtland Commission, 1987)
- **Sustainability** is the practice of using natural resources responsibly today, so they are available for future generations tomorrow. (National Geographic, 2022)

For Refractories this Means....

1) Lowering the emissions (carbon and others) from raw material mining ⟶ transportation ⟶ manufacturing ⟶ product use/reuse ⟶ burial: circular economy / life cycle analysis

2) Lowering the energy requirement from mining production ⟶ bringing into use ⟶ finding a new home: circular economy

3) Develop new products to better address the user's requirements: lower consumption / eco-design

4) Ensure water consumption/contamination is minimized throughout the life cycle: lower consumption

Cont'd

5) Modify mining & refractory manufacturing steps to lower waste: circular economy /eco-design

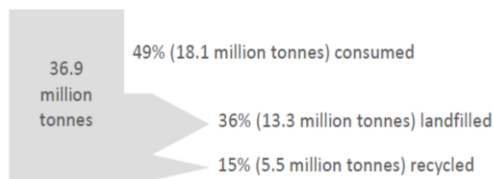
6) Develop new applications or new products for used refractories / by-products: recycling / circular economy

7) Consider the user's process to improve refractory life: lower consumption

8) Other

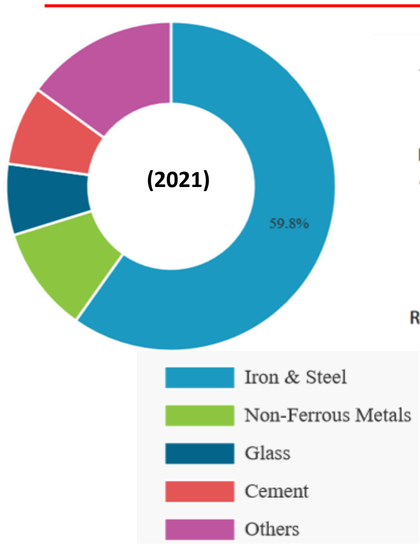
Refractories: Some Numbers

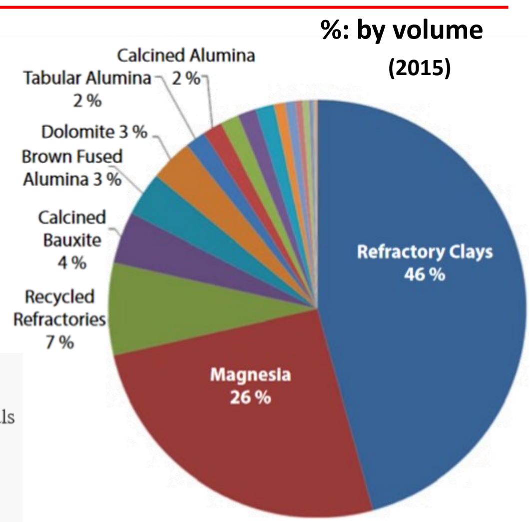
- 36.9 million tonnes produced in 2014, about 2/3 in China (in 2025 expected to reach 52.4 million tons*[18])
- The steel industry uses about 60-75% of ALL refractories
- Every year almost 20 million tonnes of refractory waste are produced



"Life cycle assessment of refractory waste management in a Spanish steel works", I. Muñoz, LCA consultants, 2020

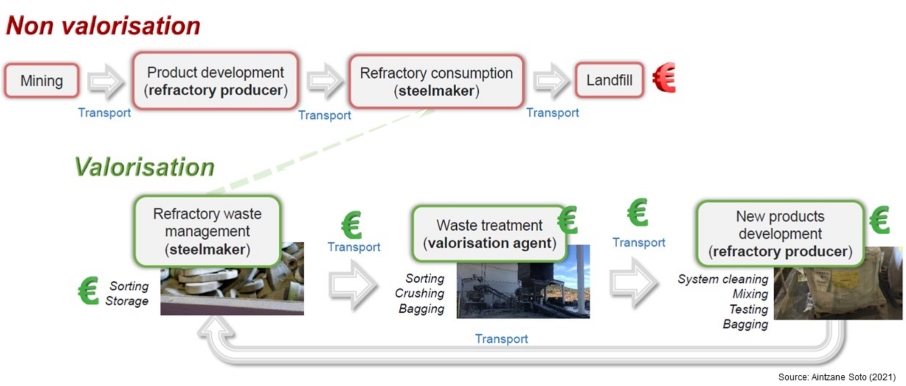
Global Market Share[21] & Consumption[6]



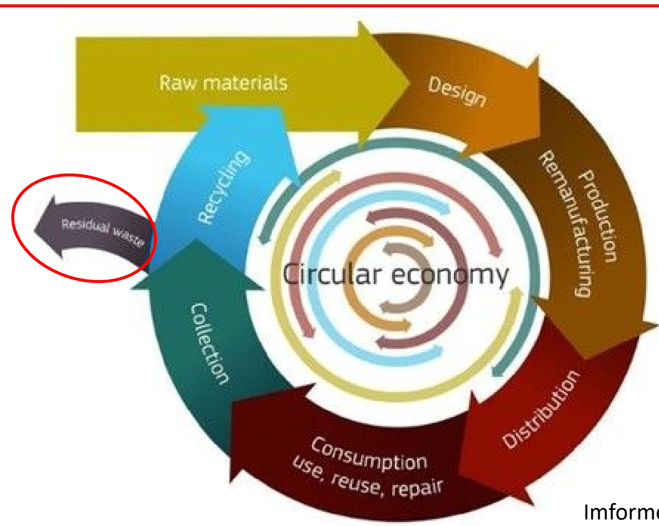


Estimated world consumption of refractory minerals: total ~35m tonnes (Imformed)

Refractory “Waste” Management*2

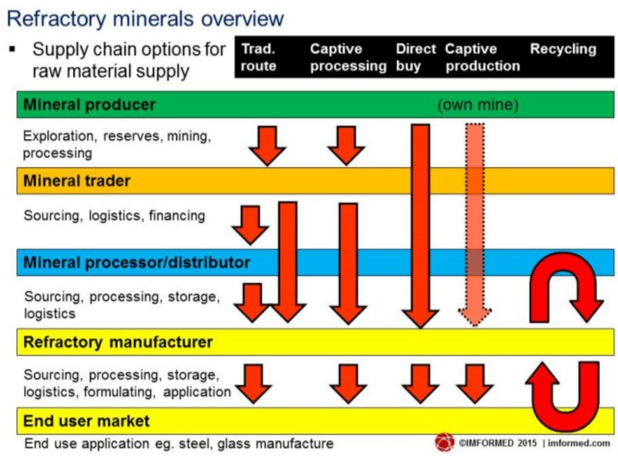


Circular Economy for Refractories



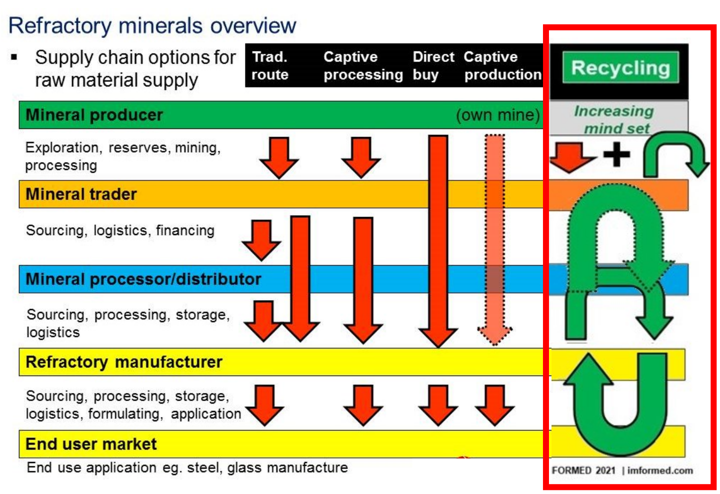
Imformed

Raw Materials: Supply Chain Options



UNITECR 2015

Raw Materials: Supply Chain Options



Greenhouse Gases

Gases in the Earth's atmosphere that trap heat.

Main ones are:

- Water vapor (H2O)
- Carbon dioxide (CO2)
- Methane (CH4)
- Ozone (O3)
- Nitrous oxide (N2O)
- Chlorofluorocarbons (CFCs)

Carbon Management Technologies

Several technologies under development for decarbonization (required to achieve zero emissions)

Reuse: injection of captured CO_2 into fresh concrete during manufacturing; reacts with the cement to form a carbonate (mineral) that strengthens the concrete*[22]

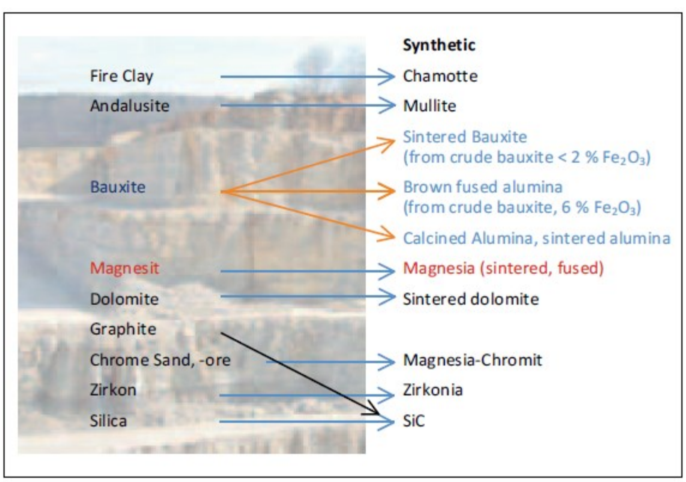
Sequestration: CO_2 is dissolved in water which is injected into the subsurface. There it reacts with porous basalt rock. In less than two years, the CO_2 forms solid carbonate minerals*[23]

Raw Materials: Sources

- Natural: mined, generally somewhat modified prior to use, ex. magnesite to magnesia
- Manufactured: mined, greatly modified, ex. fused magnesia-chrome, white or brown fused alumina

Mining: responsible for 4 to 7% of greenhouse gas emissions*[10]

Main Raw Materials



"Refractory raw materials – development, trends, availability", A. Baake et al., RWF, 2012

Bauxite Tailings Treatment*[14]

- Reworking the tailings
  - Increases deposit’s lifetime
  - Adds product capacity
  - Reduces discharge
- Case study showed:
  - Al2O3 improvement from 50.0% to 72.3%
  - SiO2 reduction from 12.1% to 4.4%

ECO2 Magnesia (Quebec, Canada)

Production based on offering a "second life" to currently discarded and unused waste materials by “decontamination of mine tailings” www.eco2-magnesia.com/index.html

Technology uses mine tailings, water & CO_2 to “extract” MgO
Product: up to 99% pure MgO

Has build a demonstration plant; hopes to have a plant in operation (2025)

Other Re-application of Mine Tailings

- **Cr ore tailings** treated for PGM (platinum, rhodium, palladium, etc.) recovery with 10 plants in operation or under construction (2011)
- Economically proven using standard equipment

(www.miningreview.com/top-stories/treating-chrome-tailings-for-pgms/, visited Jan. 2023)

The 3Rs of "Waste" Management

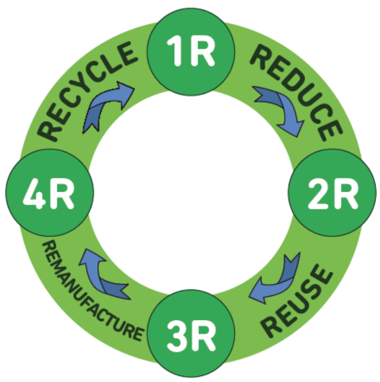
Refractory strategies to achieve the 3Rs:

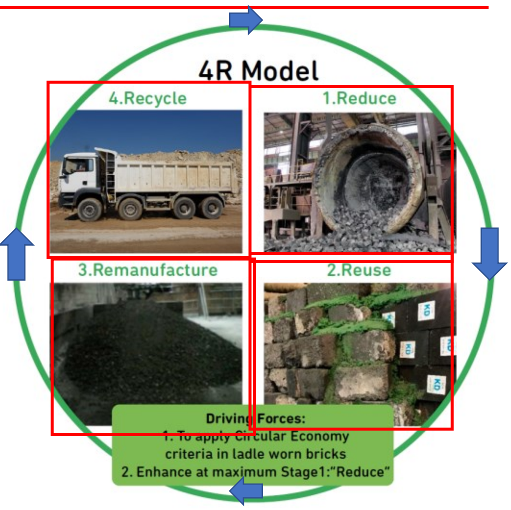
reduce the amount of refractories used

reuse of raw materials

recycle the spent refractories

The 4Rs

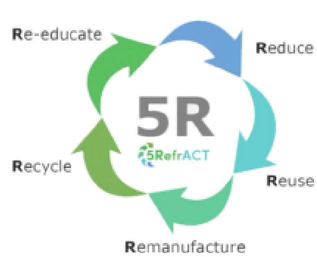




"Best Practices in Refractory Waste Management", A. Soto, M.A. Mangas, D. Maza, 5RefrACT

The 5Rs

According to the 5 R's, four actions should be taken before reaching 'recycling': **refuse/reject** (waste), **reduce** (consumption)**, reuse, repurpose/repair, and only *then* recycle.**



and the Rs continue coming…..6, 7,….

What is being done with refractories!

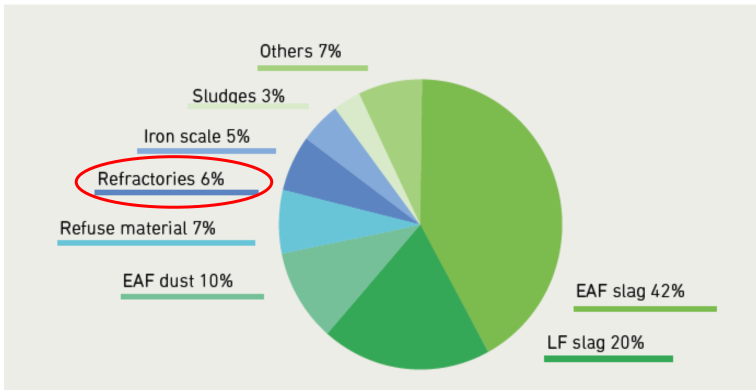
Life 5ReFRACT Project: Purpose

- Extend the "4R" approach to "5R": **r**educe-**r**euse-**r**emanufacture-**r**ecycle-**r**e-educate
- Apply this to the steel sector and refractory's market
- Duration: July 1, 2018 to Sept. 30, 2020; location: Sidenor

  (Basque Country, Spain)
- **<u>Documented their results</u>**

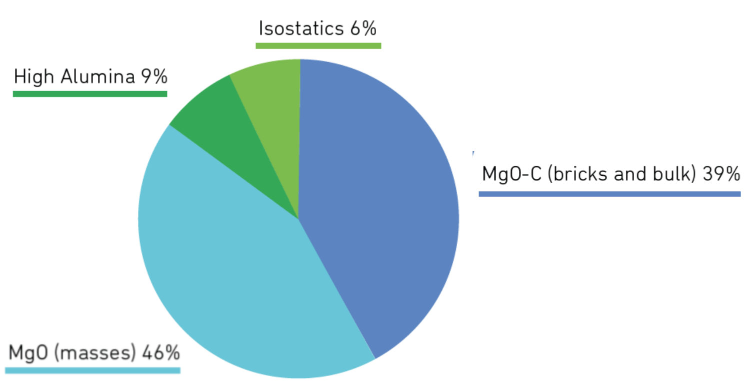
(www.life5refract.eu/en/, visited Febr. 2021)

Waste Distribution in a Steel Mill (EAF)



"Best Practices in Refractory Waste Management", A. Soto, M.A. Mangas, D. Maza, Sidenor, 5RefrACT

Recoverable Refr. Waste Distribution (2018)



"Best Practices in Refractory Waste Management", A. Soto, M.A. Mangas, D. Maza, Sidenor, 5RefrACT

Re-Use: Electric Arc Furnace (EAF)

Install used MgO-C brick as a wall in front off new brick:

- Reduce the thickness of the new brick
- Improve flow of steel at tap time

DOES NOT REQUIRE <u>TOTAL</u> SLAG REMOVAL

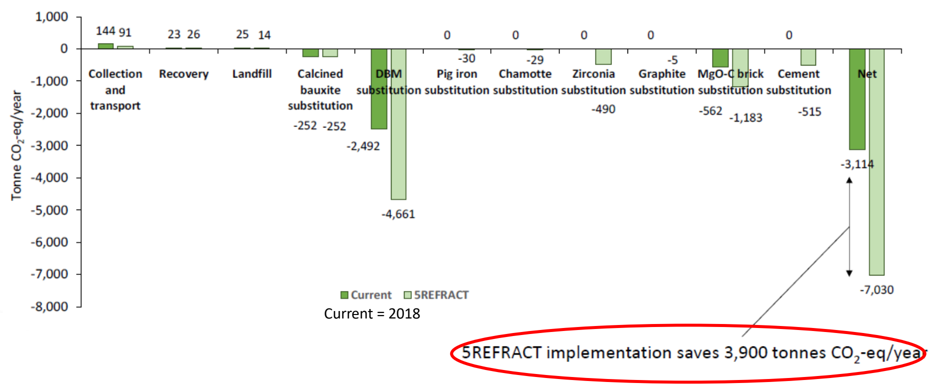
Detail of prewall using recycled brick

"Best Practices in Refractory Waste Management", A. Soto, M.A. Mangas, D. Maza, Sidenor, 5RefrACT

New Product Using "Refractory Waste"

"Layman's Report",5RefrACT

Greenhouse Gas Emissions per Year

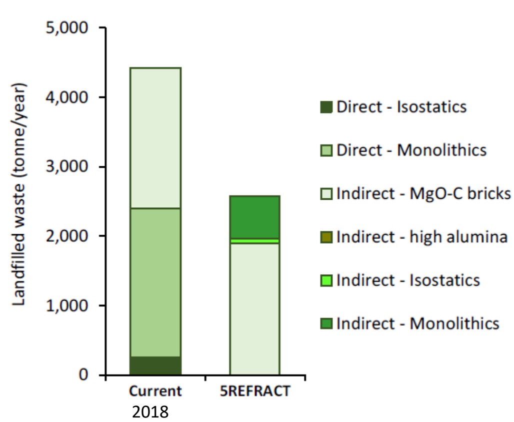


"Life cycle assessment of refractory waste management in a Spanish steel works", I. Muñoz, LCA consultants, 2020

5reFRACT Program Saved:

28 TJ/year primary energy from fossil sources

1,800 tonnes of waste from going to landfill



"Life cycle assessment of refractory waste management in a Spanish steel works", I. Muñoz, LCA consultants, 2020

CESAREF

Concerted European Action on Sustainable Applications of REFractories:

Efficient use of raw materials and recycling

Microstructure design for increased sustainability

Anticipation of hydrogen steelmaking

Energy efficiency and durability

Kick off meeting: February, 2023

(NOTE: this is for **steel** and it assumes "breakthrough technologies will be achieved through the use of **Hydrogen**")

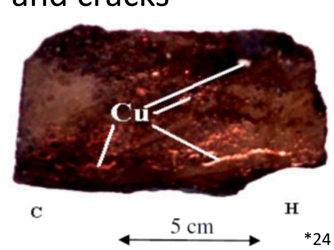
Metals Recovery from Spent Refr.

Mag-chrome bricks used to produce: Fe-alloys, Cu, PGM, Pb and others

Crush and

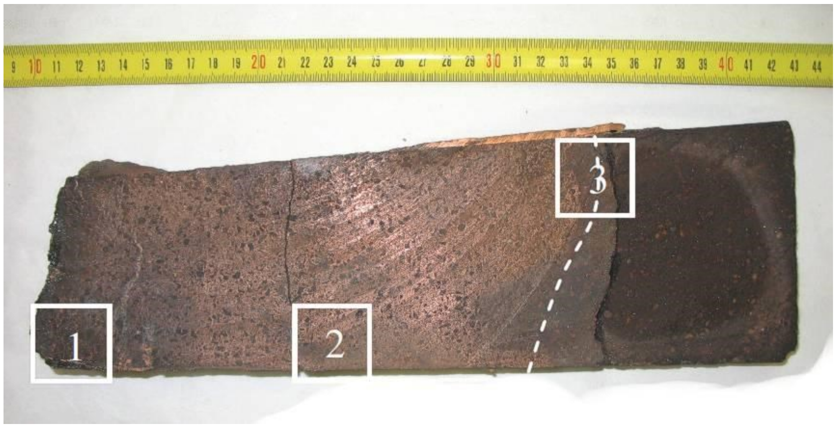
1.- recover, often through leaching, Cu, Ag, Pb, Bi, Sb, Au and other valuable metals which have penetrated into the brick's porosity and cracks

2.- reduce the Cr oxide to metallic



*24

Used MgO-Cr2O3 Brick



Matte and slag: deeply penetrated into the brick, J. Rigby, linkedin, 2022

For Recycling

- Removal of “contaminated” material
- Sorting of incoming material: refractories are highly heterogenous and arrive as mixed materials

The product can then be used in or added to

Production of new refractories

Additives to a process (slag/dross modifier, addition to cement, etc.)

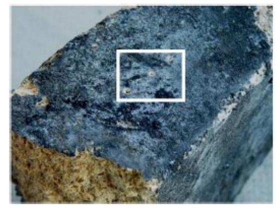
Incorporated into new, non-refractory, product(s)

During manufacture, unused refractories are routinely added back into the mix

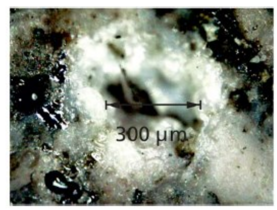
Refractory Sorting - LIBS

Demonstrator*[4]

Concept proven in 2016 by sorting 30 tonnes of mixed bricks; analyzed oxides were CaO, MgO, SiO_2, Fe_2O_3, Al_2O_3.*[3]

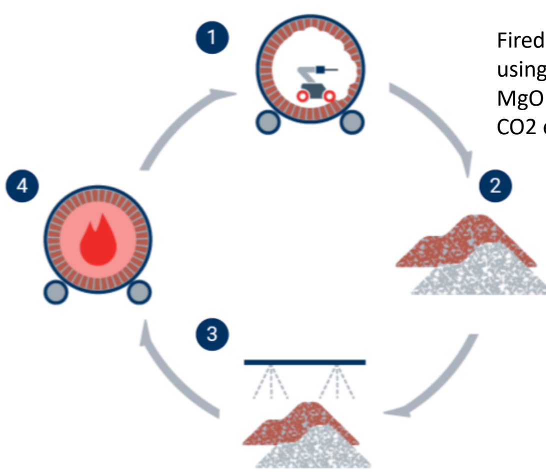


Measurement spots: through altered layer*[12]



Detail view of the "crater", Diameter appr. 300 µm*[12]

Spinel Brick



Fired spinel brick (MgO base) using recycled Dead Burned MgO: up to 14% reduction in CO2 emissions

www.rhimagnesita.com/pt/industries-we-serve/cement/rhi-magnesita-leading-the-way-to-circular-economy/, visited 1/18/23

Added to New Refractories

Tempered MgO-C bricks produced with Al_4C_3- containing secondary raw materials*8

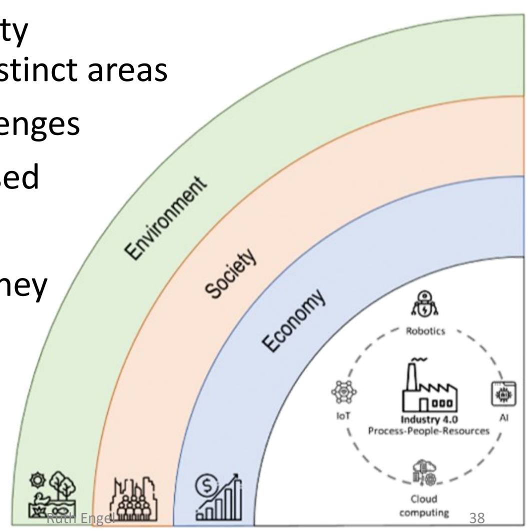
Expected, but not always a problem

Conclusions

- Refractory sustainability encompasses many distinct areas
- Each has its own challenges
- **All** need to be addressed

It will be an exiting journey

THANK YOU!



Sustainability related concepts in circular economy and industry 4.0 context*9

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*3 “LIBS analyses for industrial applications – an overview of developments from 2014 to 2018”. R. Noll, C. Fricke-Begemenn, S. Connemann, C. Meinhardt, V. Sturm, J. Anal. At. Spectrom., 2018

*4 “Review of Element Analysis of Industrial Materials by In-Line Laser—Induced Breakdown Spectroscopy (LIBS)”, J.D. Pedarnig, et al., Appl. Sci., 2021

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*6 “Industrial Waste Resources Will Become the New Normal”, interview with Mike O’Dricoll, Refractories Manual, 2020

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*24 “Degradation Mechanisms of Copper Anode Furnace Refractory Linings”, V. Petkov, thesis, 2007