Refractory Sustainability & Steel Challenges

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Order of Presentation

- Definition
- Consumption/markets
- Raw materials
- Green house gasses
- Iron/steel decarbonization
- “Waste” management
- What is being done

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)

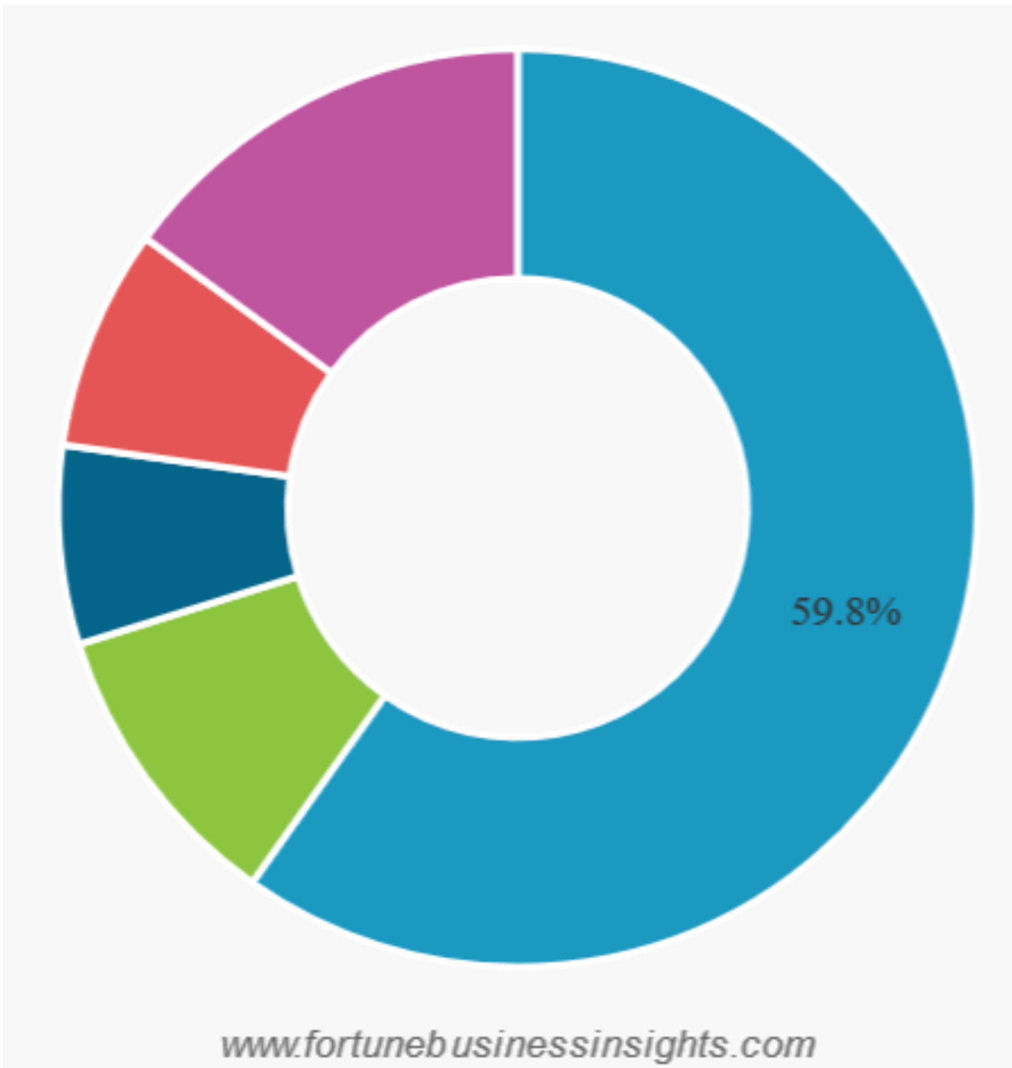
Definition

- 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)

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 75% of ALL refractories
- Every year almost 20 million tonnes of refractory waste are produced

Global Refr. Market Share (2021)



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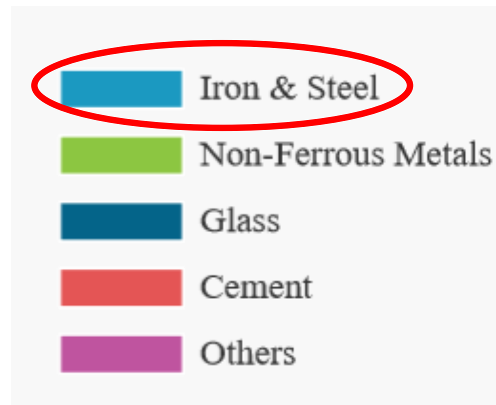
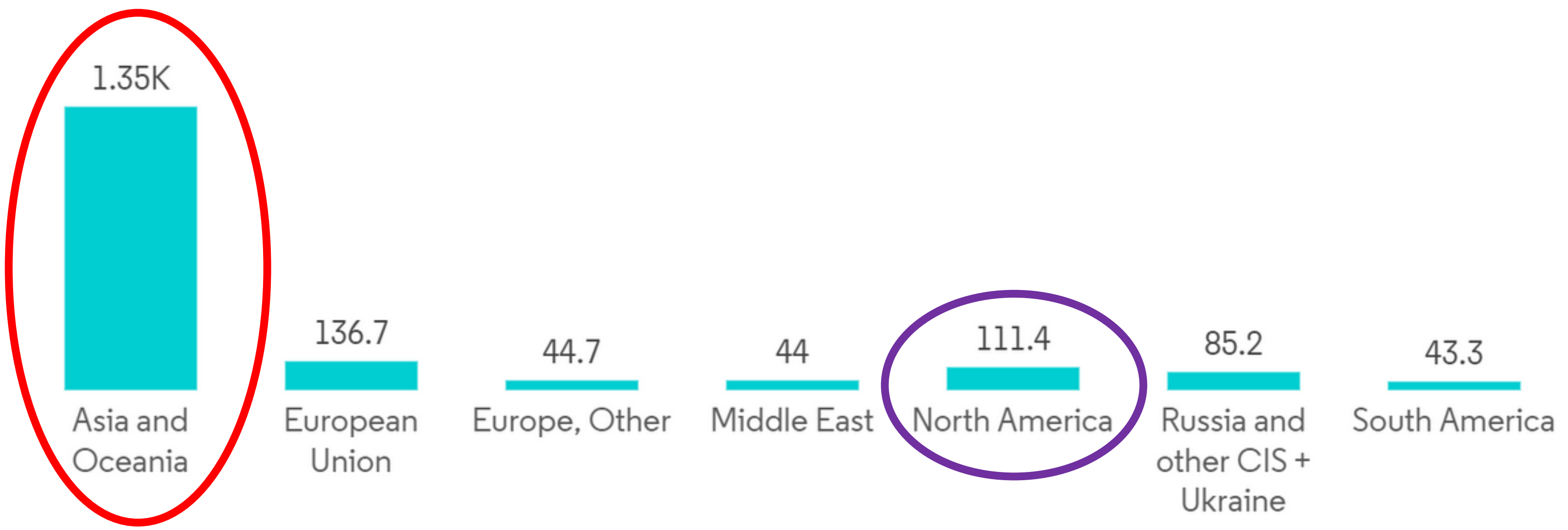


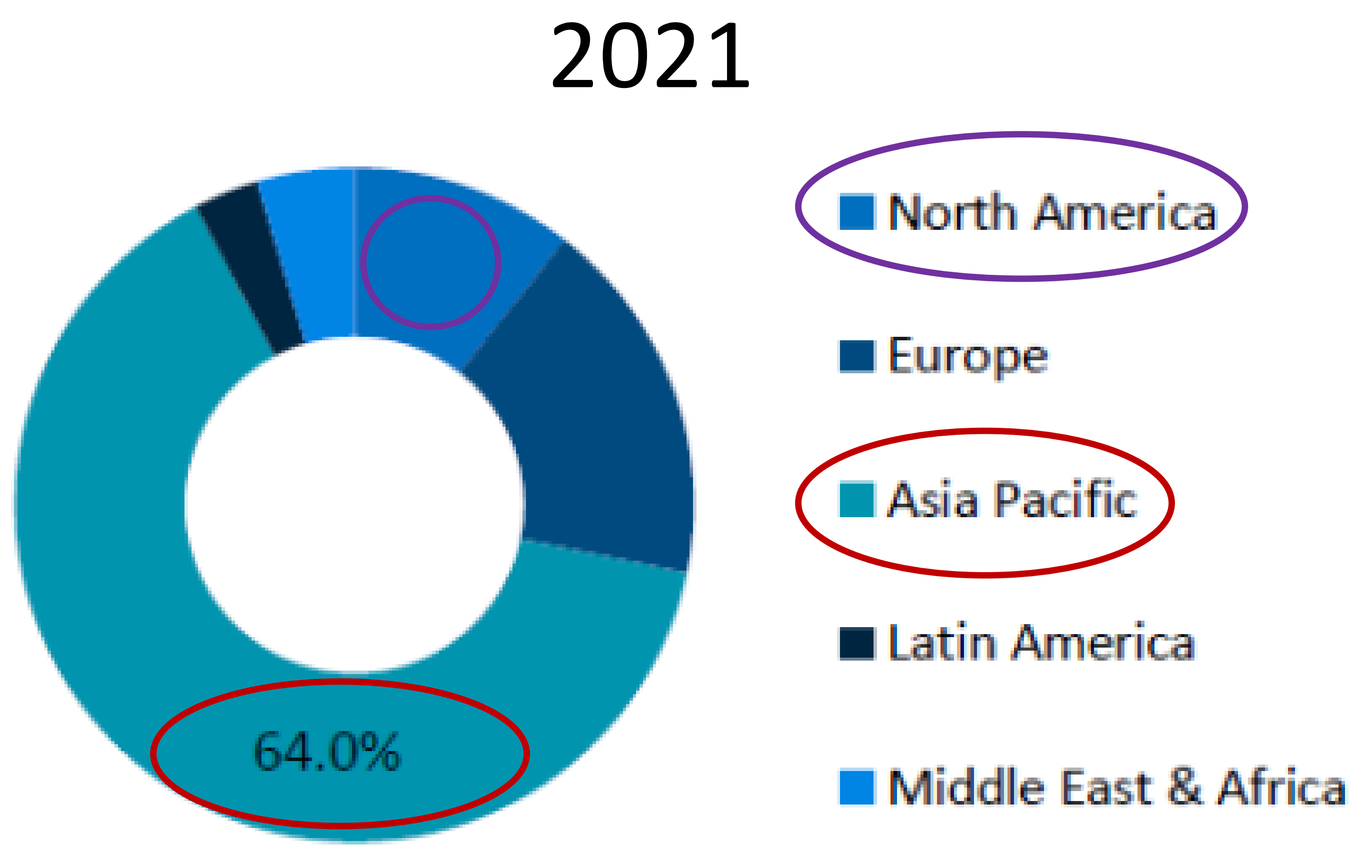
www.fortunebusinessinsights.com/refractories-market-103287, visited Febr. 2023

Crude Steel Production by Area, 2022



Source: World Steel Association

Global Markets by Geographic Areas



"Refractories – Global Market Analysis, Insights & Forecast, 2022-2029", www.fortunebusinessinsights.com

World's Consumption of Raw Materials

(www.theguardian.com/environment/2020/jan/22/worlds-consumption-of-materials-hits-record-100bn-tonnes-a-year, visited Jan. 2023)

Some Numbers

- Worldwide consumption of raw materials for refractory products about 35 million tonnes/year*[5]
- Only 7% is recycled*[5]

Consumption:

10-15 kg/t steel*[5]

3 kg/t non ferrous metal

1 kg/t cement

4 kg/t glass

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]

Greenhouse Gases - Decarbonization

Carbon dioxide (CO_2) emissions are the main cause of rising atmospheric temperatures, methane is the second most abundant greenhouse gas. It persists in the atmosphere for long time periods, up to several centuries.

Methane's (CH_4) heat-trapping potential is up to 87 times more potent than carbon dioxide. Methane's ability to rapidly warm the atmosphere highlights the urgency to investigate and address its sources.

Steel and CO_2 Production

The steel industry, responsible for 7 to 10 % of global CO_2 emissions, faces increased pressure to reduce its carbon footprint.

“Green Hot Metal: Introducing the Smelter”, A. Fleischanderl, G. Wimmer, Metals Mag., 2023

Decarbonization of Steel

- Improve efficiency
- Use biomass/syngas as a reductant
- Increase use of DRI: mainly in EAFs
- Develop alternate/improved DRI production methods: hydrogen, biosyngas
- Iron ore electrolysis
- Increase the use of oxyfuel combustion for increased energy efficiency

Most emphasis is on the iron side

Decarbing Iron Making*[25]

Required Change in Carbon Intensity 2015 to 2050

Global Iron Production: by Technology

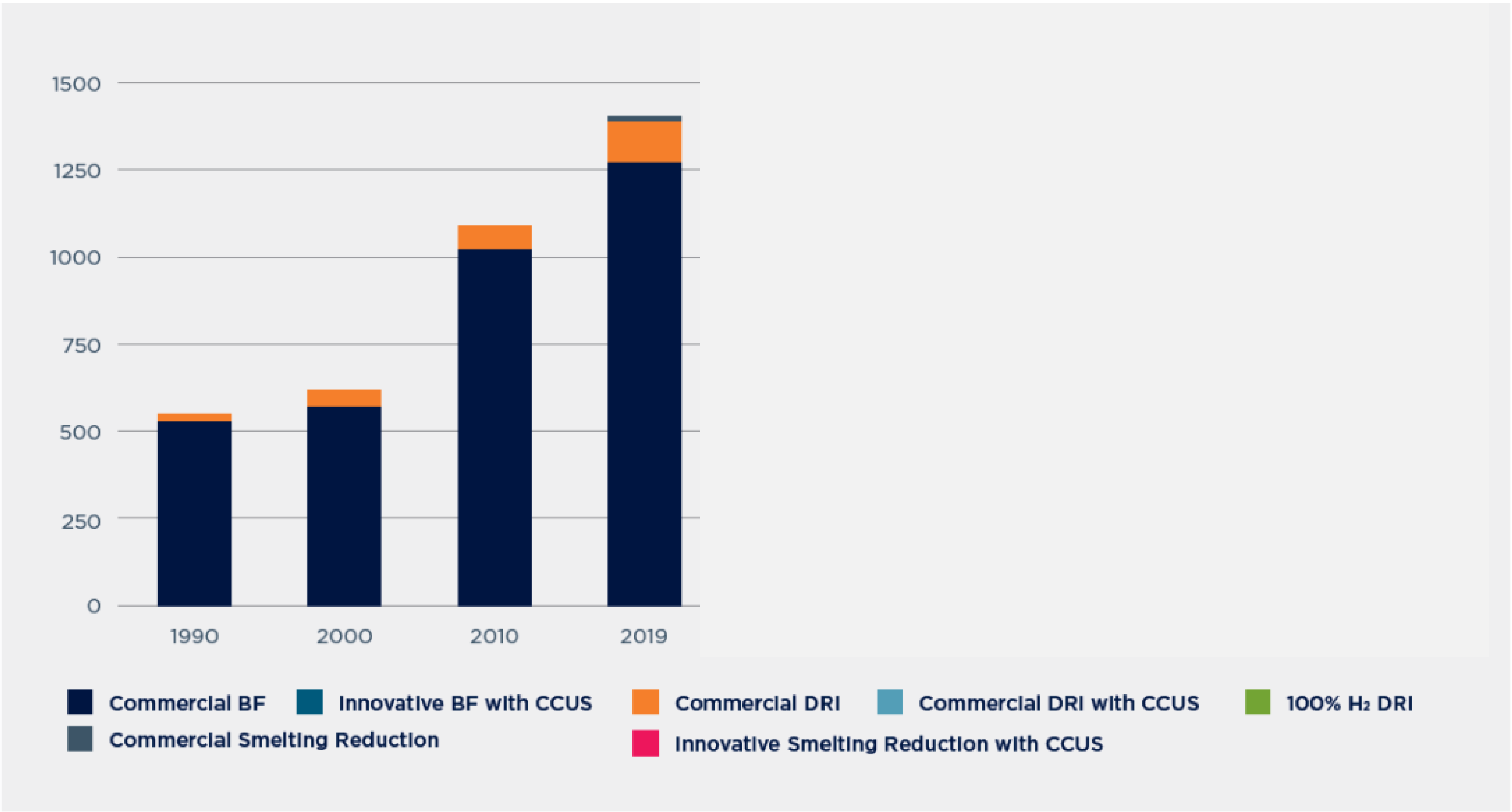
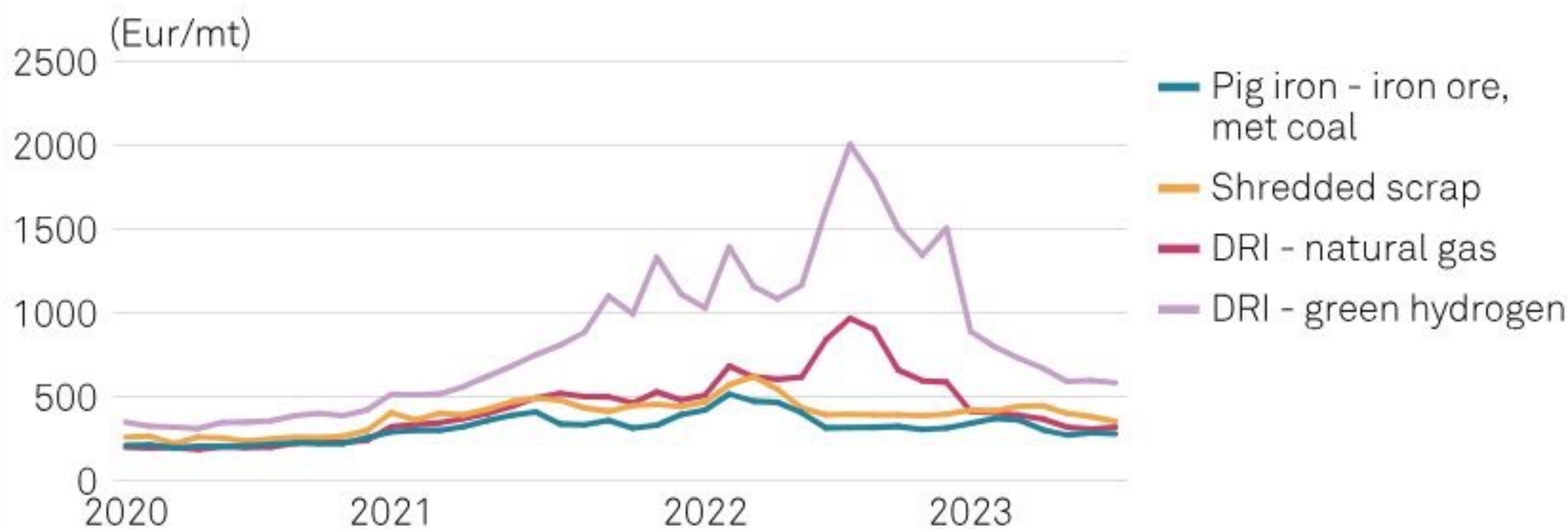


FIGURE 3. *Global iron production by technology in the "sustainable-development scenario" (SDS) from 2020 onward, according to the International Energy Agency (BF: blast furnace; CCUS: carbon capture, utilization, and storage; DRI: direct reduced iron)*

"The New Age of Hot Briquetted Iron (HBI)", J. Rothberger, R. Millner, W. Sterrer, Direct from Midrex, 3th qtr, 2023

DRI Costs (Europe)

Using green and blue hydrogen vs. scrap , pig iron



Note: Hydrogen prices based on Platts production cost-based assessments for the Netherlands.
The chart is based on estimates using Platts iron ore, DR pellets, met coal and scrap assessments.
Source: S&P Global Commodity Insights

Posted Aug. 2023

“Waste” Management

The 3Rs of "Waste" Management

Refractory strategies to achieve the 3Rs:

reuse of raw materials

reduce the amount of refractories used

recycle the spent refractories

but there are models with 4, 5 or more Rs

Re-use: Mine Tailings

Bauxite Tailings Treatment*[14]

- Reworking the tailings
  - Increases deposit's lifetime
  - Adds product capacity
  - Reduces discharge
- Case study showed:
  - Al_2O_3 improvement from 50.0% to 72.3%
  - SiO_2 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; in 2025 hopes to have a plant in operation

Carbon Management Technologies

Several technologies under development for decarbonization; either as CCUS or capture

- Reuse: injection of captured CO_2 into fresh concrete during manufacturing; reacts with the cement to transform into a carbonate (mineral) that strengthens the concrete*[22]
- Sequestration: CO_2 is dissolved in water which is injected into the subsurface, where it reacts with the porous basalt rock found there. In less than two years, the CO_2 forms solid carbonate minerals*[23]

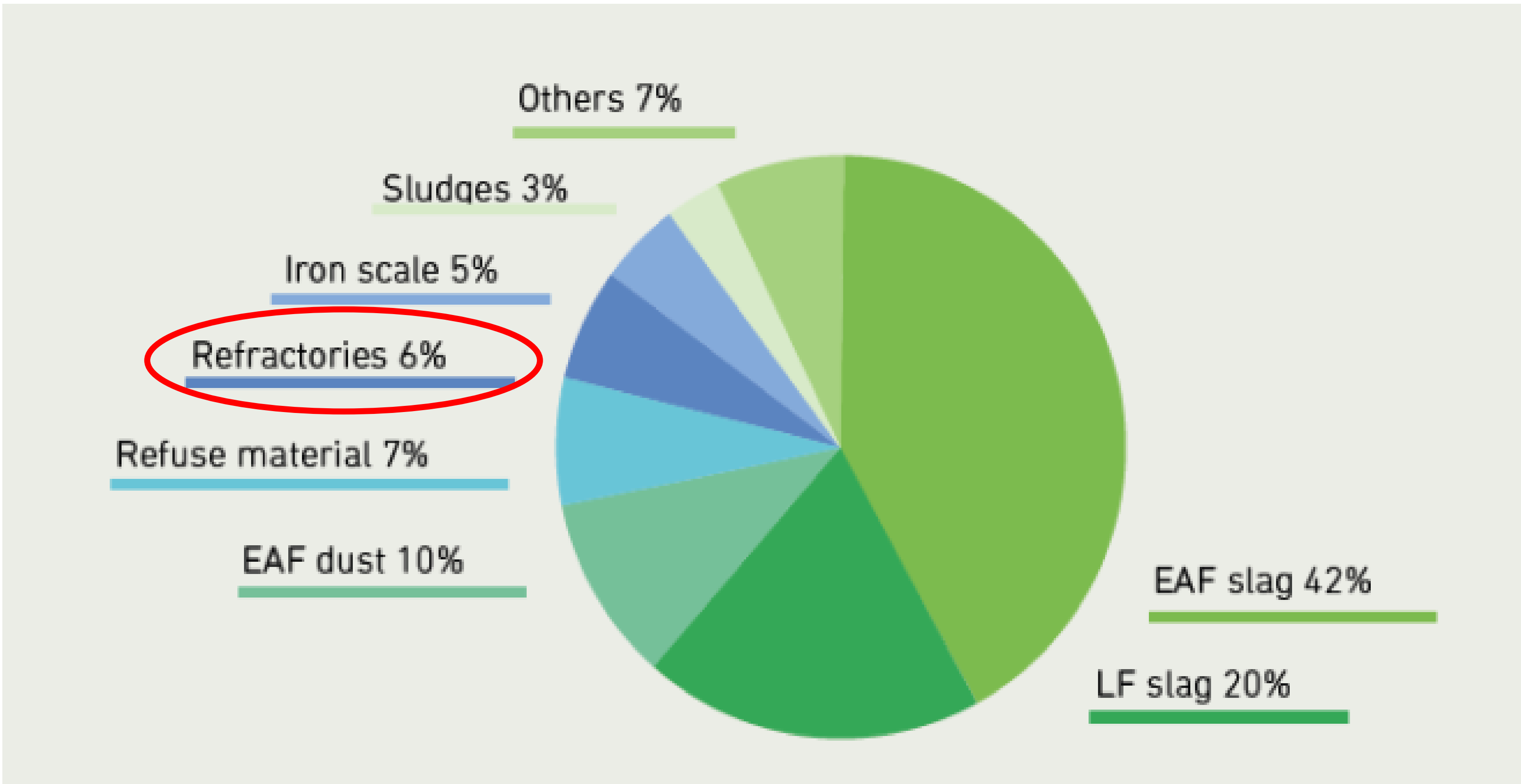
What is being done with refractories!

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: Basque Country, Spain: Sidenor
- **Documented their results**

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

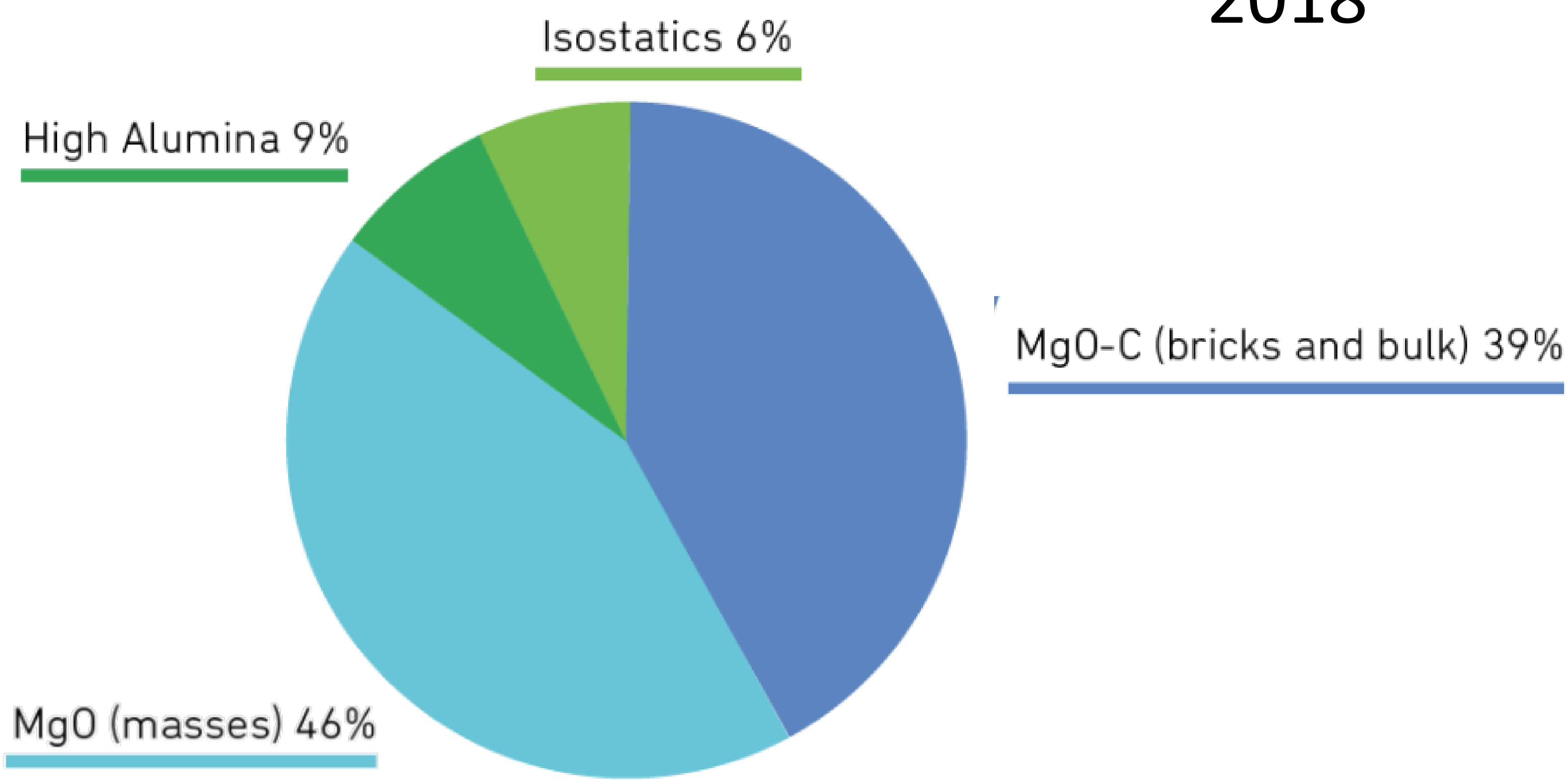
Waste Distribution in Sidenor (EAF)



"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

Sidewall Lining Reusing Refr.

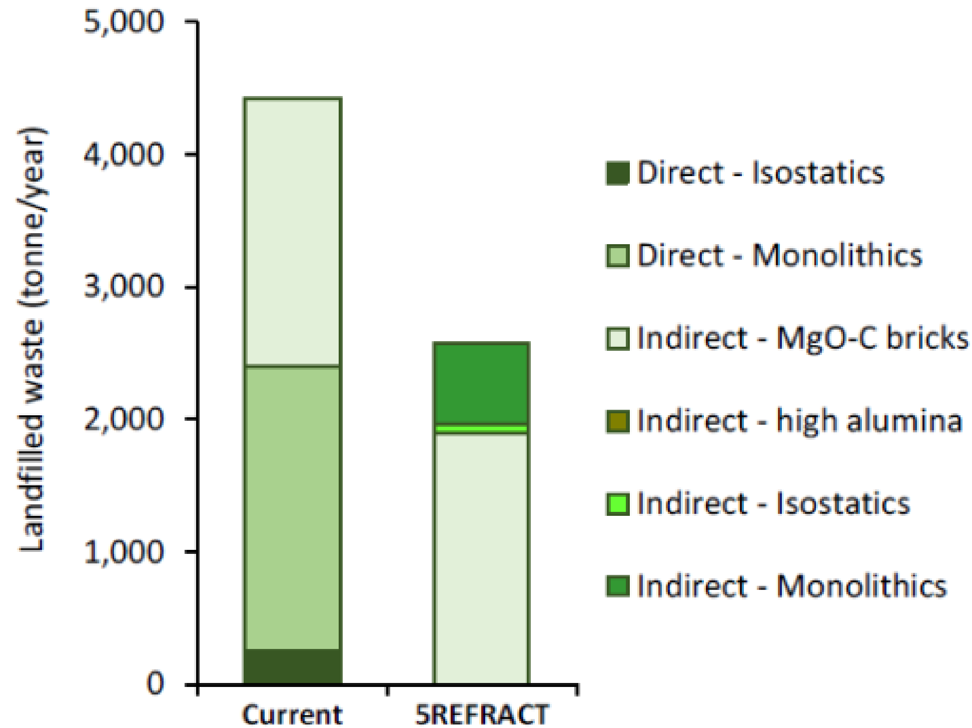
The Life 5 Refractory Project: **r**educe-**r**euse-**r**emanufacture-**r**ecycle-**r**e-educate
www.life5refract.eu/en/life-5refract-project/, visited Febr. 2021

New Product Using “Refractory Waste”

“Layman’s Report”,5RefrACT

5reFRACT program saved:

- 28 TJ/year primary energy from fossil sources
- 1,800 tonnes of waste from going to landfill
- 3,900 tonnes of CO_2 eq./yr



"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**")

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 added back into the mix on a routine bases

Sorting

Several methods

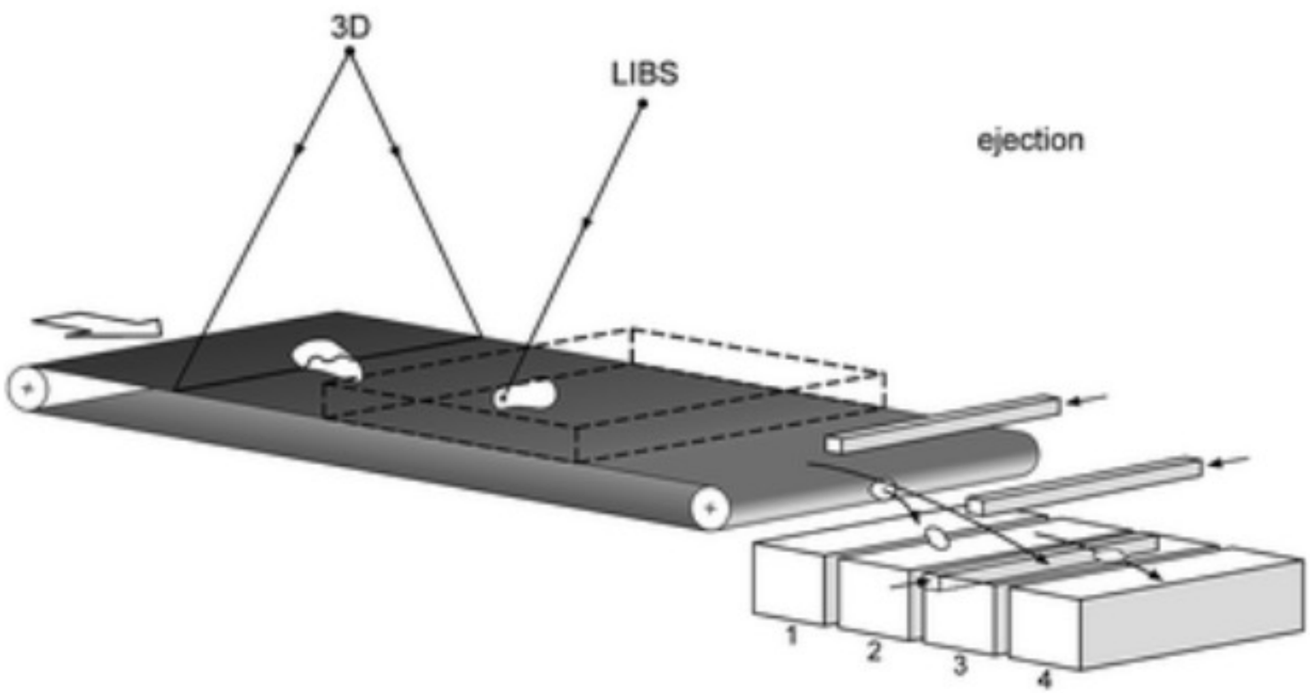
- Hand sorting: slow, difficult, requires decision based on visual clues
- Laser Induced Breakdown Spectroscopy (LIBS):

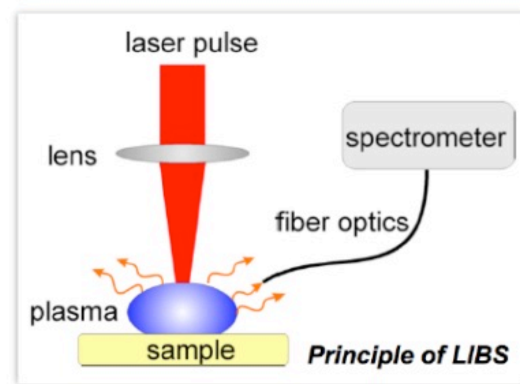
1) uses a laser pulse to remove a very small amount of material, heat it to high temp.- plasma, identifies element specific spectral emission lines

2) ability to analyze and sort based on MgO, Al_2O_3, SiO_2, AMC.

- Leaching and flotation

Sorting*[3]





LIBS basics*[13]

Inline 3D measurement of single objects moving on a belt conveyor, LIBS analysis and sorting to different fractions 1 to 4.

Concept proven in 2016 by sorting 30 tonnes of mixed bricks; analyzed oxides were CaO, MgO, SiO2, Fe2O3, Al2O3.

Re-use into New Refractories

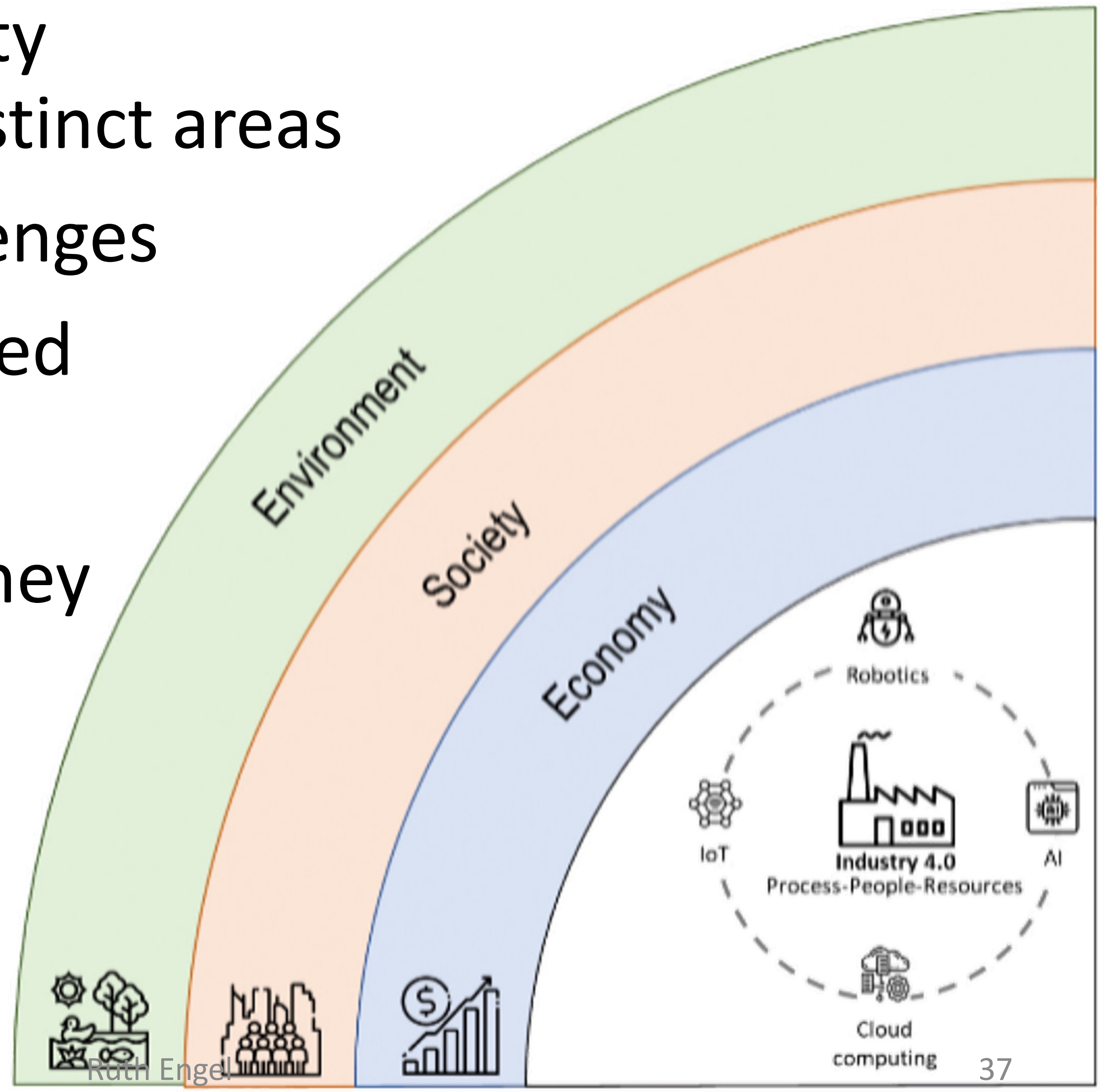
Tempered MgO-C bricks produced with Al_4C_3- containing secondary raw materials*8

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

References

*1 “Global Carbon Budget 2022”, P. Friedlingstein et al., Earth Syst. Data, 2022

*2 “Requirements for implementing Circular Economy in the refractory waste management of a steel plant”, A. Soto, M.A. Mangas, D. Maza, Imformed, Mineral Recycling Forum, 2021

*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

*5 “Recycled Refractory Materials : Ambitions with a Future?”, Interceram Review, 2020

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

*7 “Recycling refractories: entering a new era”, Imformed, 2016

*8 “Innovative Aluminium Carbide Detection and Treatment Technologies to Increase Magnesia-carbon Recycling”, S. Heid, A. Leitner, S. Knogshofer, The J. of Refrac. Innovations Bulletin, 2022

References

*9 "Theorizing the Principles of Sustainable Production in the context of Circular Economy and Industry 4.0", E. Viles, F. Kalemkerian, J. A. Garza-Reyes, J. Antony, J. Santos, Sustainable Product. & Consumption, 2022

*10 "Climate risk and decarbonization: What every mining CEO needs to know", L. Delevingne, W. Glazener, L. Gregoir, K. Henderson, McKinsey & Co, 2020

*11 "Supply and Demand of High Alumina Raw Materials for Refractories in Europe", A. Buhr, O. Koegel, J. Dutton, RWF, 2013

*12 "LIBS analyses for industrial applications – an overview of developments from 2014 to 2018", R. Noll, C. Fricke-Begemann, S. Connemann, C. Meinhardt, V. Sturm, JAAS, 2018

*13 "Laser Induced Breakdown Spectroscopy (LIBS) in recycling of refractory material outbreak", J-U. Gunther, C. Schilder, A. Feierabend, C. Bohling, Mineral Recycling Forum, 2016

*14 "Bauxite Tailings Valorization: From Test Works to Industrial Scale Up", T. Baumann, Mineral Recycling Forum 2022

*15 "Recovering CO2 and H2O from waste streams", M. Rameshni, S. Santo, Decarb. Tech., 2022

*16 "Zero Waste: A Sustainable Approach for Waste Management", S. Hamid, B.M. Skinder, M.A. Bhat, Innovative Waste Management Technologies for Sustainable Development, 2020

References

*17 “Study of spent refractory waste recycling from metal manufacturers in Missouri”, H. Fang, J.D. Smith, K.D. Peaslee, Resources, Conservation and Recycling, 1999

*18 https://pmarketresearch.com/in-2025-global-production-of-refractory-is-estimated-at-52-362-million-tons/, visited Febr. 2023

*19 “Life Cycle Assessment and Life Cycle Cost Analysis of Magnesia Spinel Brick Production”, A. Ozkan, Z. Gunkaya, G. Tok, L. Karacasulu, M. Metesoy, M. Banar, A. Kara, Sustainability, 2016

*20 “Magnesita: A look back at the Industry & Pathway forward for a healthy successful year”, April 27, 2015

*21 www.fortunebusinessinsights.com/refractories-market-103287, visited Febr. 2023

*22 CarbonCure, visited Febr. 2023

*23 Carbfix.com, visited Febr. 2023

*24 “Carbon Capture, Utilization, and Storage in Illinois”, Prairie Research Institute, Univ. of Illinois Urban-Champaign, 2028

*25 “Impact of Hydrogen DRI on EAF Steelmaking”, S. Hornby, G. Brooks, Direct from MIDREX, June 2021

References

*26 “A Review of Recycling of Refractories for the Iron and Steel Industry”, J. Madias, UNITECR 2017

*27 “Hierarchical nature of hydrogen-based direct reduction of iron oxides”, Y. Ma et. al., Scripta Materialia, 2022