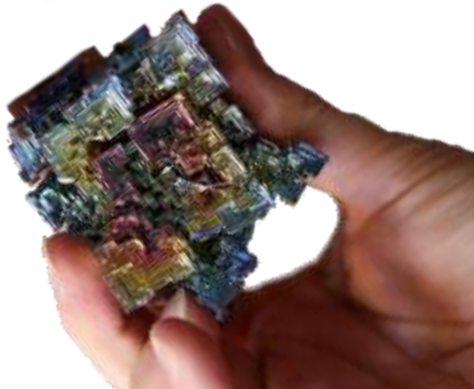
Sustainabity challenges for metals: Use of hydrogen for making steels

Dierk Raabe

kWh CO_2

Short version



DIRECT AND INDIRECT SUSTAINABILITY EFFECTS

Processes

Direct

CO_2-reduced production (reduction via H_2, NH_3, …)
Electrification using 'green' power sources (electrolysis, plasma, …)
Recycling (scrap sorting, recycling-oriented alloys, alloys for max. scrap use)
Process efficiency (near-net shape manufacturing, …)
Robust catalyst
…

Indirect

Weight reduction in transportation at higher safety (Fe: AHSS, Al: 7xxx)
Product longevity (corrosion, hydrogen, fatigue resistance)
Damage tolerance & repairability (microstructure design)
Energy conversion, higher efficiency, H as fuel (FeC, FeAl, superalloys)
Lower electrical resistivity, lower magnetic losses,… (hard magnets, Al, FeSi)
Energy harvesting: thermoelectrics, solar cell absorbers (Heusler, perowskites)
…

Metals as enablers

D. Raabe et al. Nature (2019) Strategies for improving the sustainability of structural metals

AHSS: Advanced High Strength Steels, 7xxx: High strength Aluminium alloys with Zn, Cu and Mg addition

Sustainable use of resources in the material value chain

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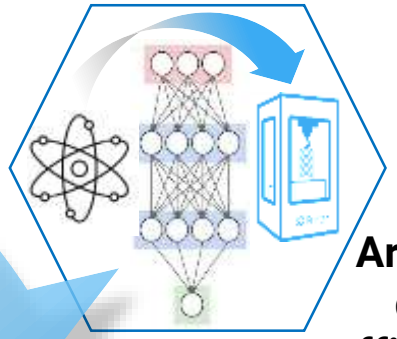

Artificial Intelligence, digitial materials, efficient manufacturing

Design of materials for infinite recycling

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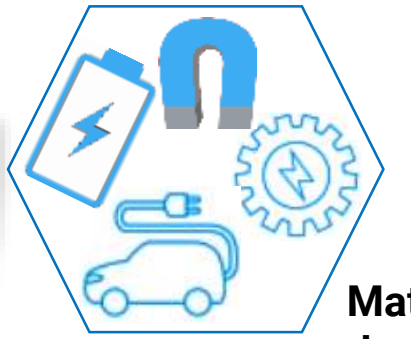
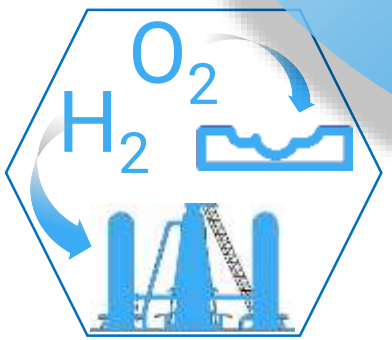
Materials Science for a Circular Economy



Materials for electrification

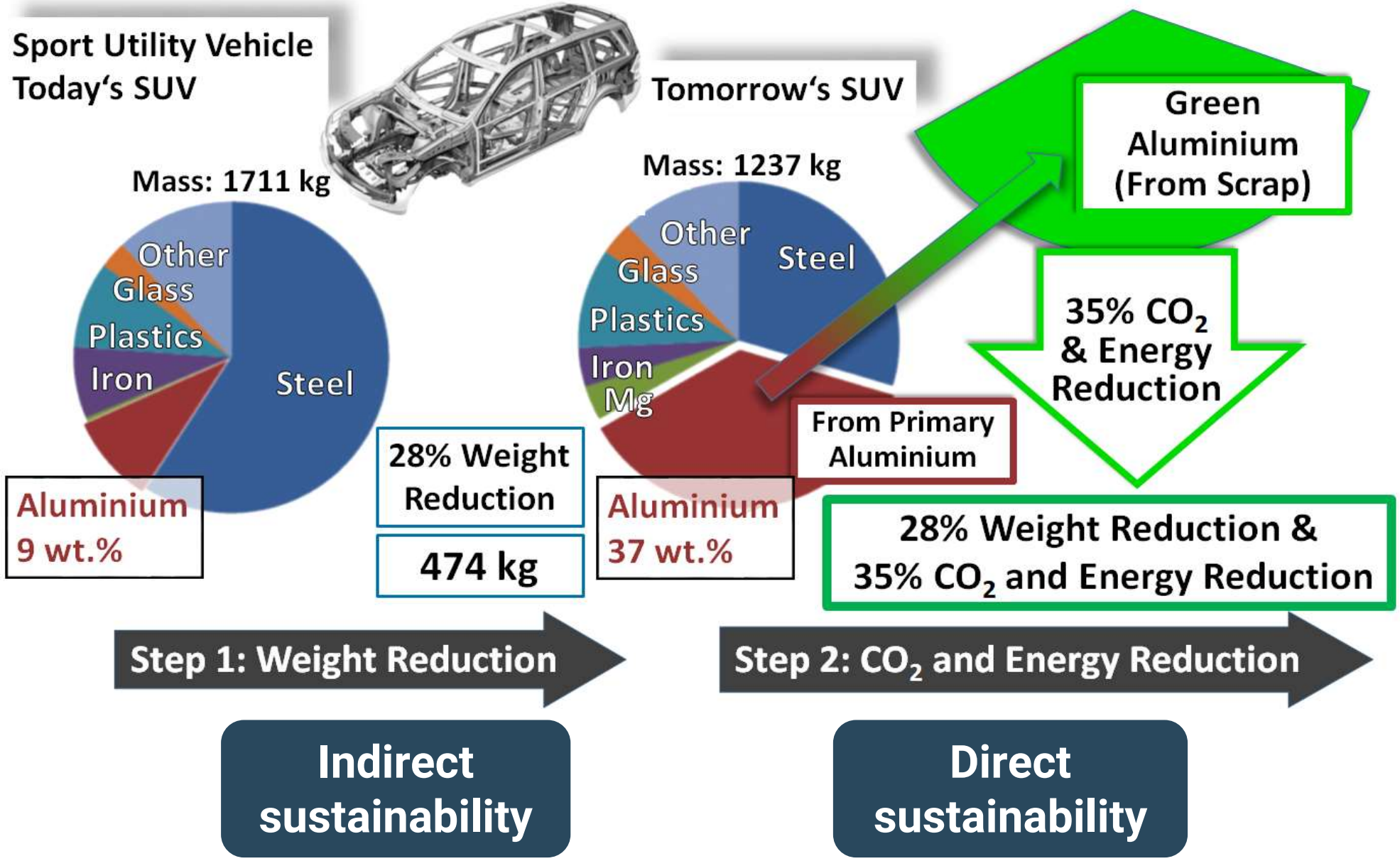


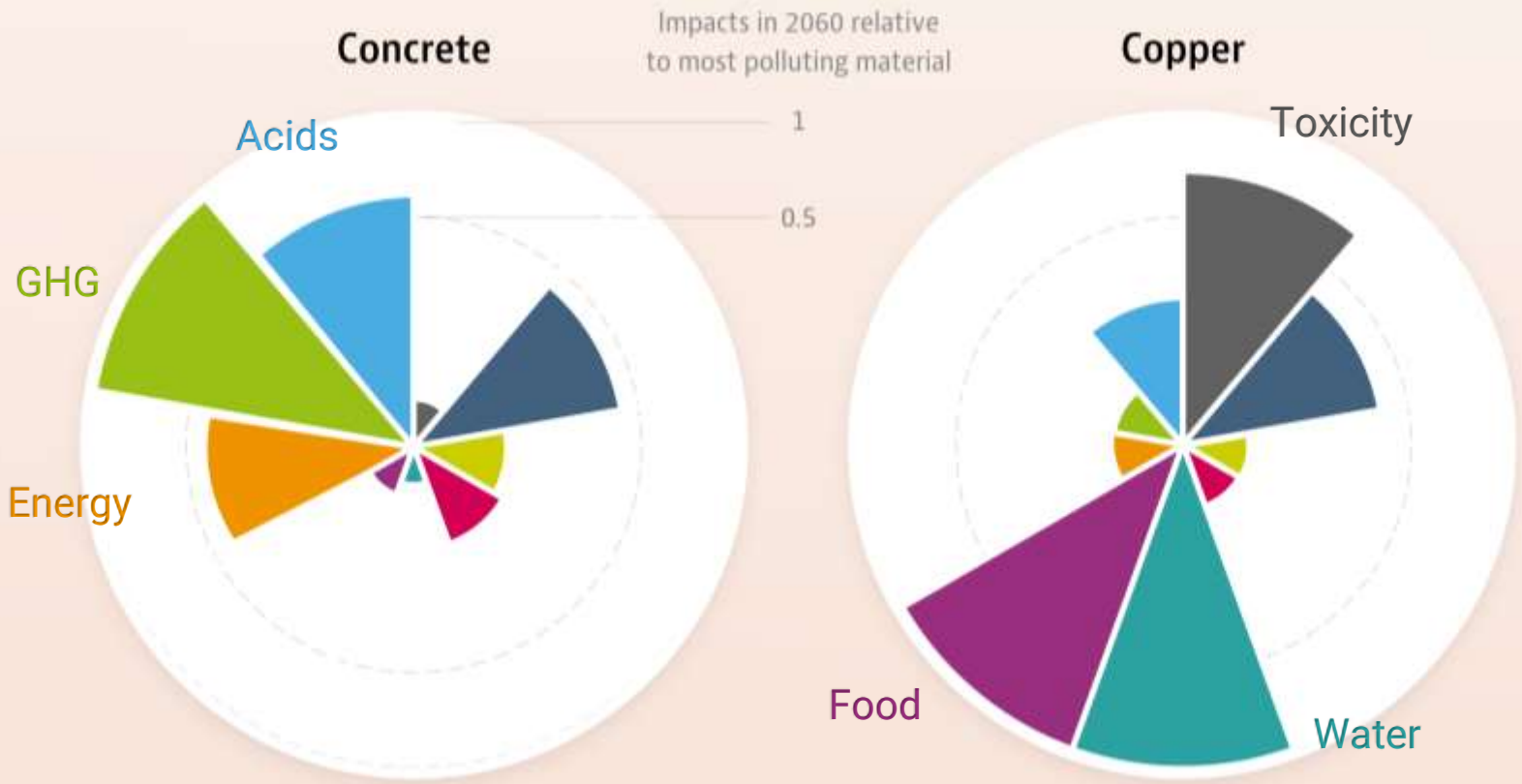
Materials for longevity and a hydrogen economy

Materials as sustainability enablers

D. Raabe et al. Nature (2019) Strategies for improving the sustainability of structural metals

EXAMPLE OF TWO TYPES OF EFFECTS: INDIRECT AND DIRECT





Acidification
Corrosive impact of pollutants (SO_2; NOx) on soil, water, ecosystems, buildings.

Climate Change
Radiative forcing of GHGs causing rising temperatures, sea level rise, extreme weather events.

Cumulative energy demand
Total energy use along the production chain.

Eutrophication
Impacts of nutrients (N, P) on soil and water quality affecting ecosystems and drinking water.

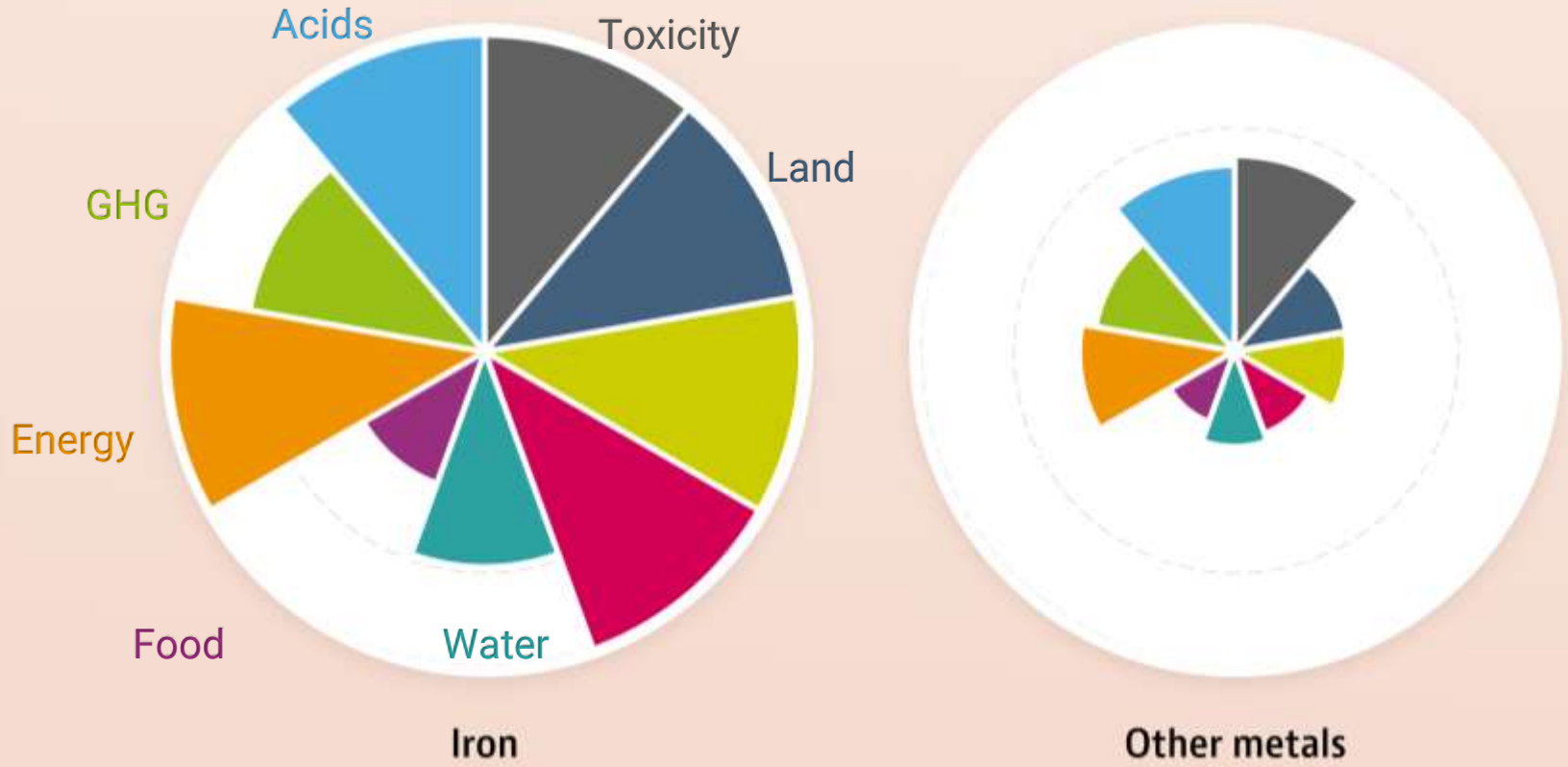
Freshwater aquatic ecotoxicity
Impacts of toxic substances on freshwater aquatic ecosystems.

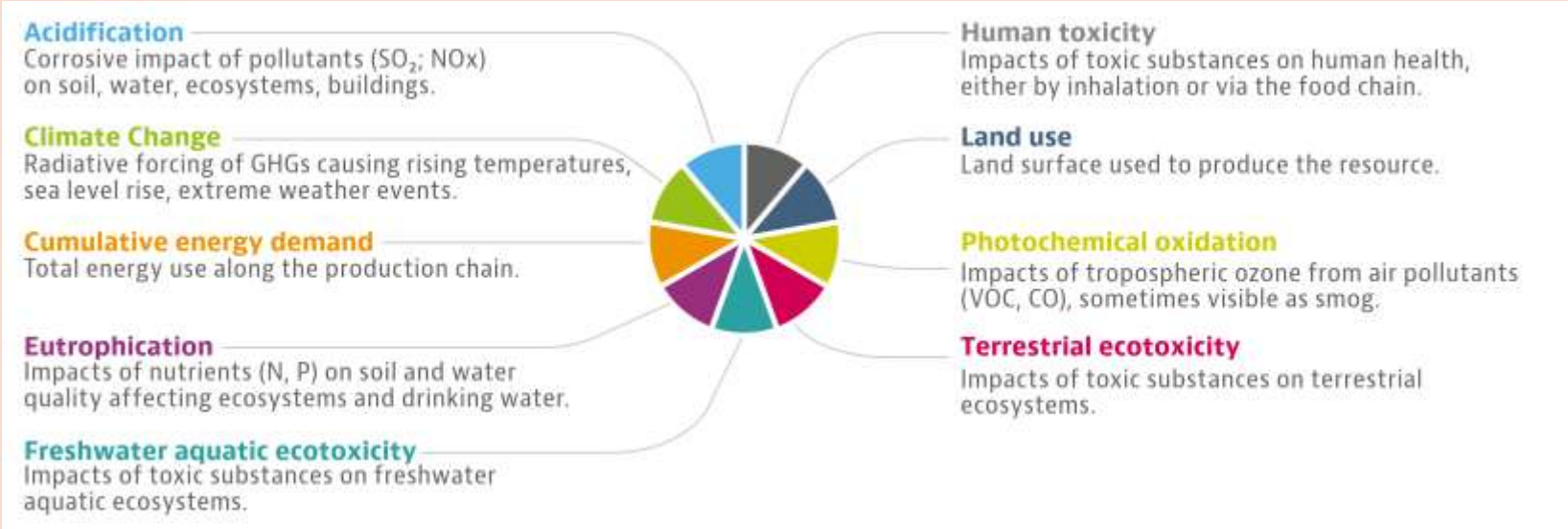
Human toxicity
Impacts of toxic substances on human health, either by inhalation or via the food chain.

Land use
Land surface used to produce the resource.

Photochemical oxidation
Impacts of tropospheric ozone from air pollutants (VOC, CO), sometimes visible as smog.

Terrestrial ecotoxicity
Impacts of toxic substances on terrestrial ecosystems.


Acids
Toxicity
Land
GHG
Energy
Food
Water
Iron
Other metals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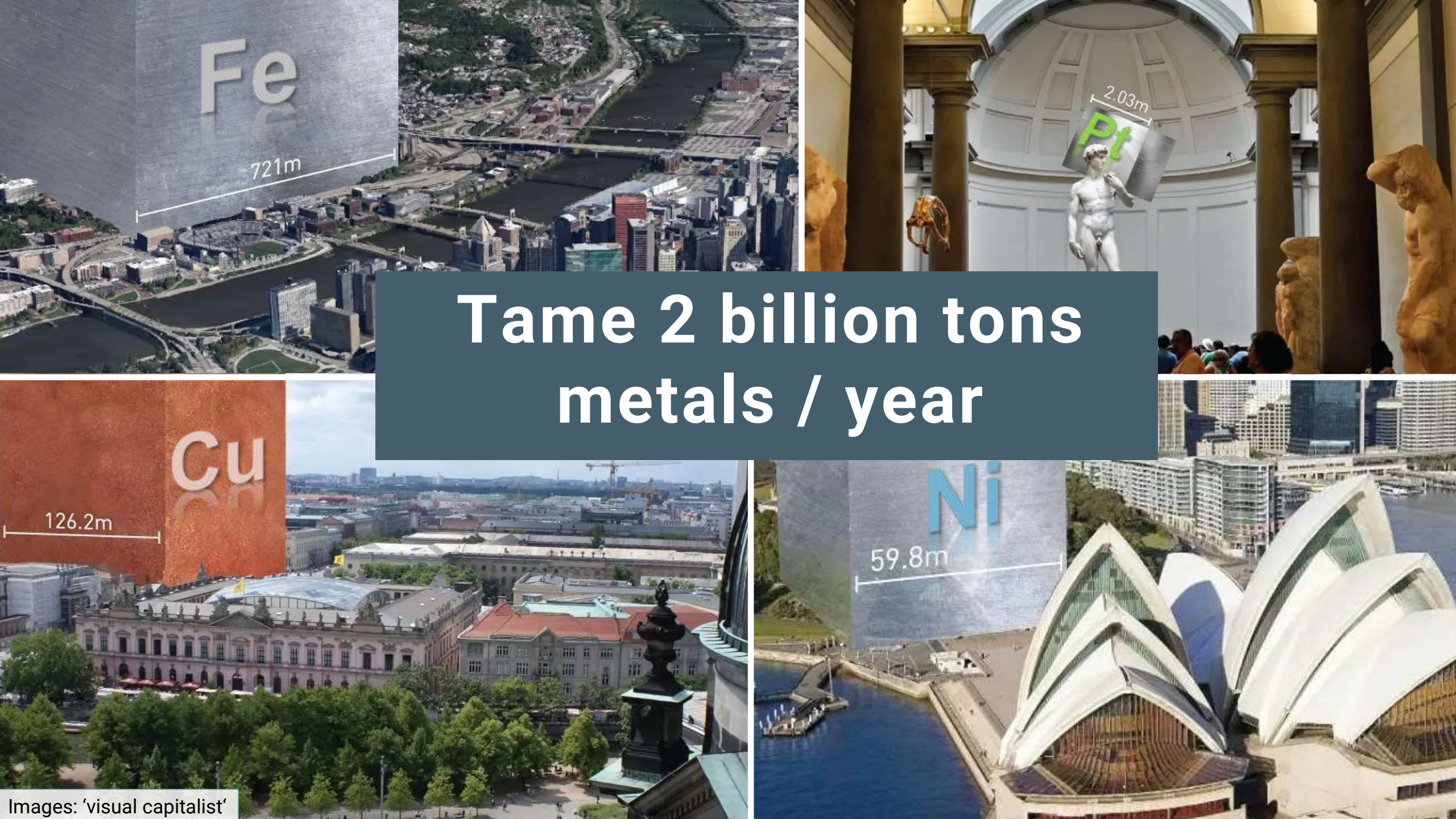
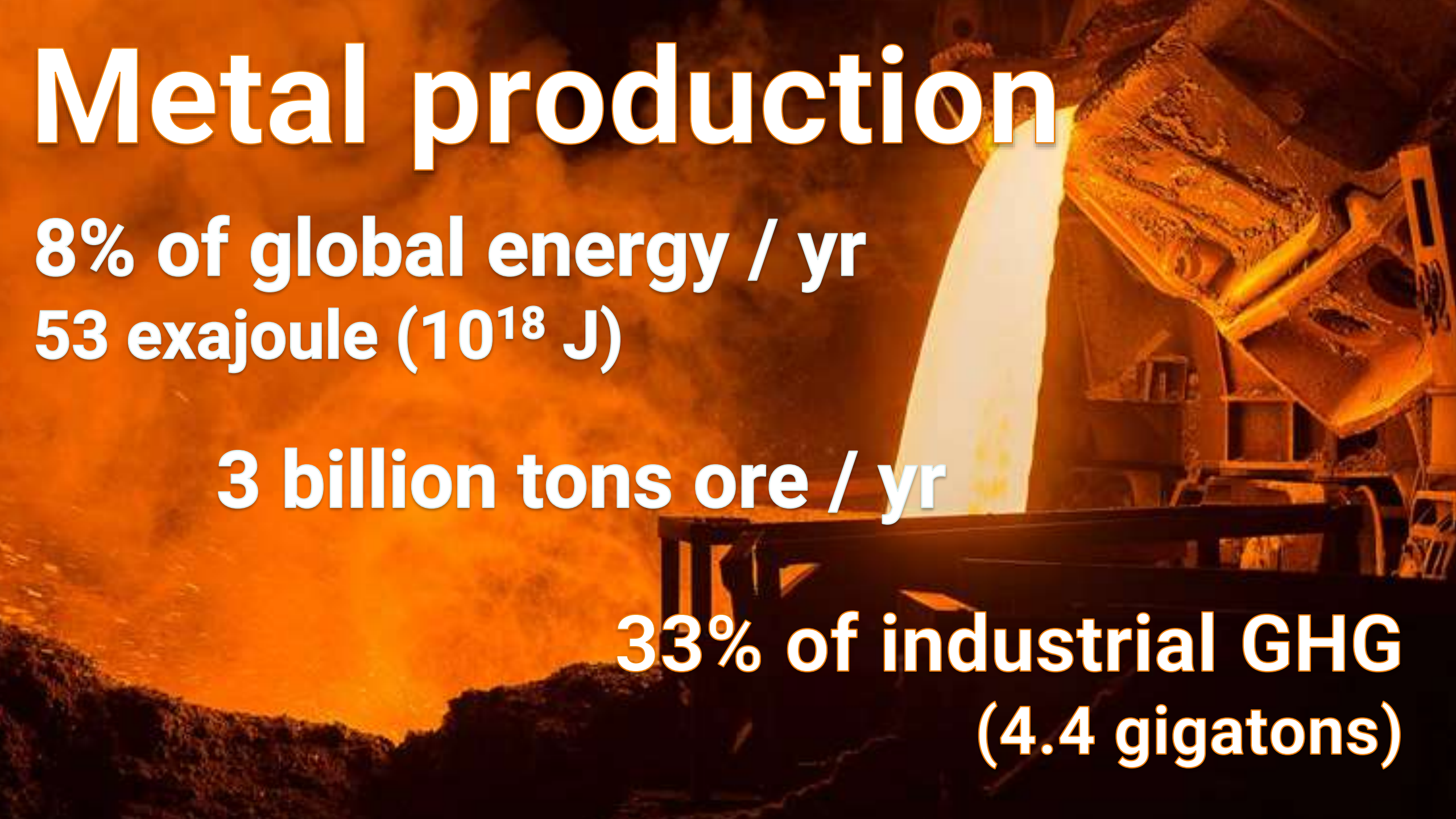


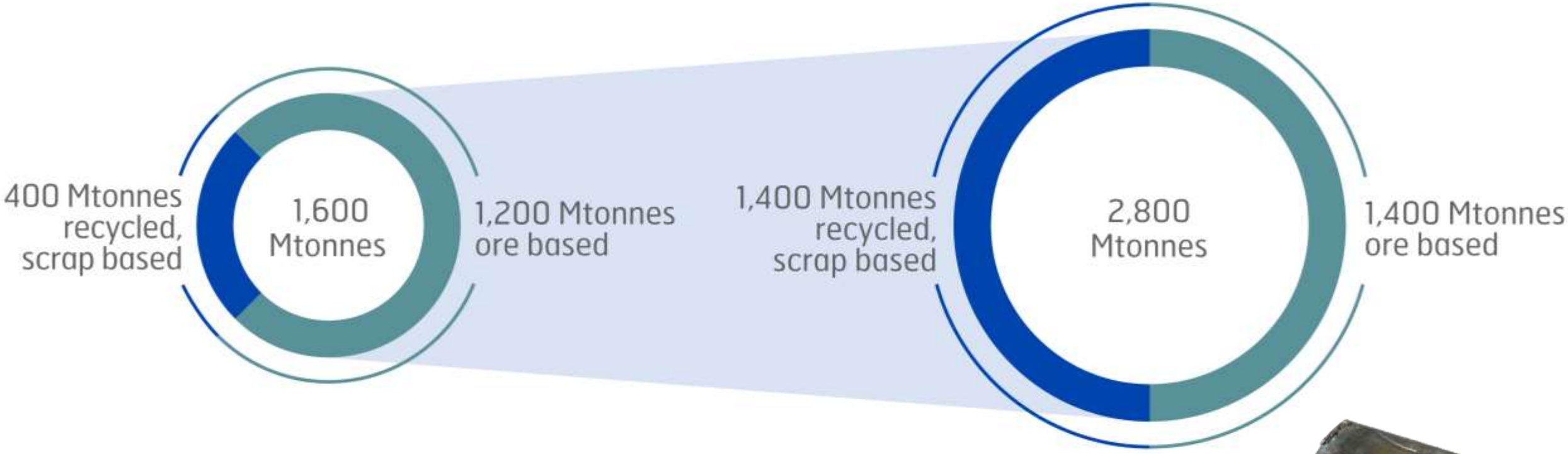
Tame 2 billion tons metals / year

Images: ‘visual capitalist‘


Metal production
8% of global energy / yr
53 exajoule (10^{18} J)
3 billion tons ore / yr
33% of industrial GHG
(4.4 gigatons)

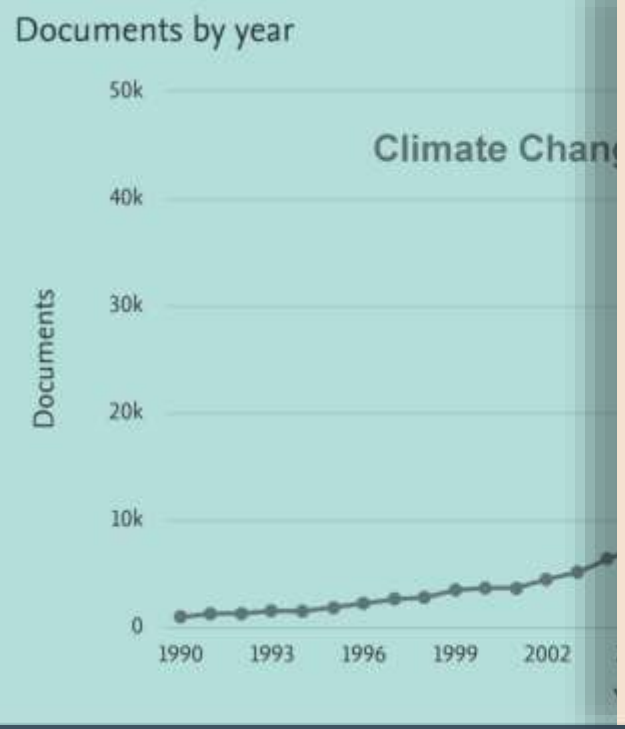
Steel demand – today and forecast 2050

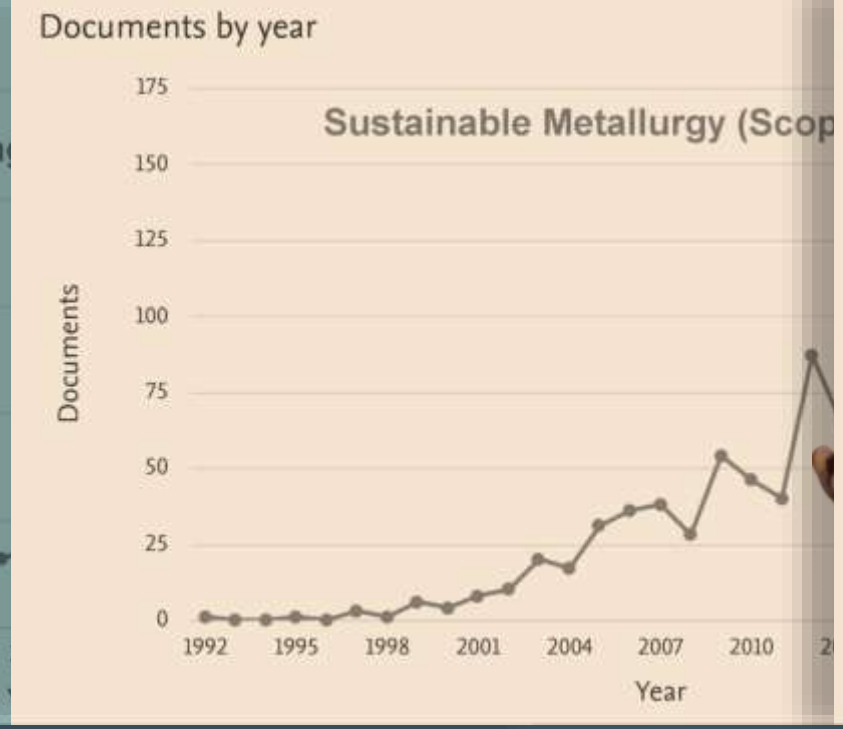
$$F_2O_3 + 3\,CO \rightarrow 2\,Fe + 3\,CO_2$$

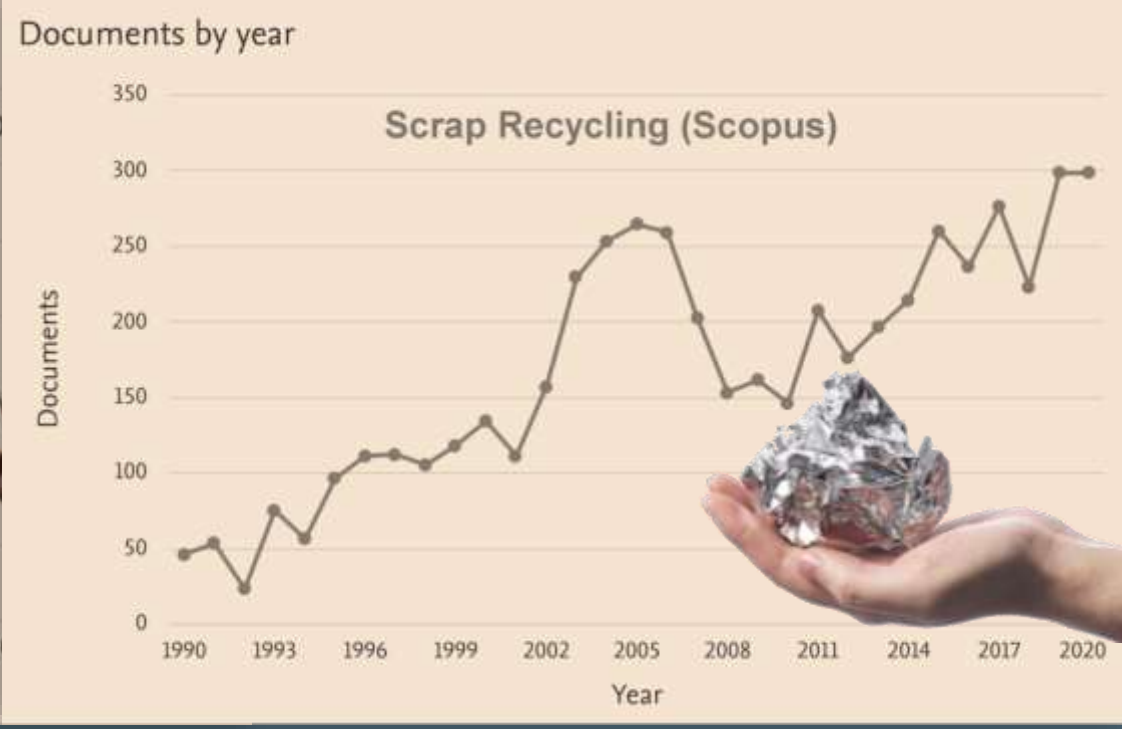


Demand is HUGE & GROWING: CO_2 problem MUST be solved

Data: Steel institute







More research !

Ironmaking

Steelmaking

Finishing

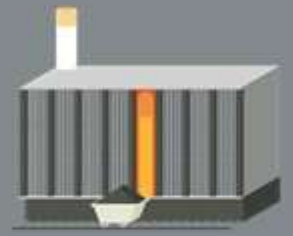
Integrated steelmaking

Iron ore

Sintering

Blast furnace

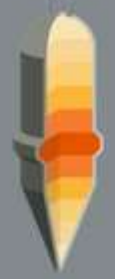
Metallurgical coal



Coke ovens

Electric steelmaking

Iron ore



Direct reduction

Direct reduced iron

Blast oxygen furnace

Scrap

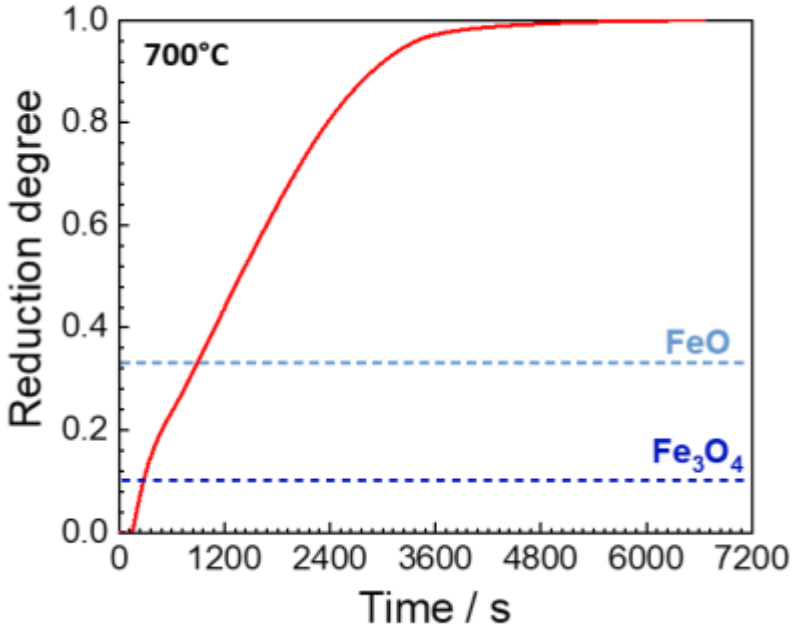
Electric arc furnace

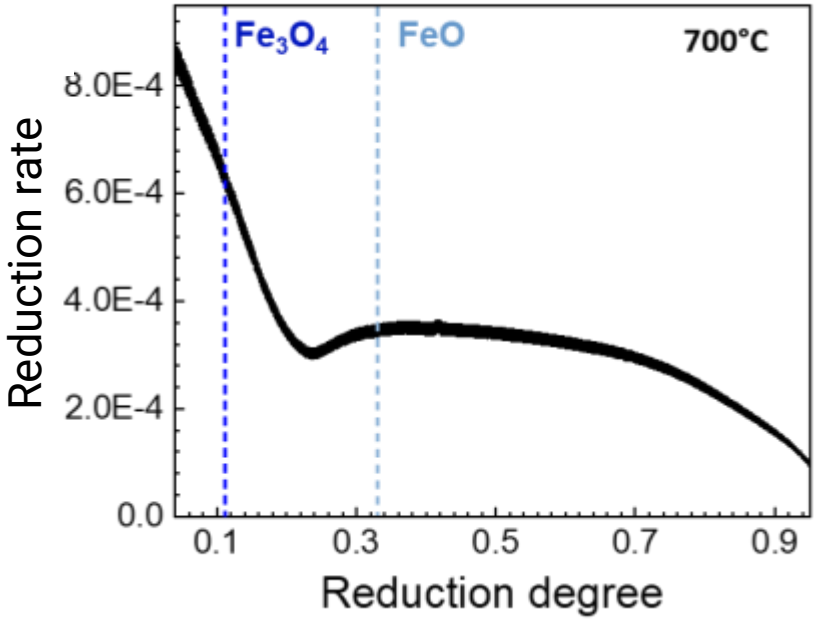
Continuous caster

Rolling

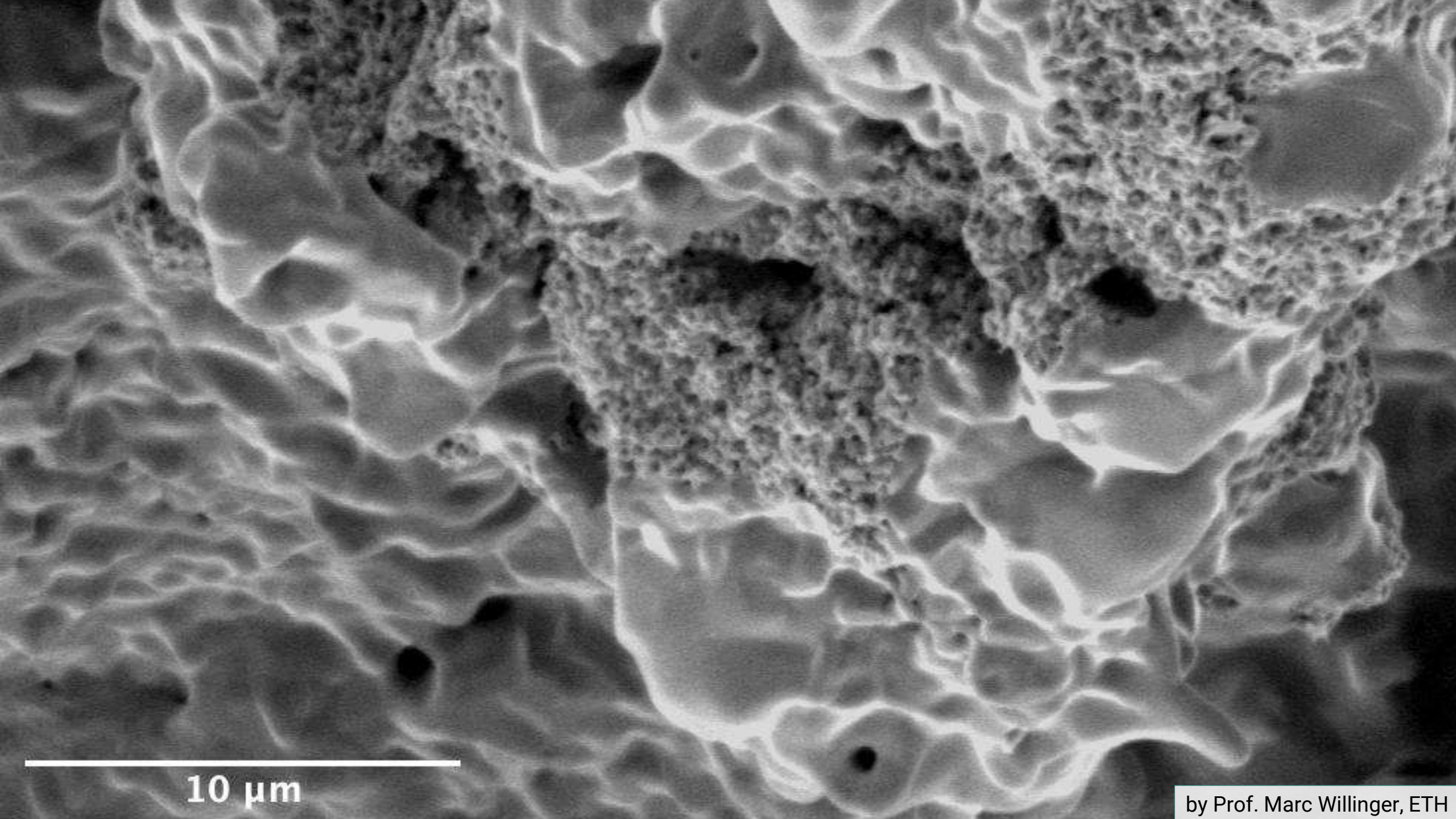
Finished product

REDUCTION KINETICS OF HEMATITE 700°C BY HYDROGEN

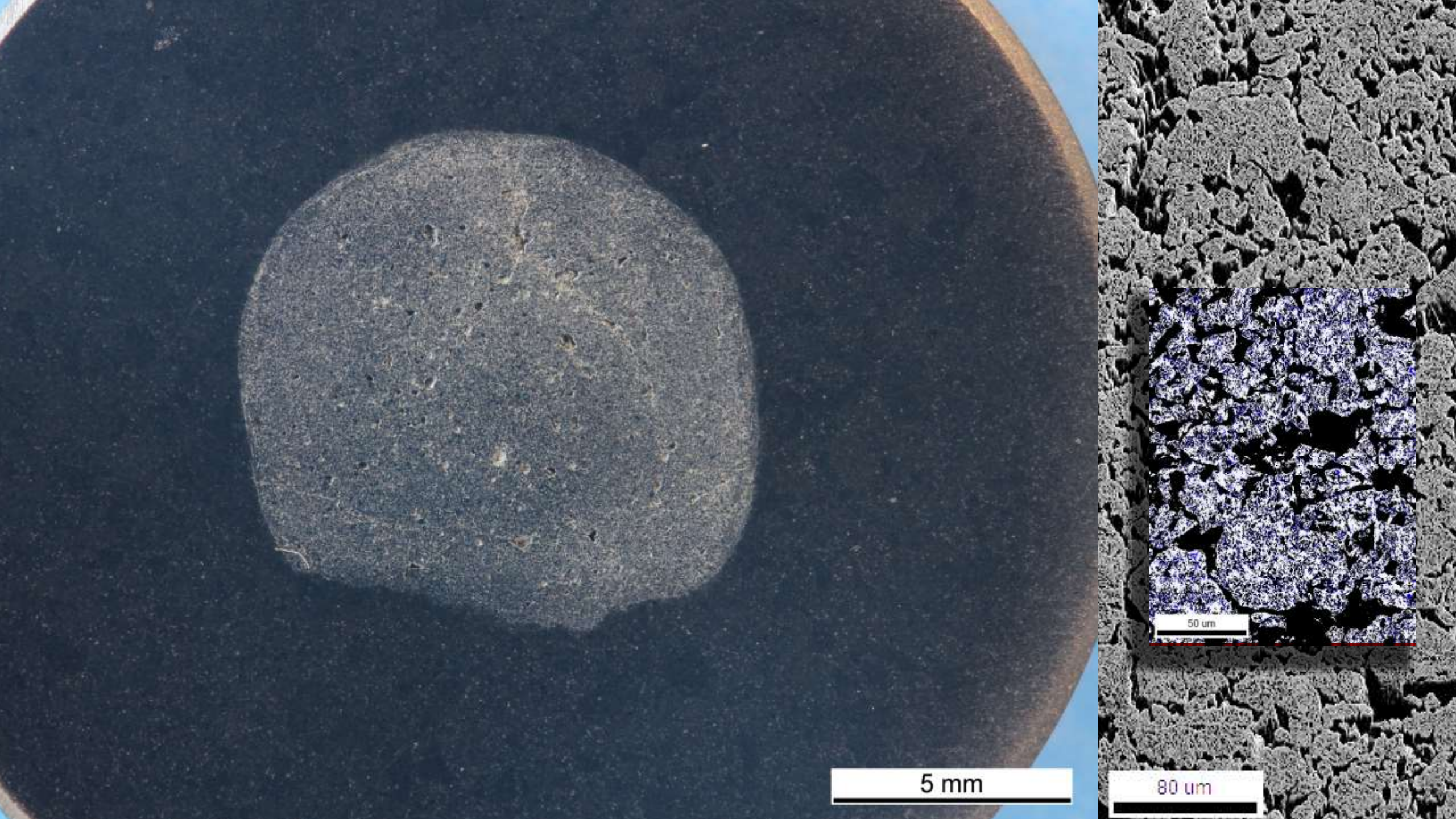




Kim et al. Acta Mater 2021 in press



by Prof. Marc Willinger, ETH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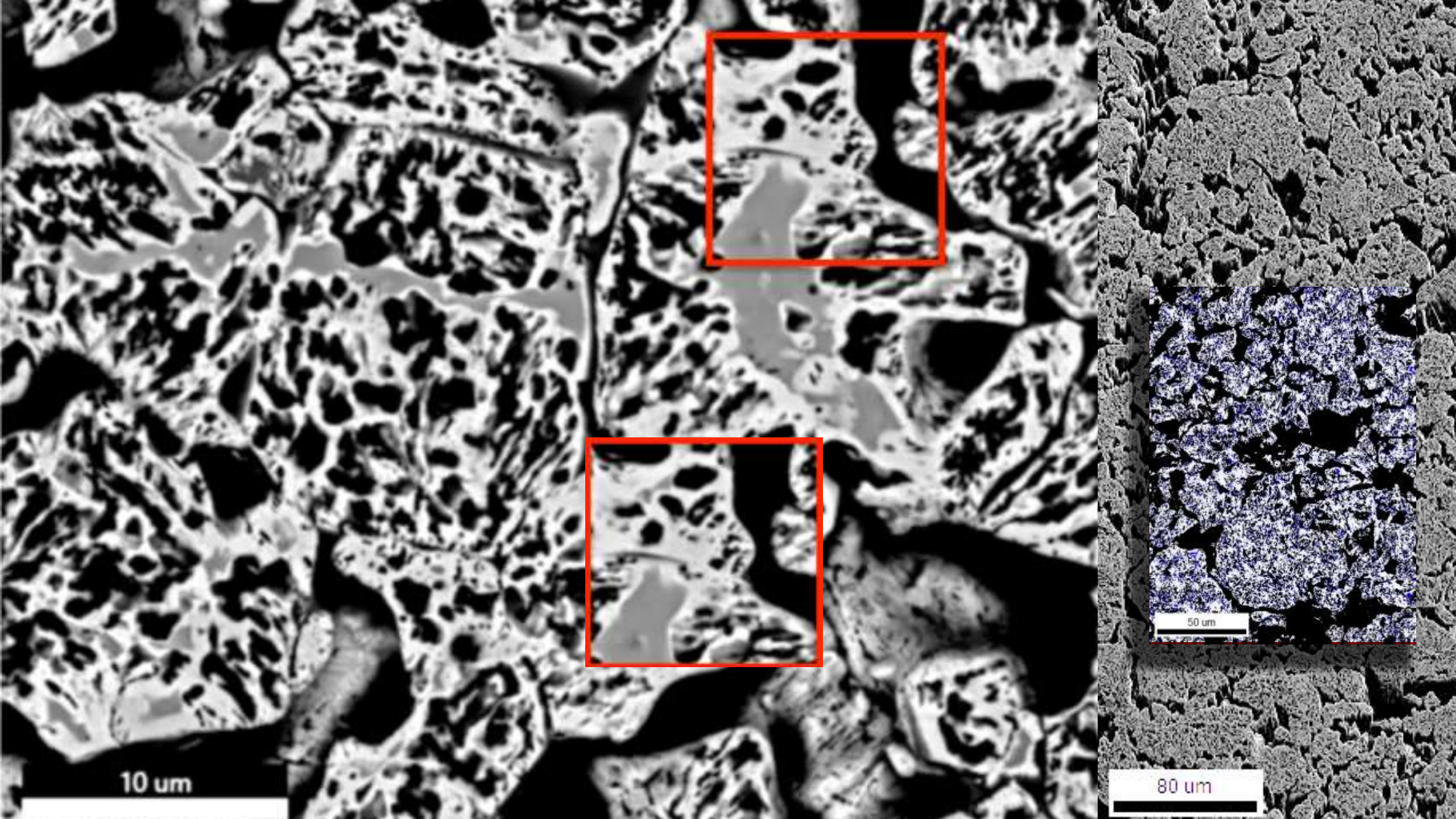
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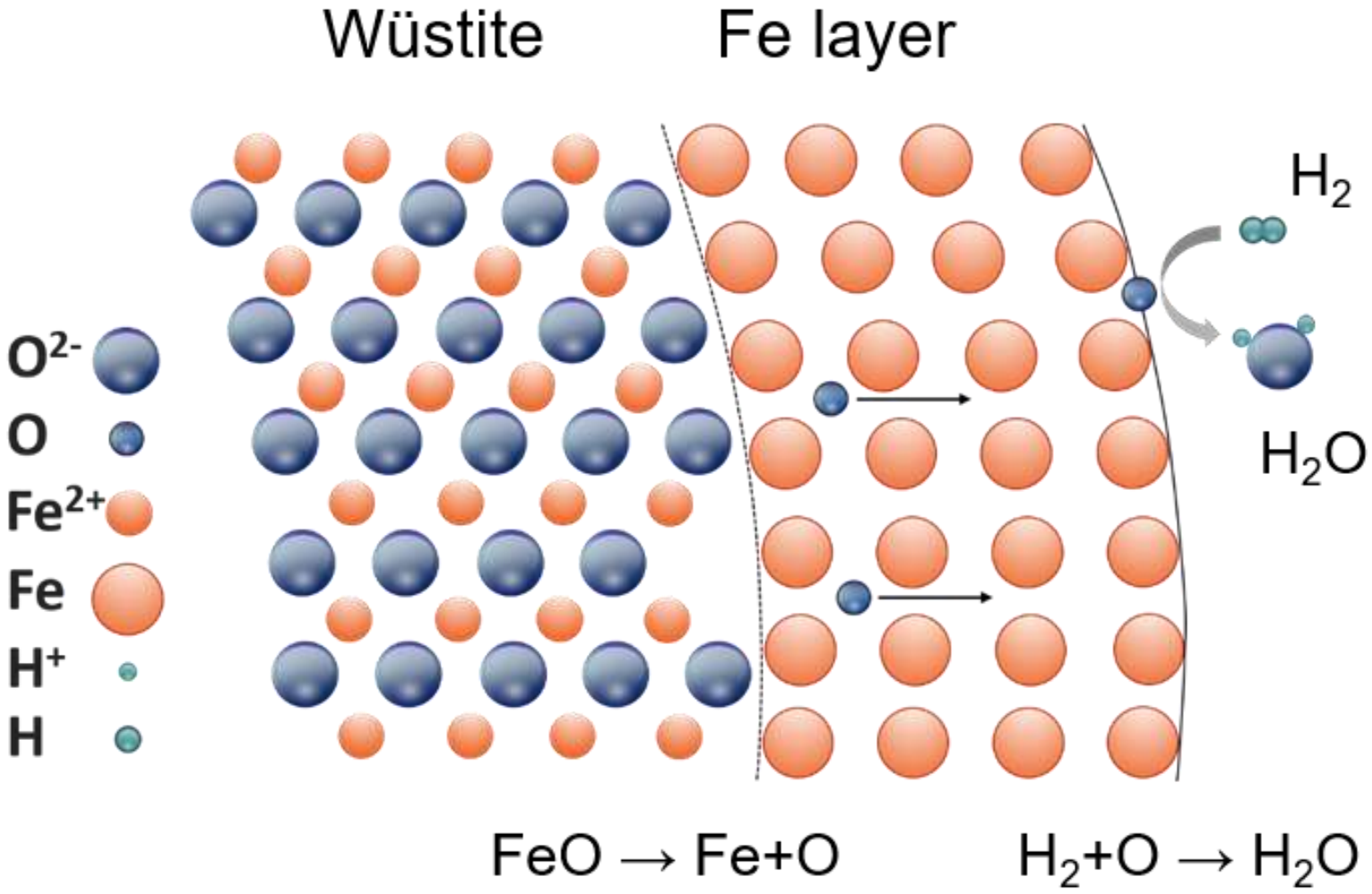
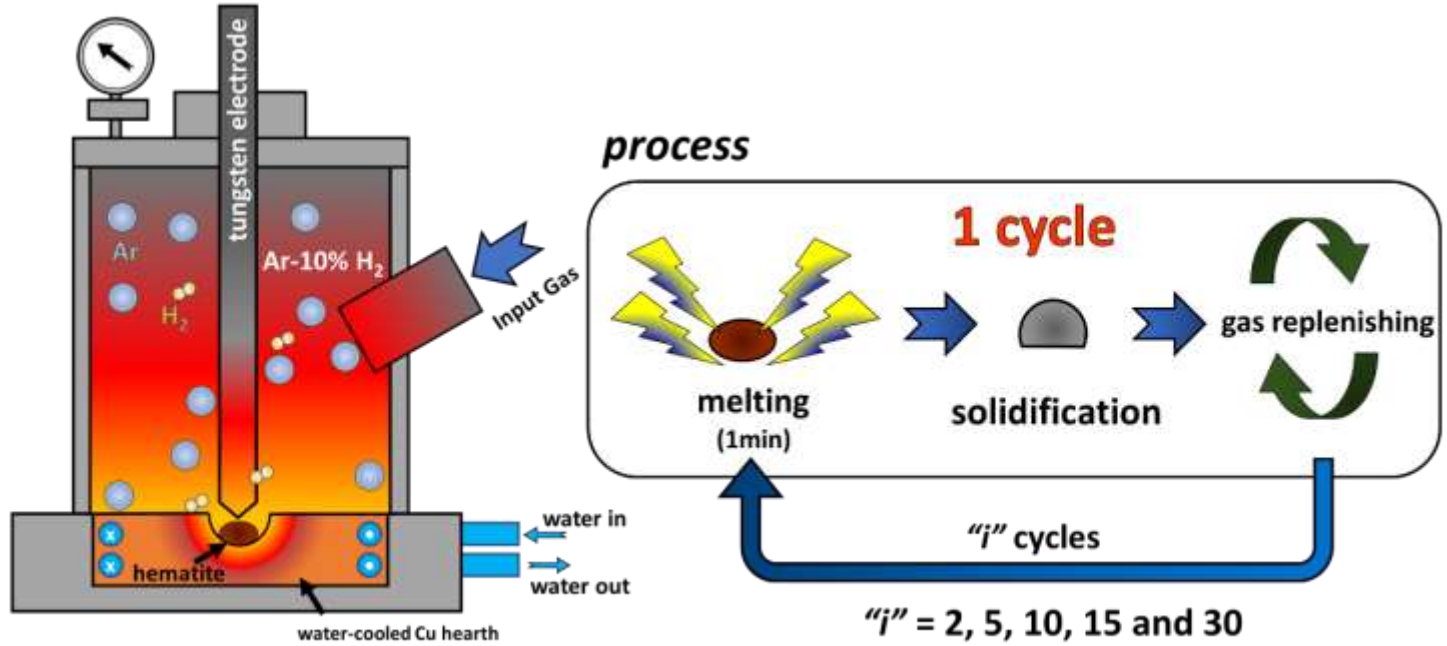
ATOMIC-SCALE SCHEMATIC VIEW OF WÜSTITE REDUCTION BY H_2



KIM ET AL. ACTA MATER 2021 IN PRESS

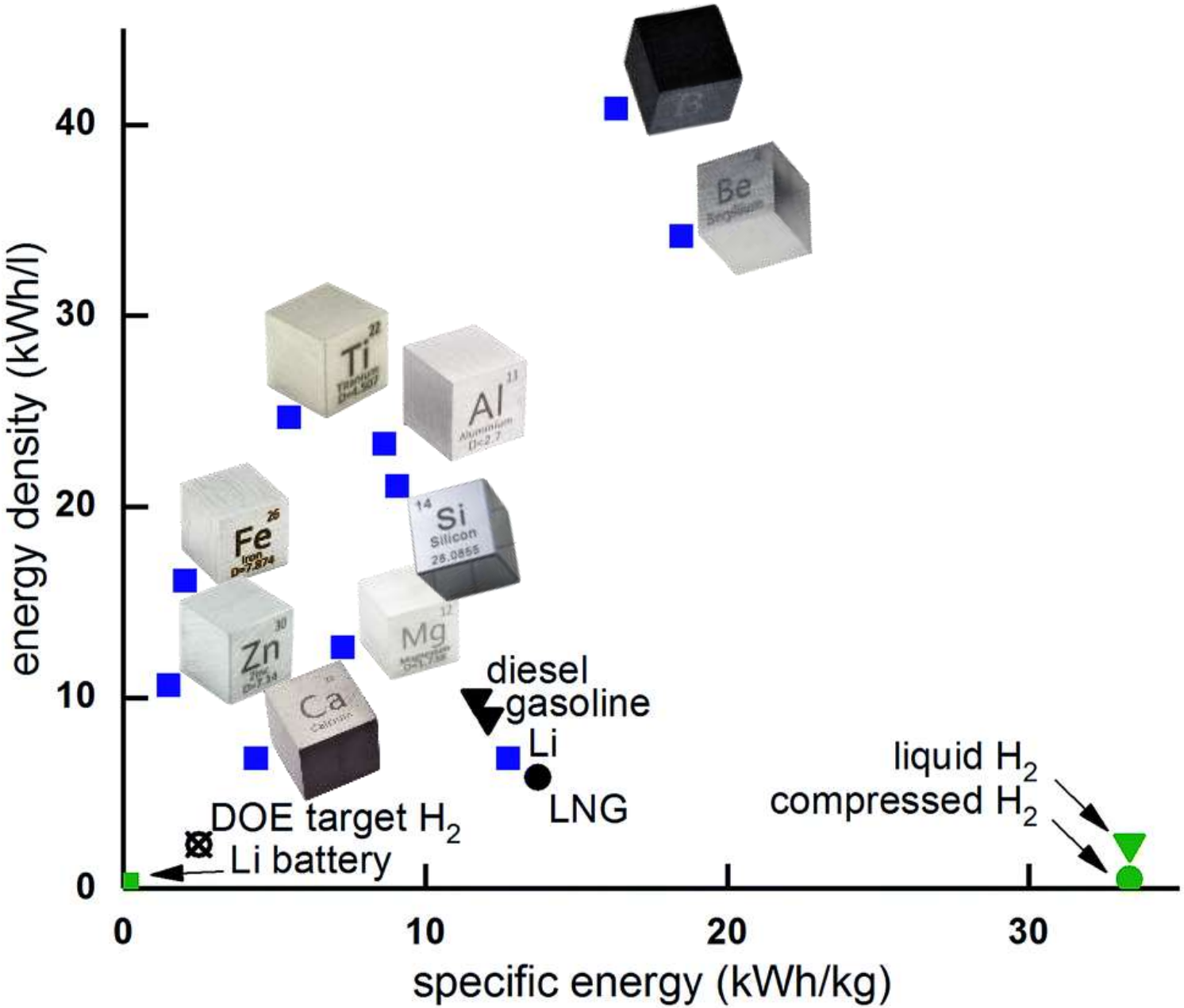
PLASMA REDUCTION

H containing plasma



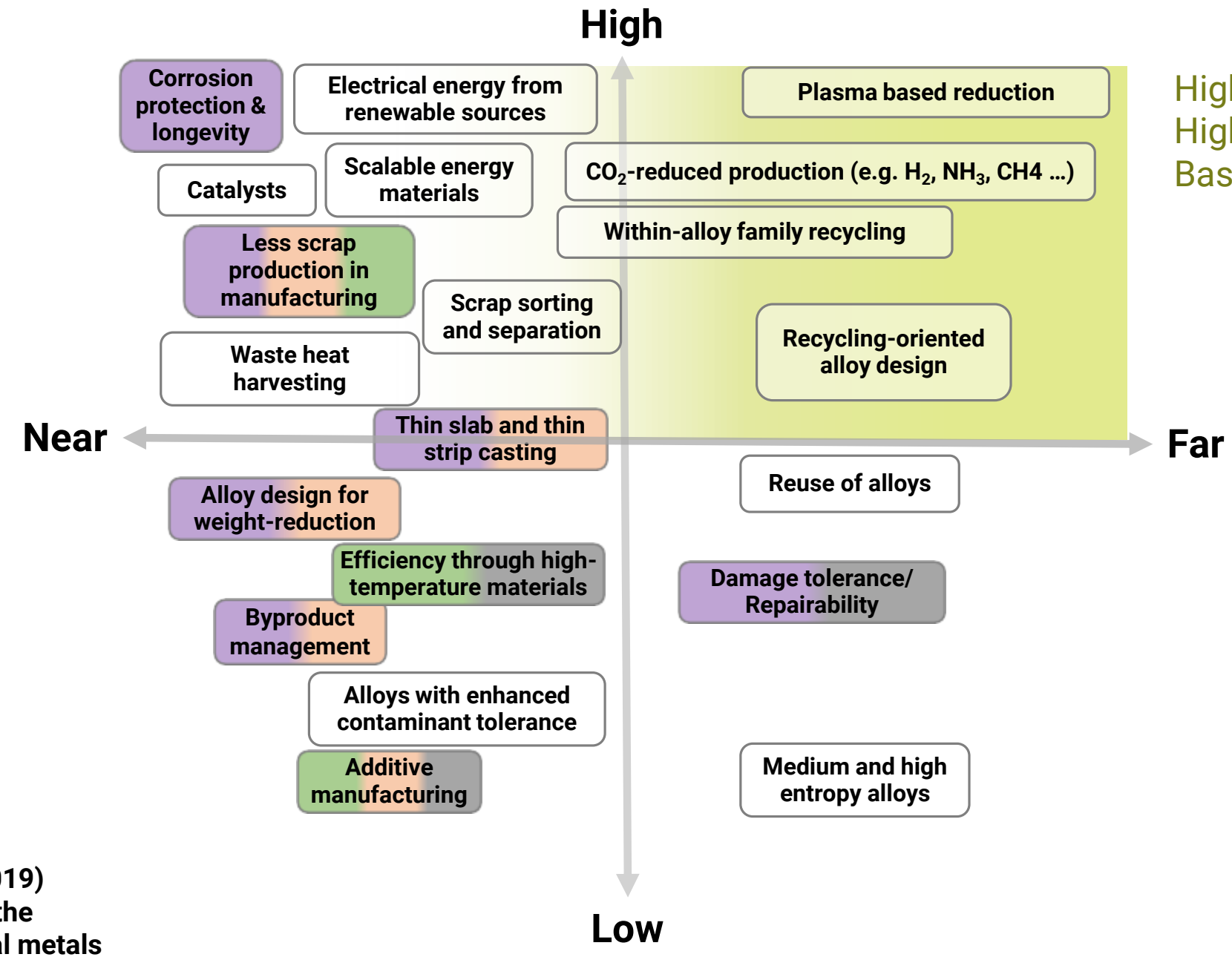
hematite inside the furnace before the process

(a)
5 mm
2 min of plasma exposure
(b)
ECCI
100 µm
ECCI
10 µm
(c)
IQ
10 µm
(d)
10 µm
(e)
10 µm
(f)
Oxygen
10 µm
(g)
Silicon
10 µm
(h)
captions:
(e) IPF:
(f) Phase map:
wüstite
ferrite
(g) oxygen content:
min.
max.
(h) silicon content:
min.
max.



P. JULIEN, J. M. BERGTHORSON, SUSTAINABLE ENERGY FUELS, 2017,1, 615-625

Potential for Impact



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