FACULTY OF ENGINEERING AND ARCHITECTURE

DEPARTMENT OF MATERIALS, TEXTILES AND CHEMICAL ENGINEERING
RESEARCH GROUP SUSTAINABLE MATERIALS SCIENCE

Towards circularity in steel industry: a joint journey between industry and universities along multiple TRL levels

Inge Bellemans and Kim Verbeken

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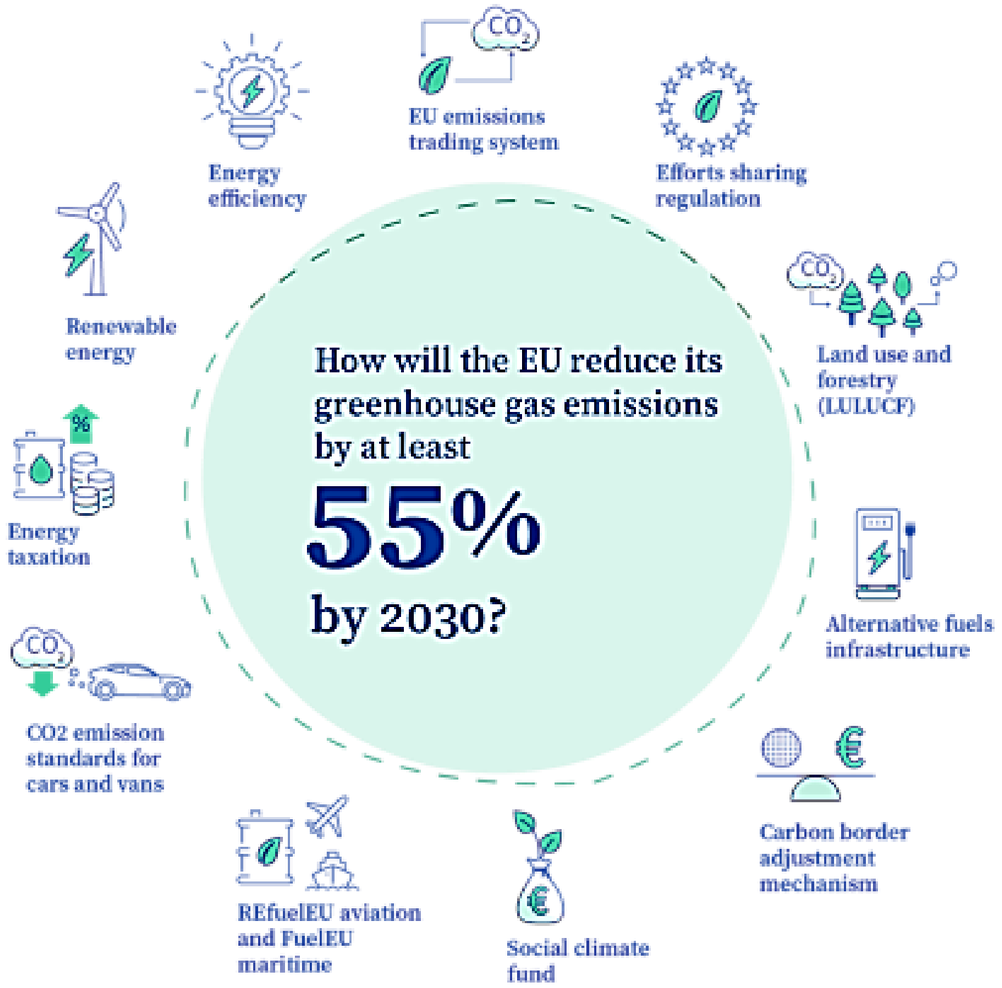
SMS
SUSTAINABLE MATERIALS SCIENCE

Fit for 55

Fit for 55: how the EU will turn climate goals into law



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Source: Council of the European Union

Steel is everywhere

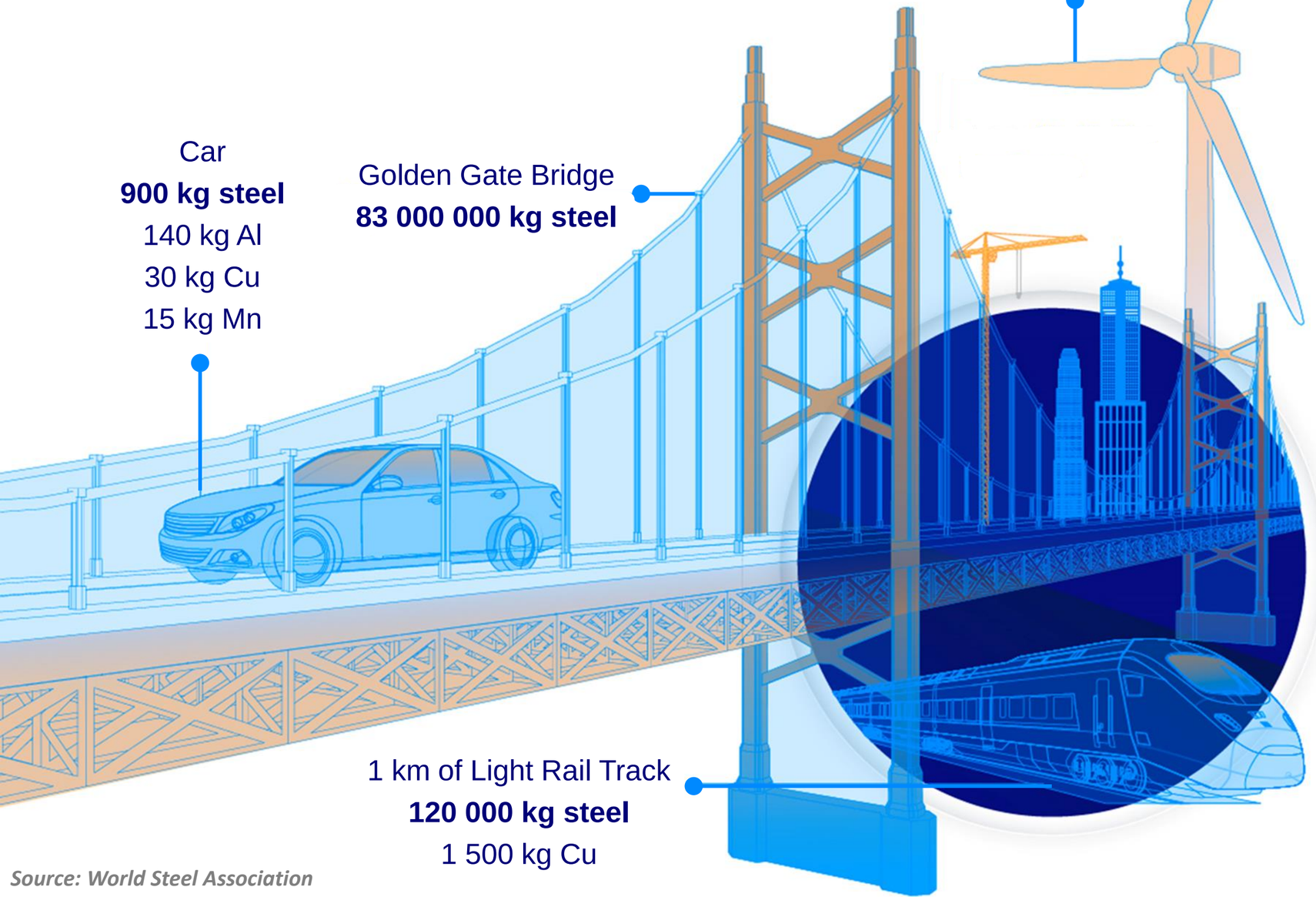
Average Wind Turbine
335 000 kg steel
4 700 kg Cu
3 000 kg Al
2 000 kg REE

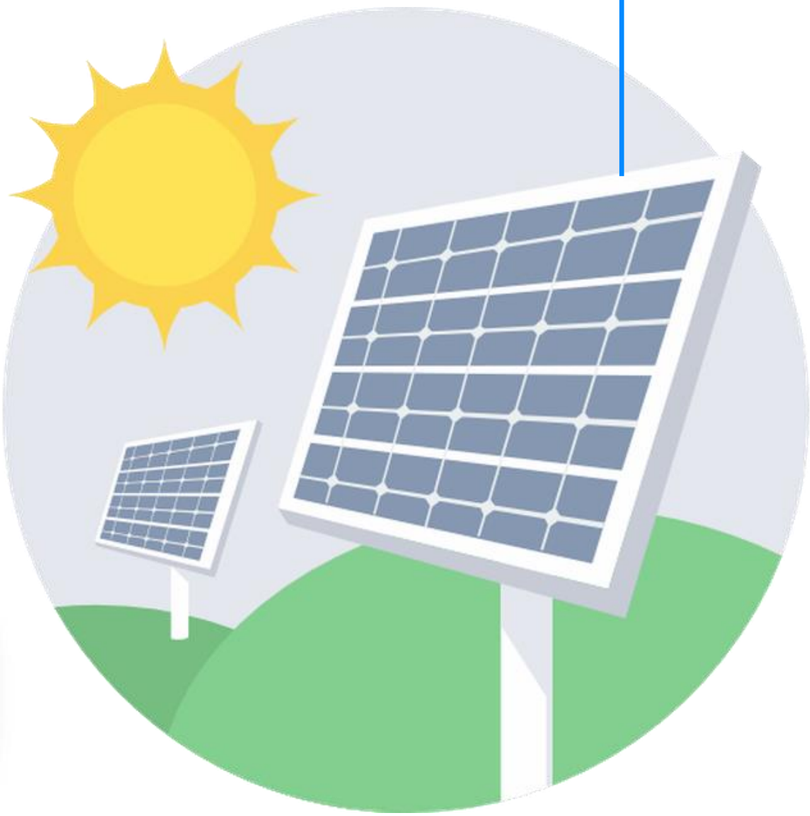
Each MW Solar power
45 000 kg steel
5 500 kg Cu

Car
900 kg steel
140 kg Al
30 kg Cu
15 kg Mn

Golden Gate Bridge
83 000 000 kg steel

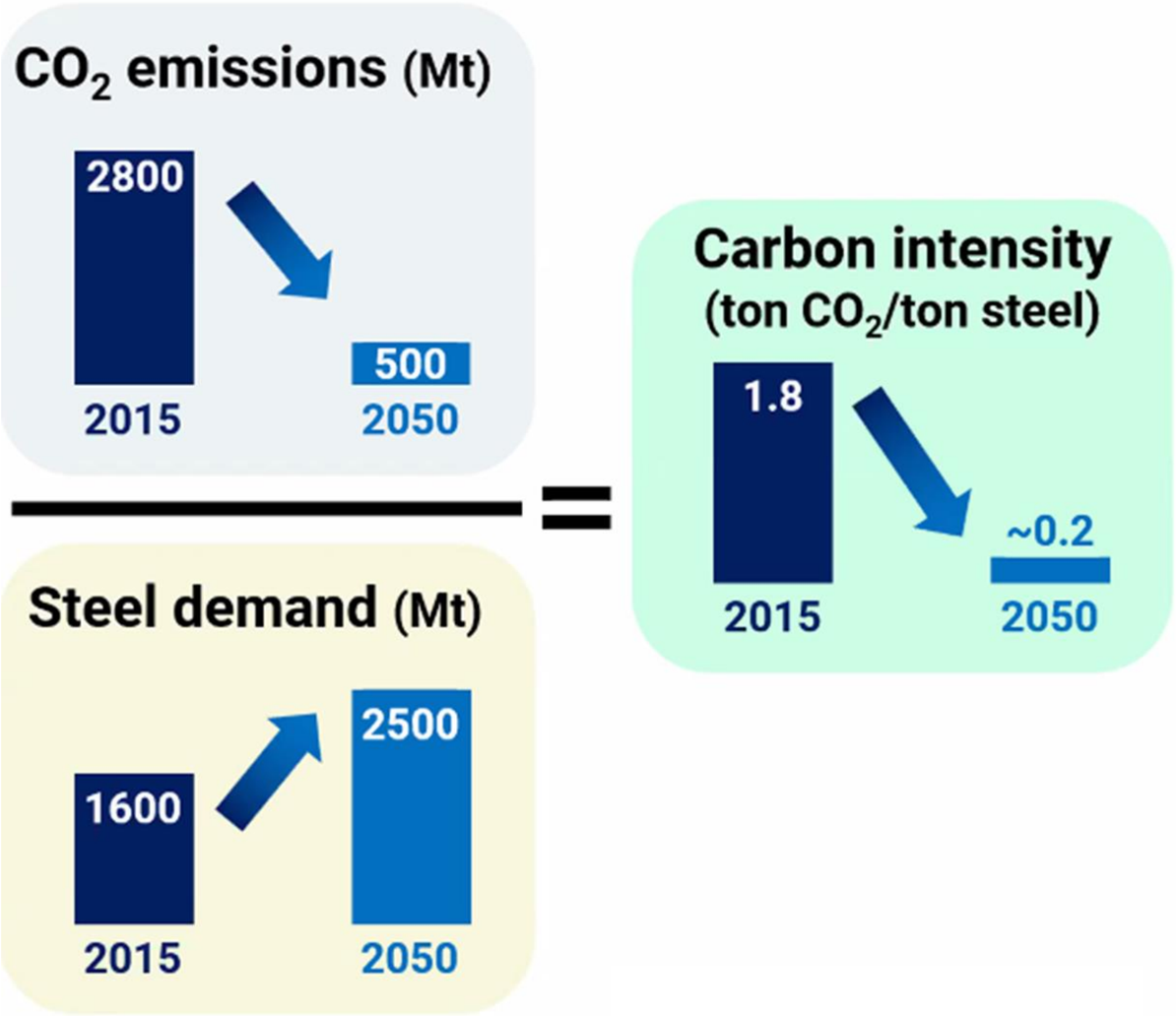
1 km of Light Rail Track
120 000 kg steel
1 500 kg Cu





Source: World Steel Association

CO_2 production



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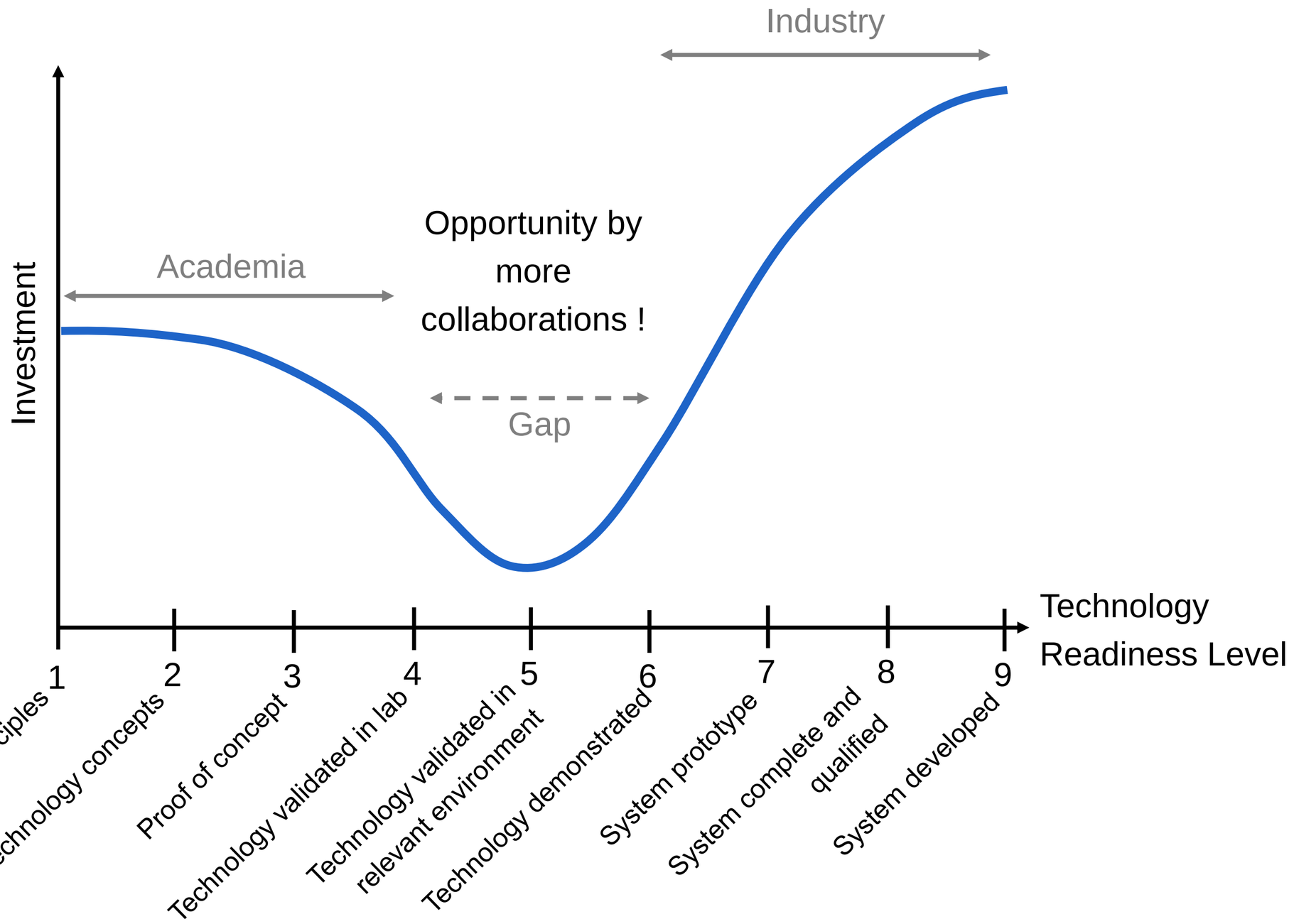
Source: Pei et al., Metals 2020, 10(7), 972

Bridging the TRL gap



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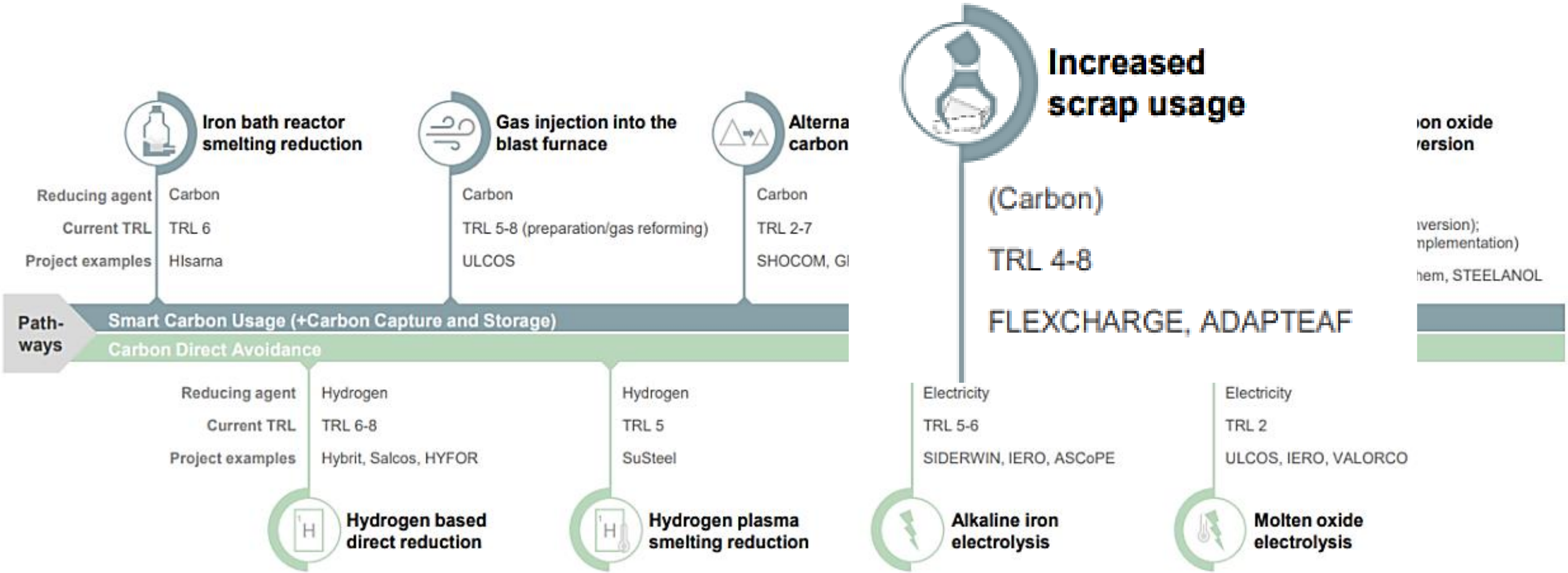
Decarbonisation technologies



Supporting technologies: CO_2 capture, hydrogen production

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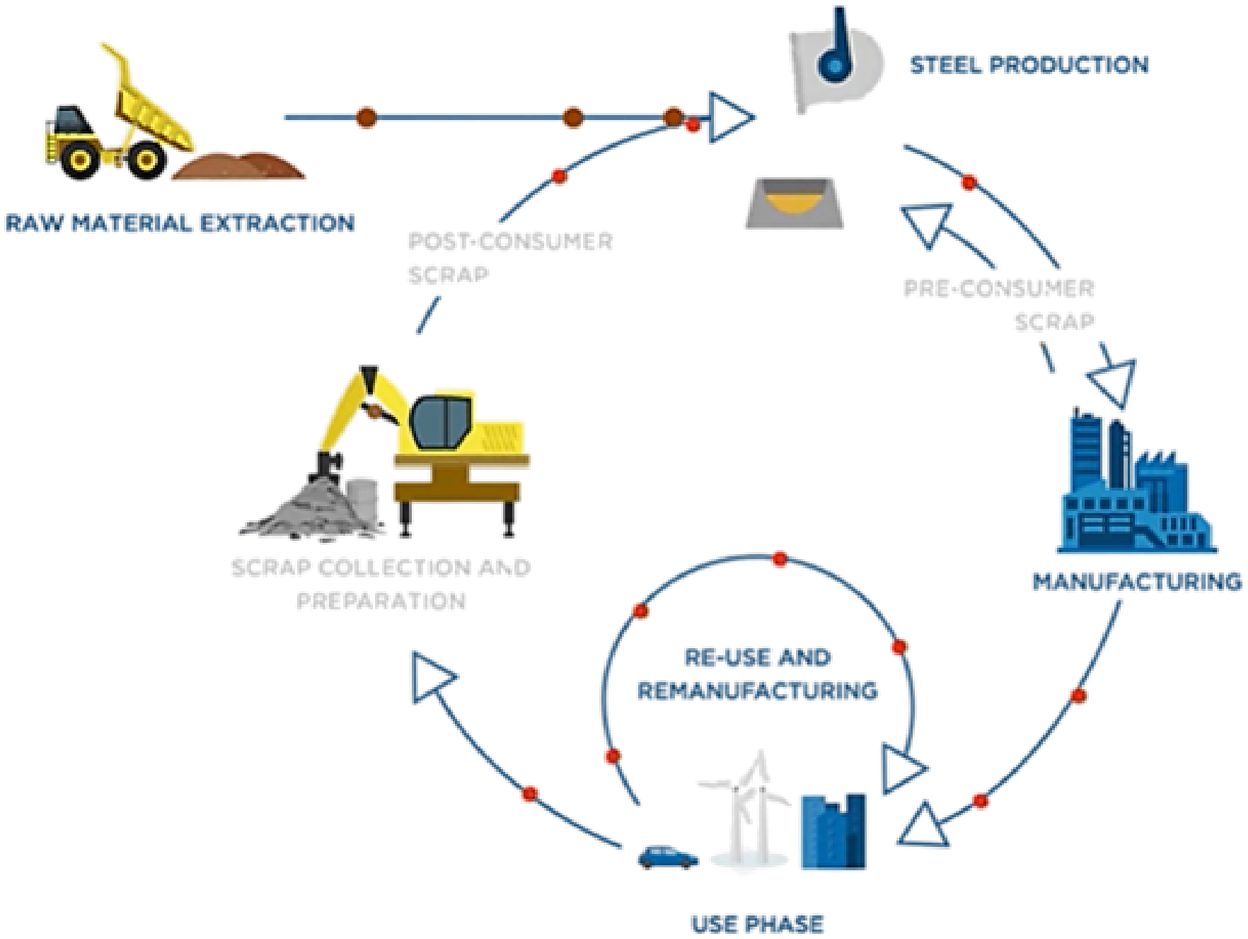
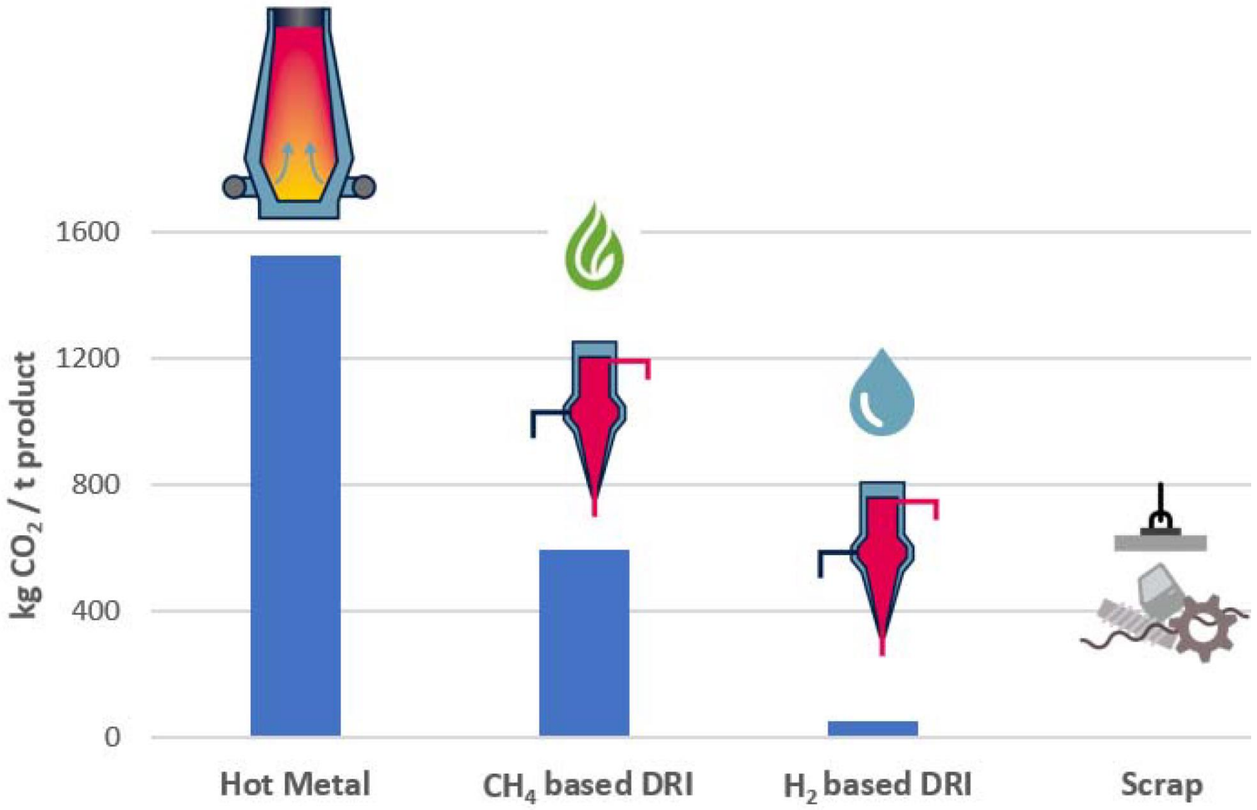
Source: Climate-neutral steelmaking in Europe – Decarbonisation pathways, investment needs, policy conditions, recommendations 2022

Increased scrap use





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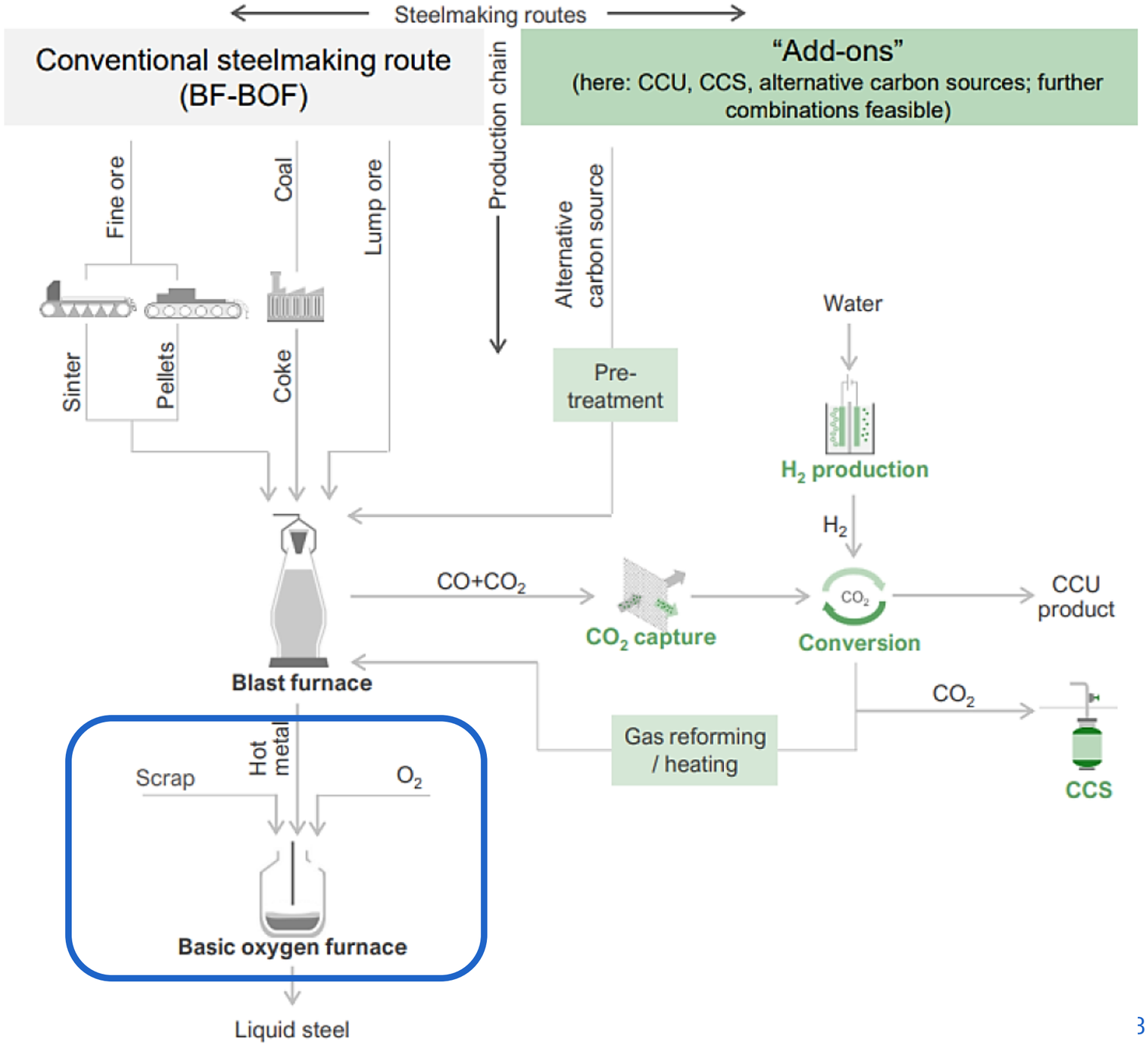
Source: Eurofer; Voraberger et al. Metals 2022, 12(3), 466;

Optimised BF-BOF



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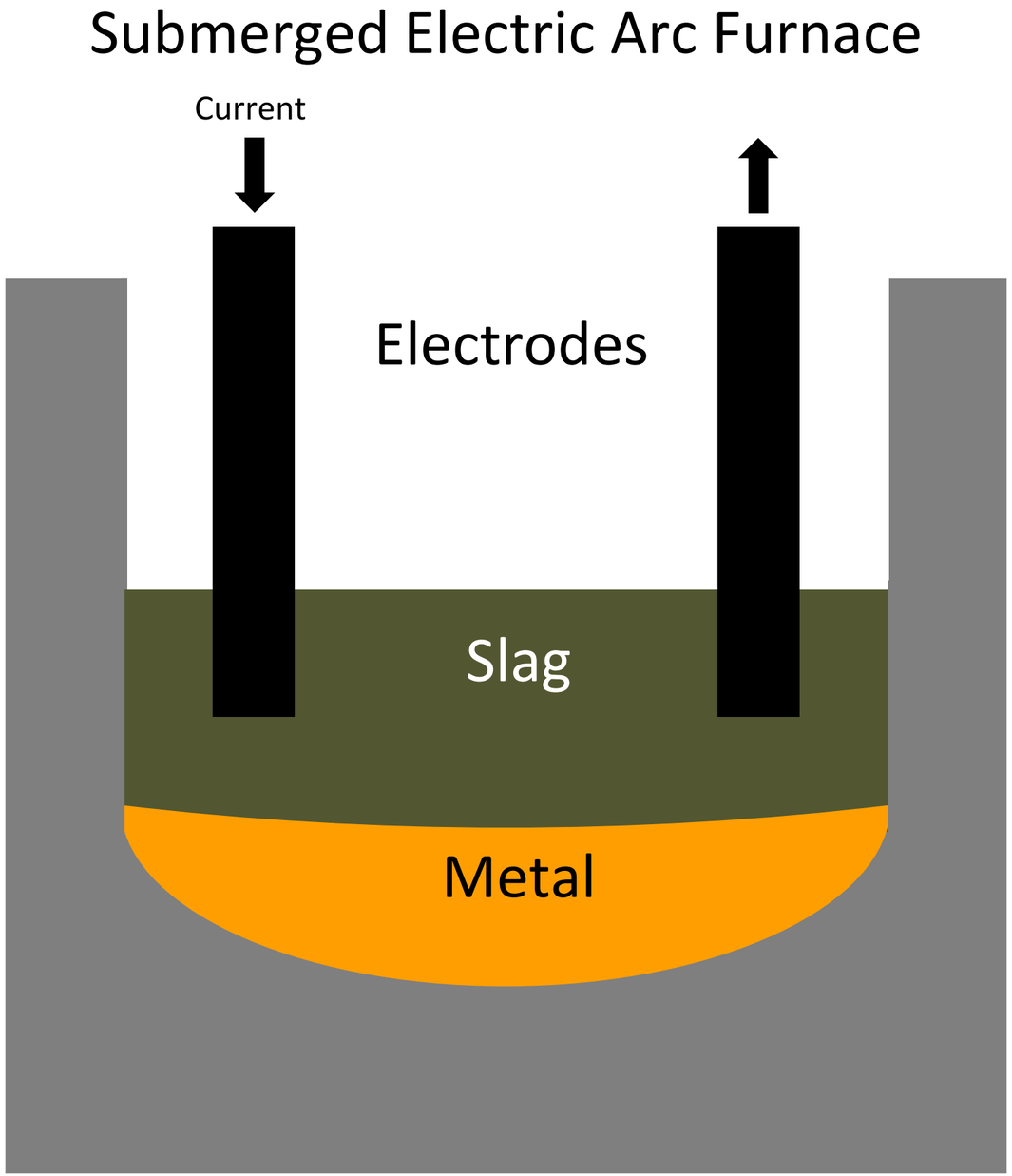
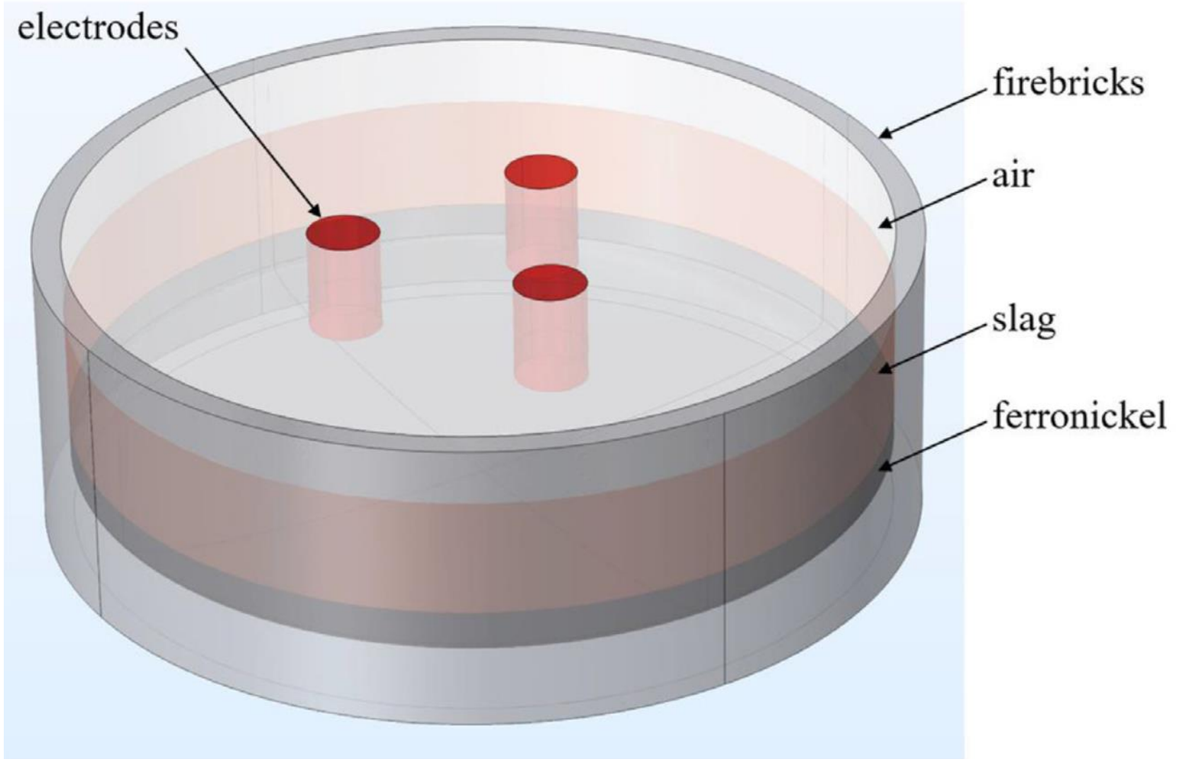
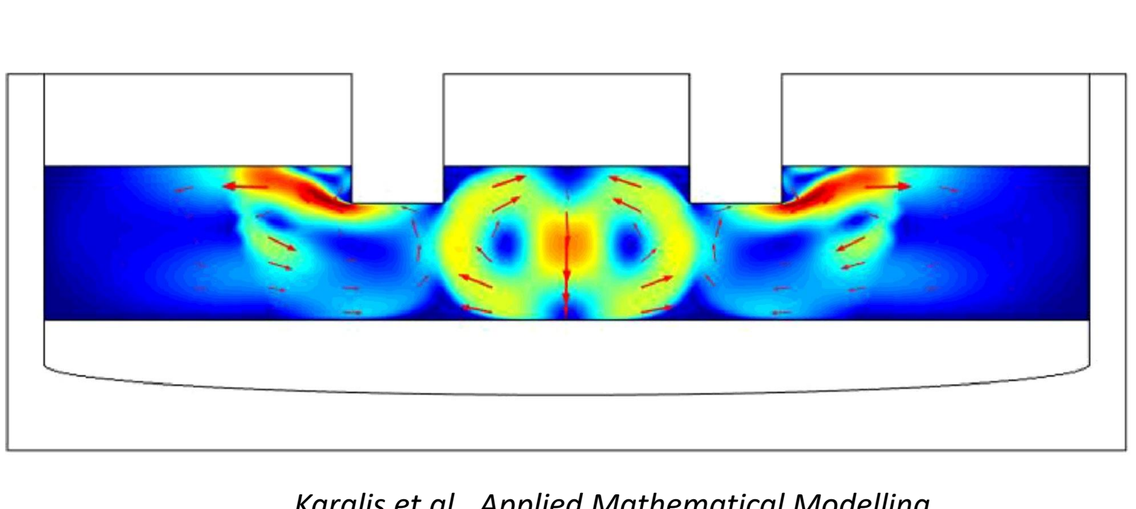
Source: Climate-neutral steelmaking in Europe – Decarbonisation pathways, investment needs, policy conditions, recommendations 2022

Electric furnaces: digital twins







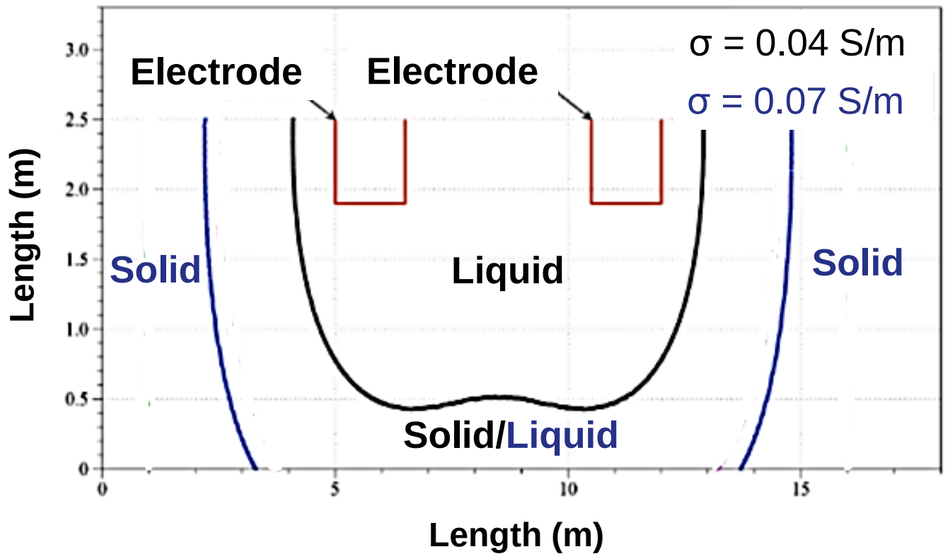
Karalis et al., Applied Mathematical Modelling
Vol 40, Issues 21–22 (2016) P 9052-9066

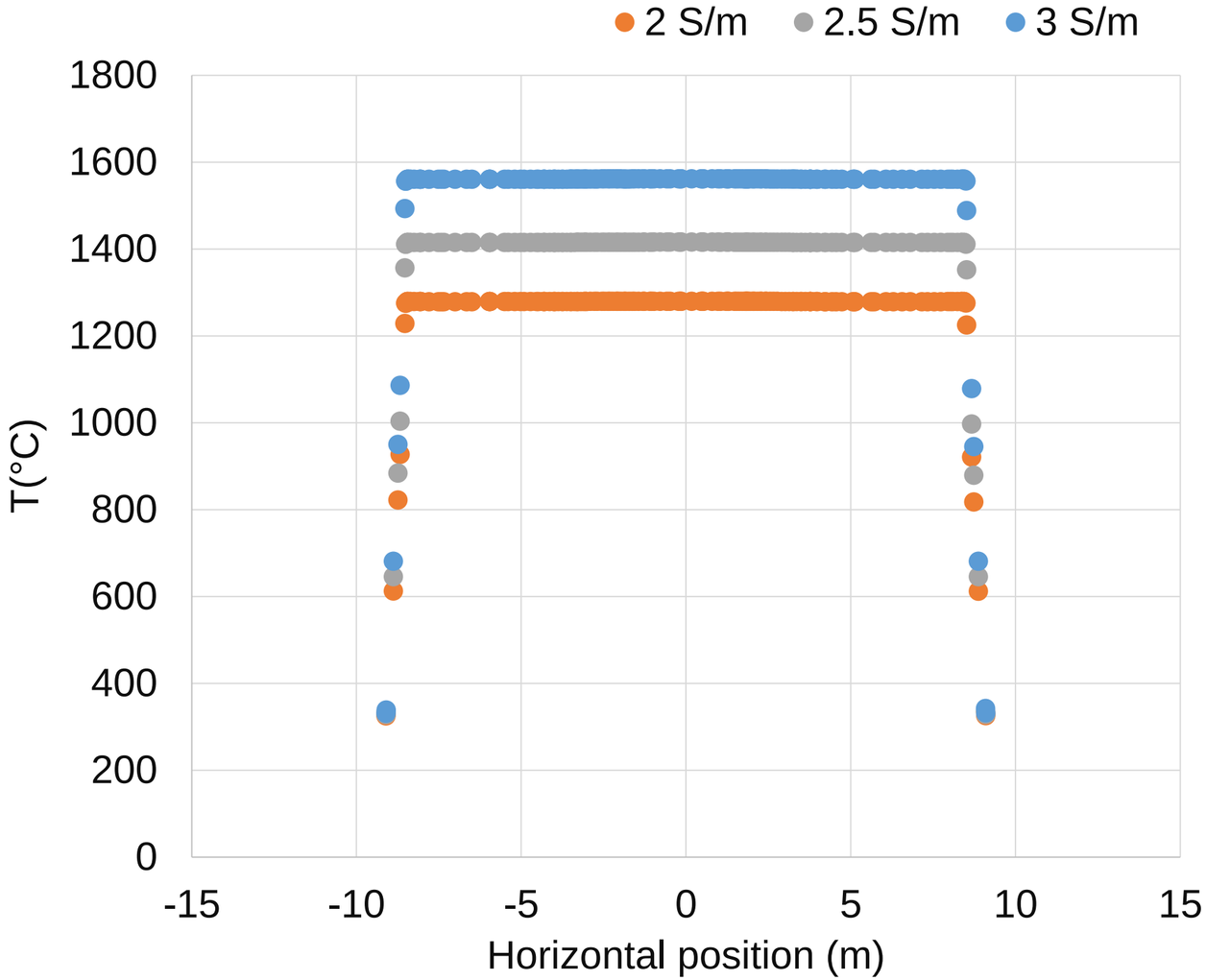
Electric furnaces: digital twins

Power generation via Joule heat

$$P = \frac{V^2}{R_{slag}}$$

$$R_{slag} \sim \frac{1}{\sigma_{slag}}$$





Karalis et al., Applied Mathematical Modelling Vol 40, Issues 21–22 (2016) P 9052-9066

PhD Pieter-Jan Boeykens ***(Ghent University)***

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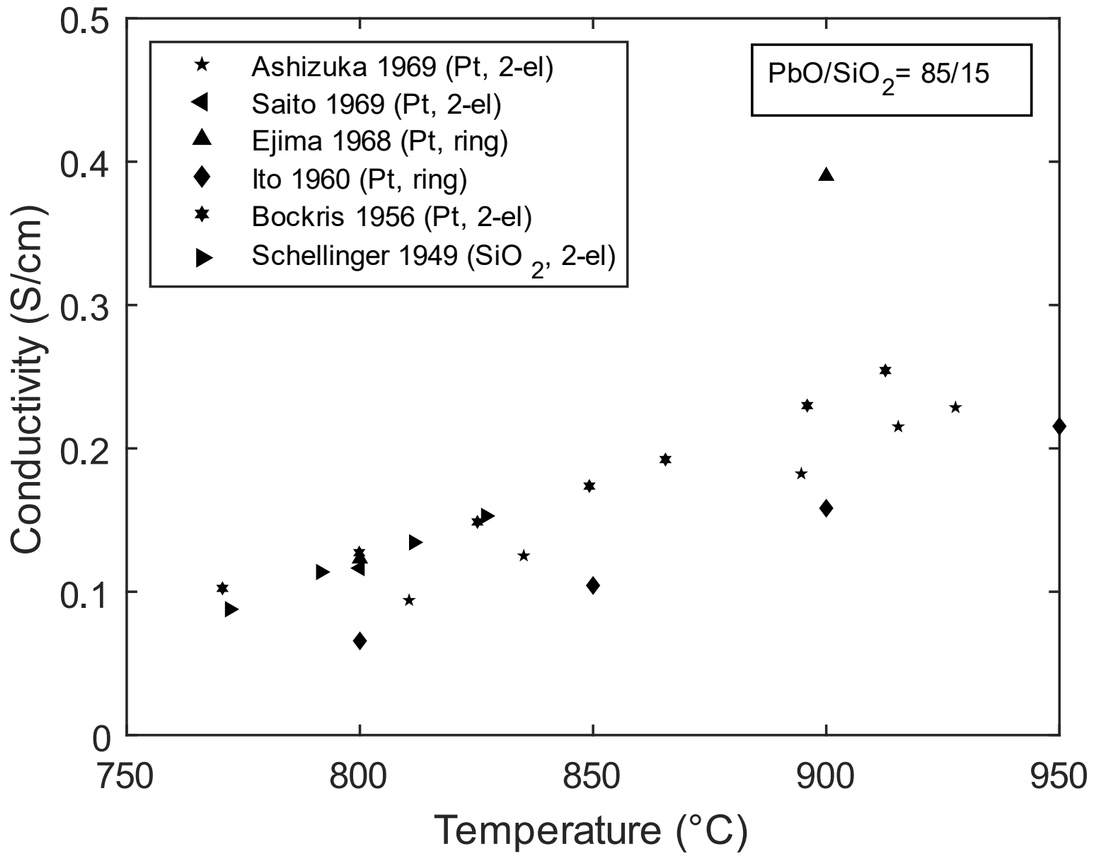
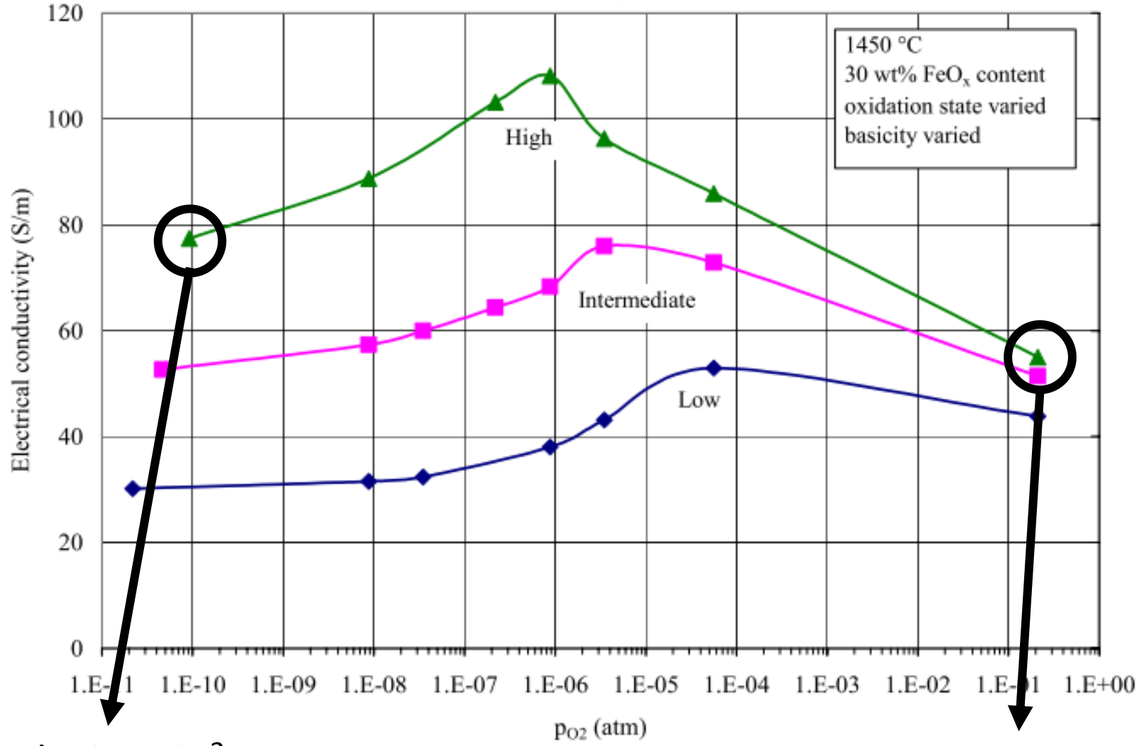
Huge spread on experimental results + 2 contributions

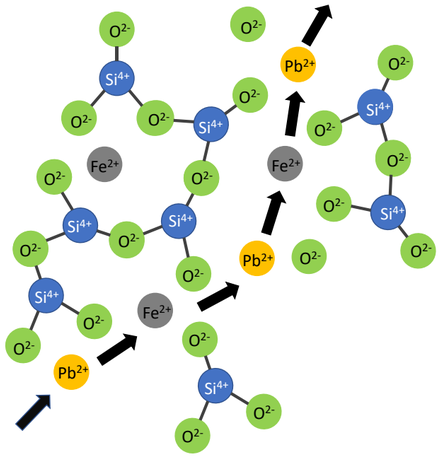


PhD Pieter-Jan Boeykens ***(Ghent University)***

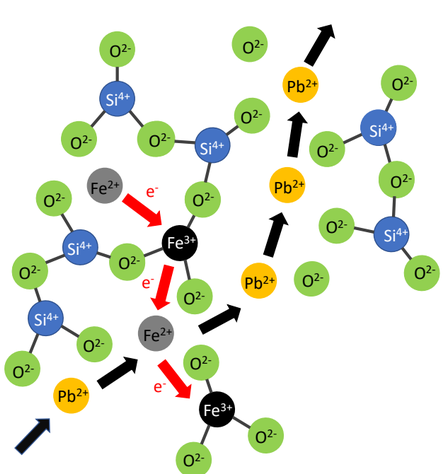
Hundermark et al., 2004, VII International Conference on Molten Slags Fluxes and Salts



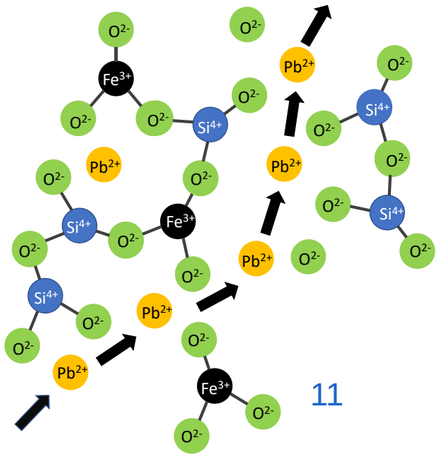
Reducing: Fe^{2+}



Intermediate: Fe^{2+} & Fe^{3+}



Oxidizing: Fe^{3+}



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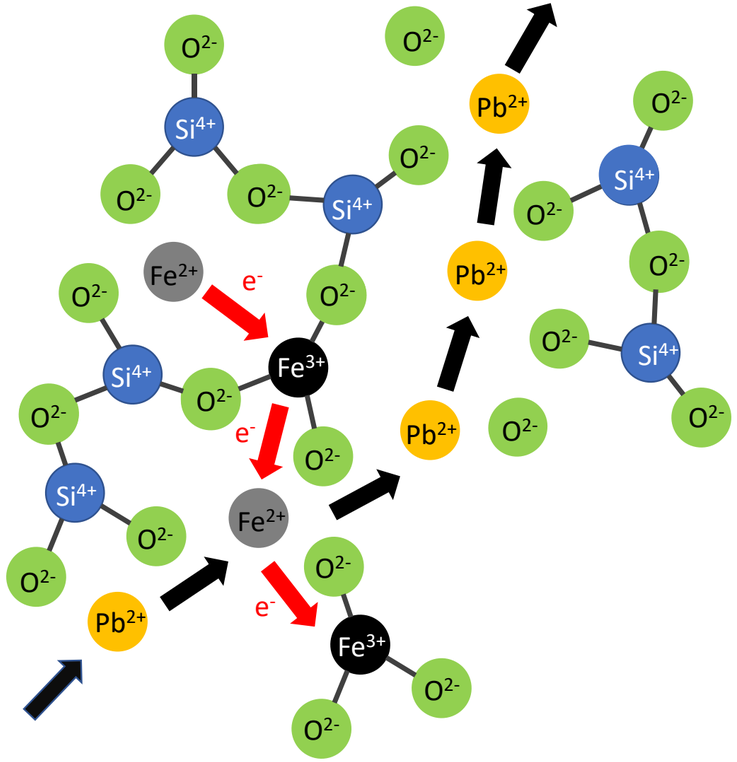
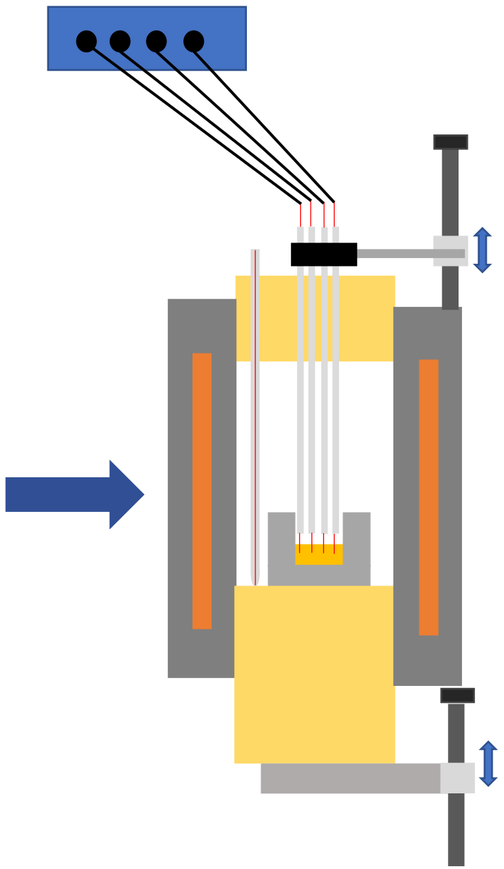
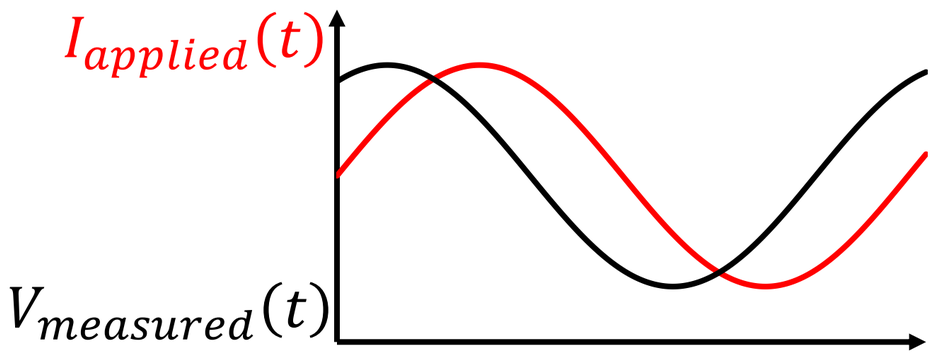
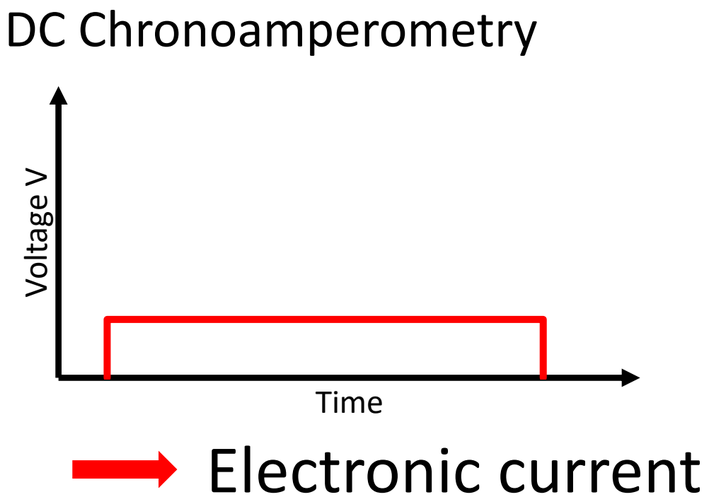
Electrical conductivity measurements









Four-electrode conductivity setup

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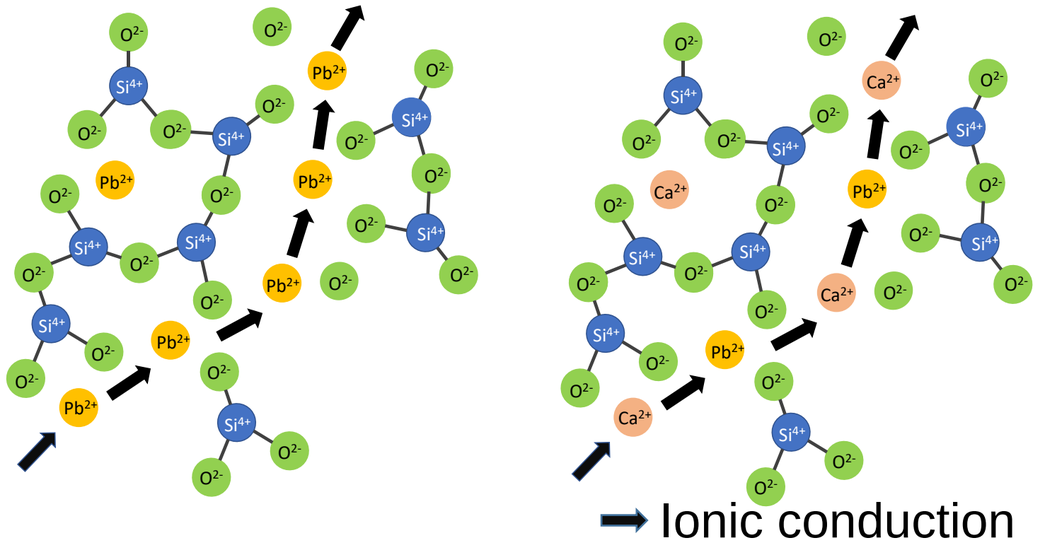
Boeykens et al., Electrochimica Acta
Vol 464 (2023) 142846
(Ghent University)

Results: Effect substitution of PbO by CaO

Sample composition: SiO_2 = 52 mol%
Varying amounts of CaO (and PbO)



Results showing that substituting CaO for PbO in a system with a constant amount of silica resulted in a significant decrease in the electrical conductivity (not described by current structure-property model)

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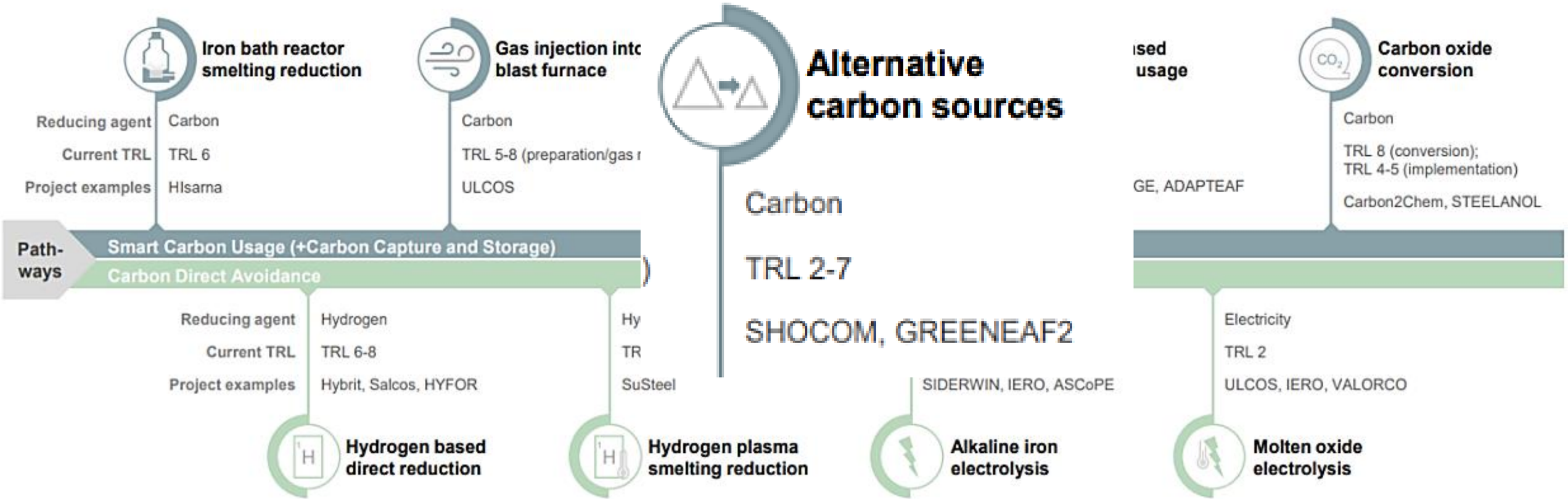
To be published

PhD PJ Boeykens ***(Ghent University)***

Decarbonisation technologies



Supporting technologies: CO_2 capture, hydrogen production

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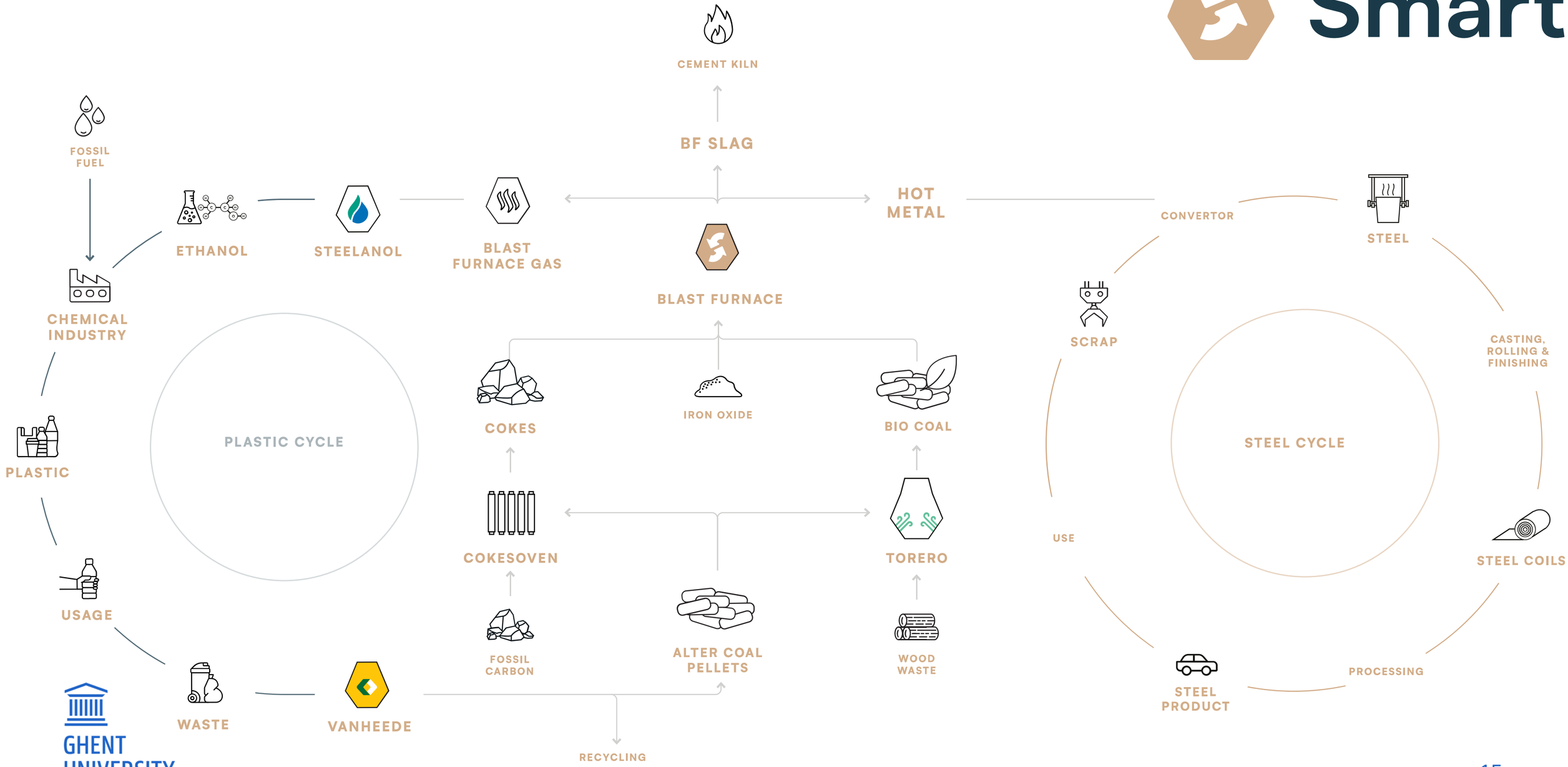
Source: Climate-neutral steelmaking in Europe – Decarbonisation pathways, investment needs, policy conditions, recommendations 2022

Alternative carbon sources: Life SMART

Smart



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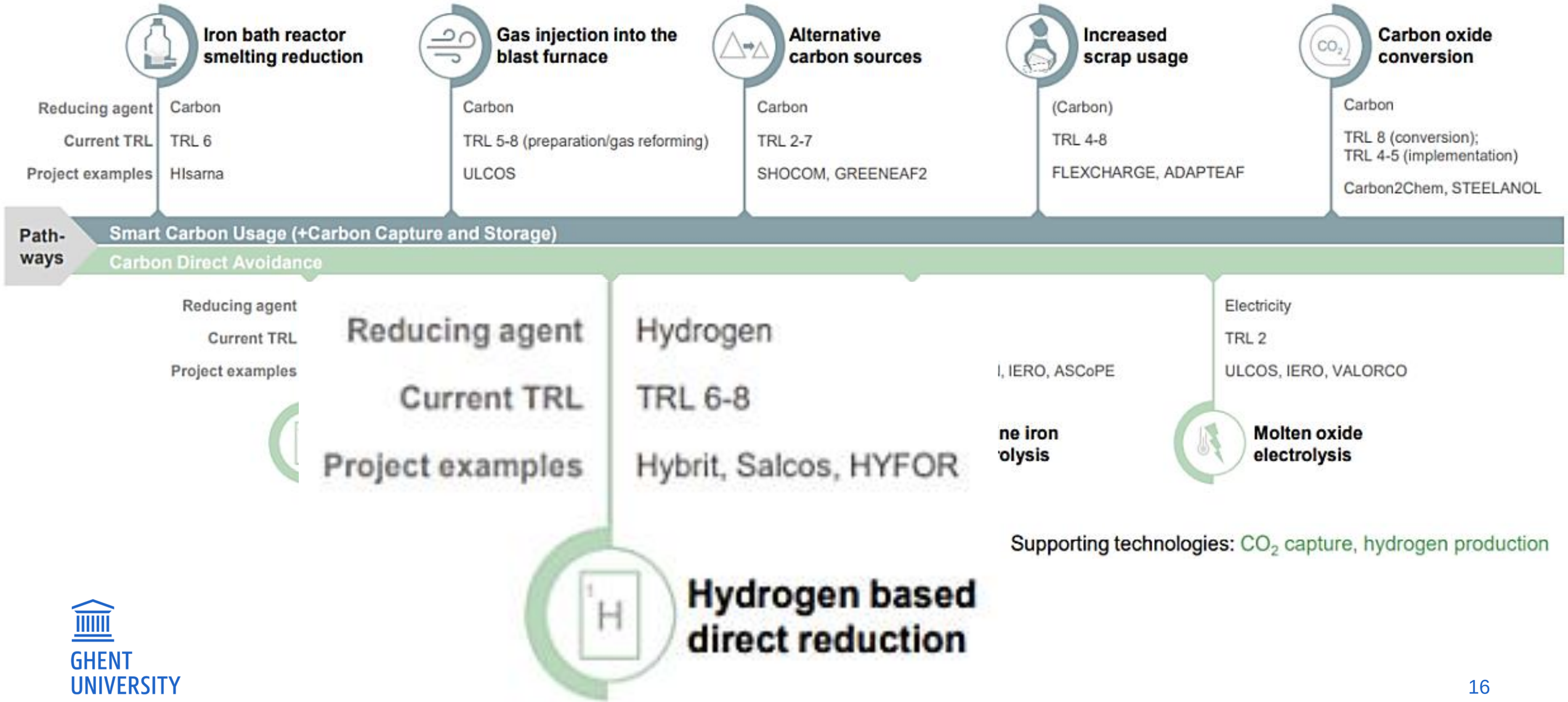
Decarbonisation technologies



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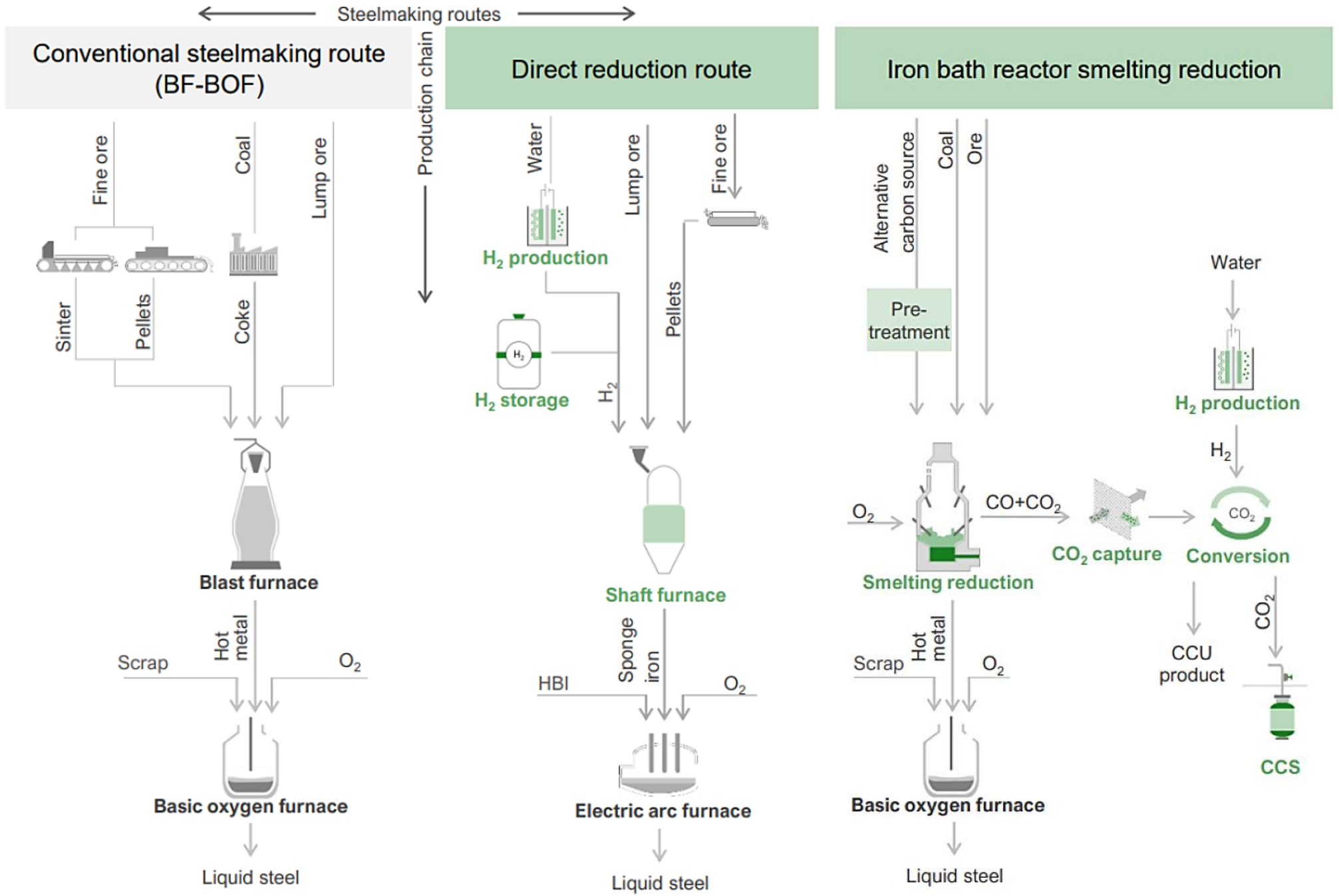
Source: Climate-neutral steelmaking in Europe – Decarbonisation pathways, investment needs, policy conditions, recommendations 2022



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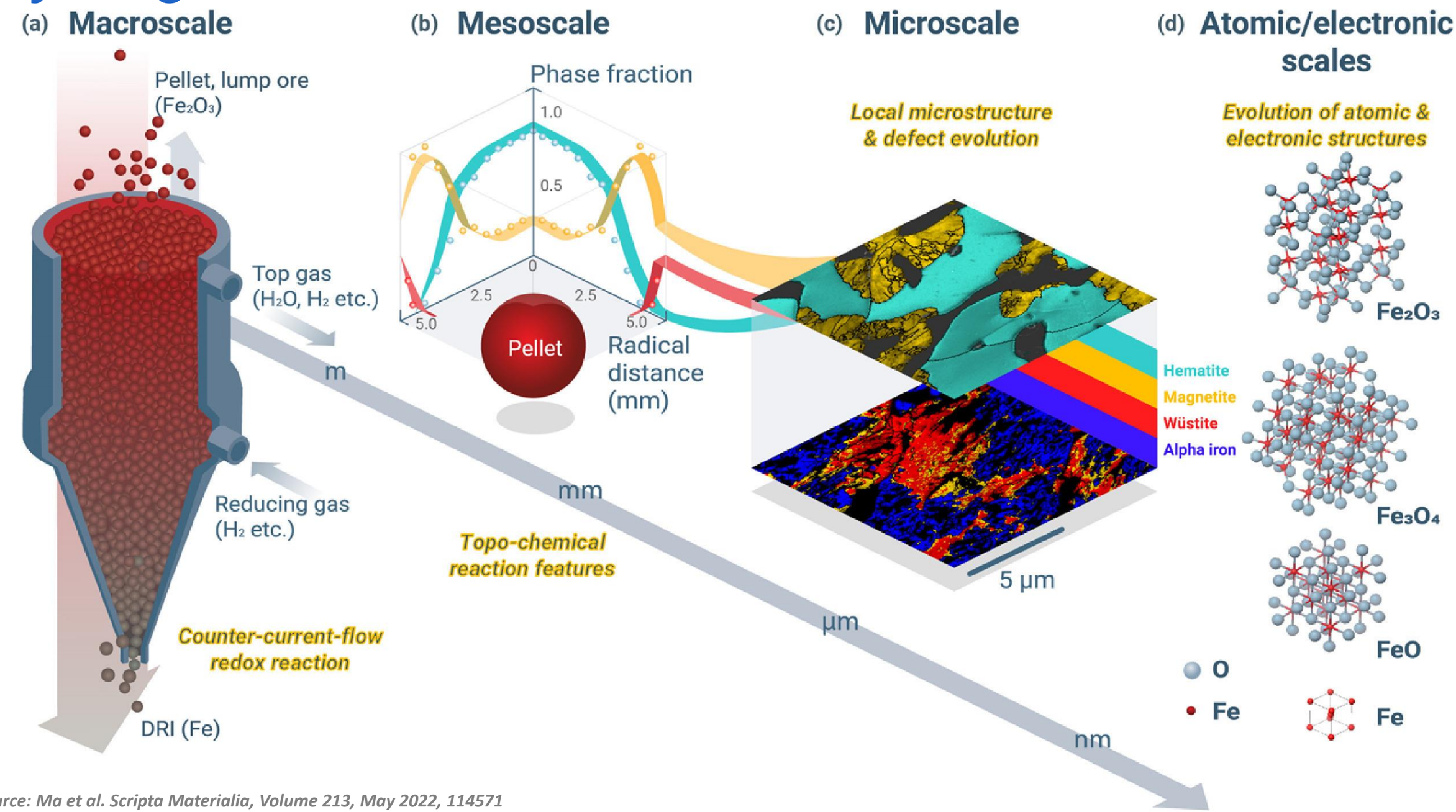
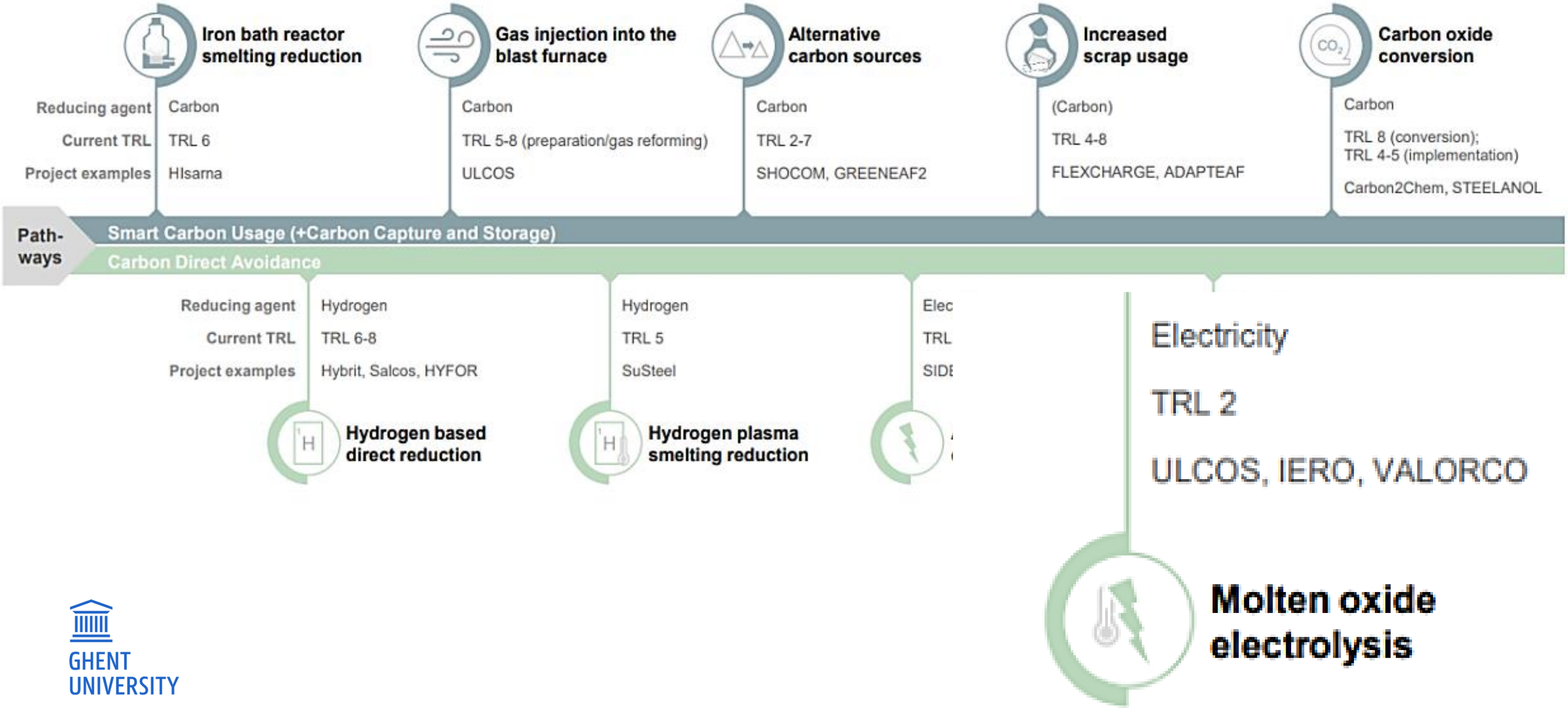
Source: Climate-neutral steelmaking in Europe – Decarbonisation pathways, investment needs, policy conditions, recommendations 2022

Hydrogen reduction



Source: Ma et al. Scripta Materialia, Volume 213, May 2022, 114571

Decarbonisation technologies



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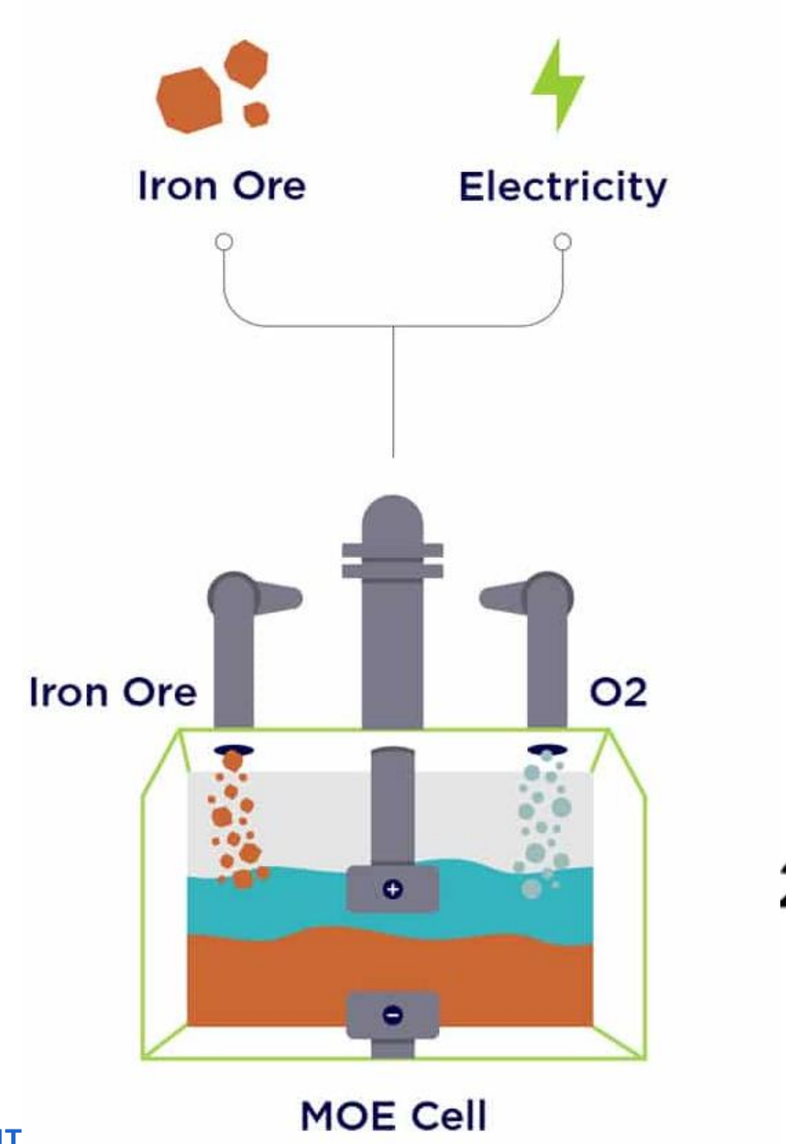
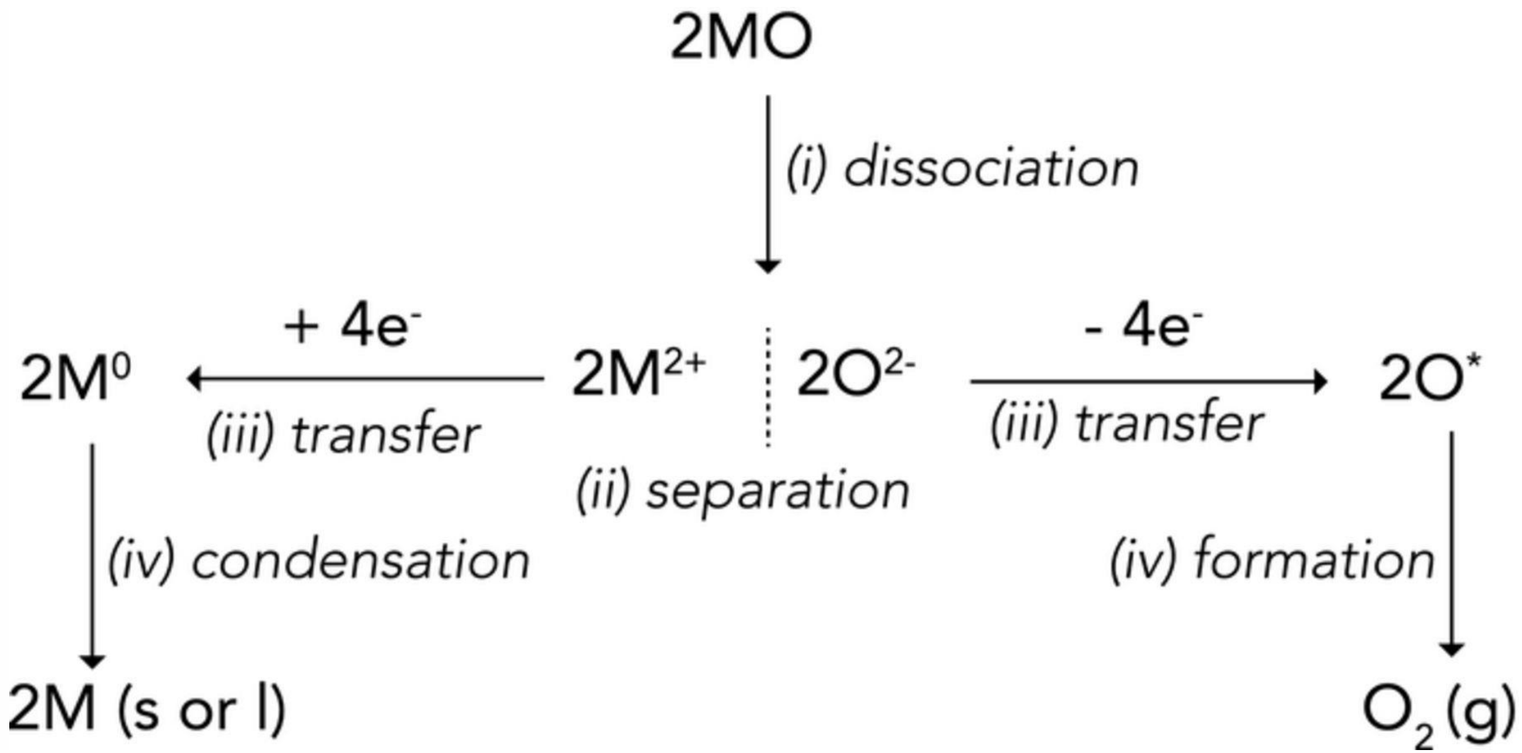
Source: Climate-neutral steelmaking in Europe – Decarbonisation pathways, investment needs, policy conditions, recommendations 2022

Molten oxide electrolysis





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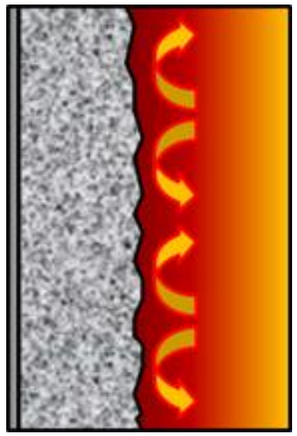
Source: Allanore, 2015 J. Electrochem. Soc. 162 E13

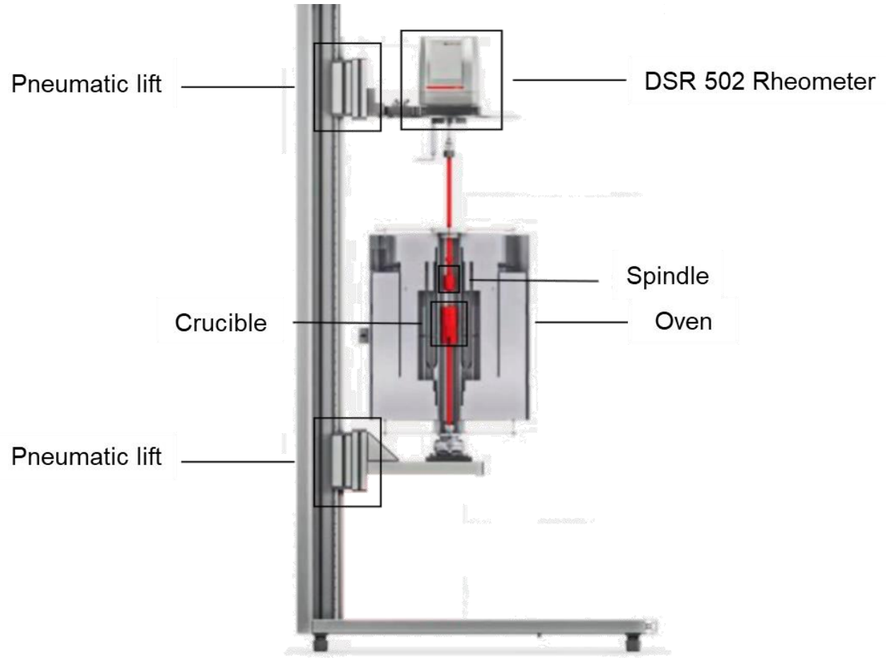
Slag viscosity

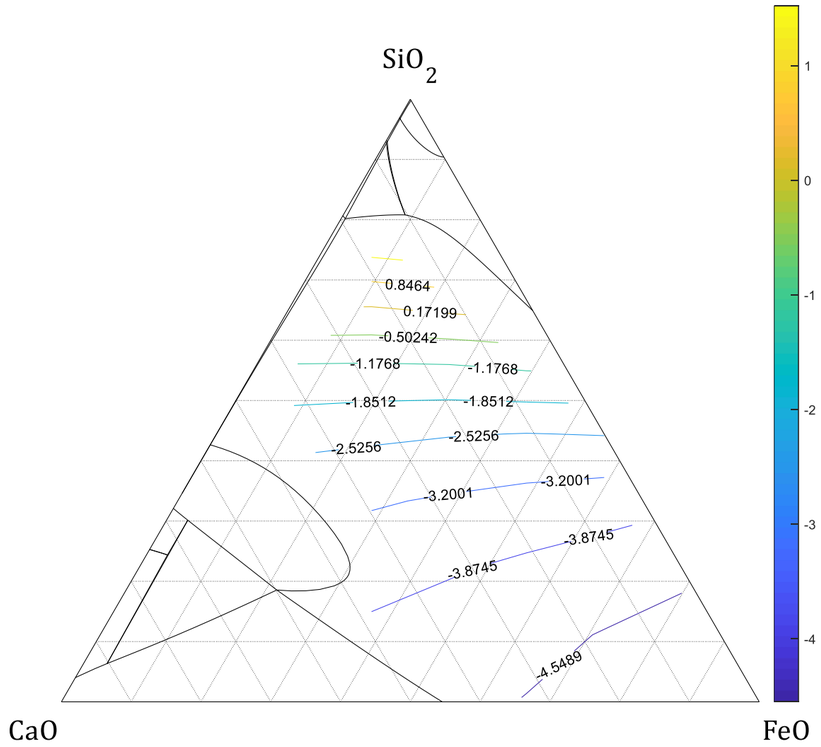
Slag tapping

Slag foaming (stable ↔ eruptive)

Slag – refractory interactions







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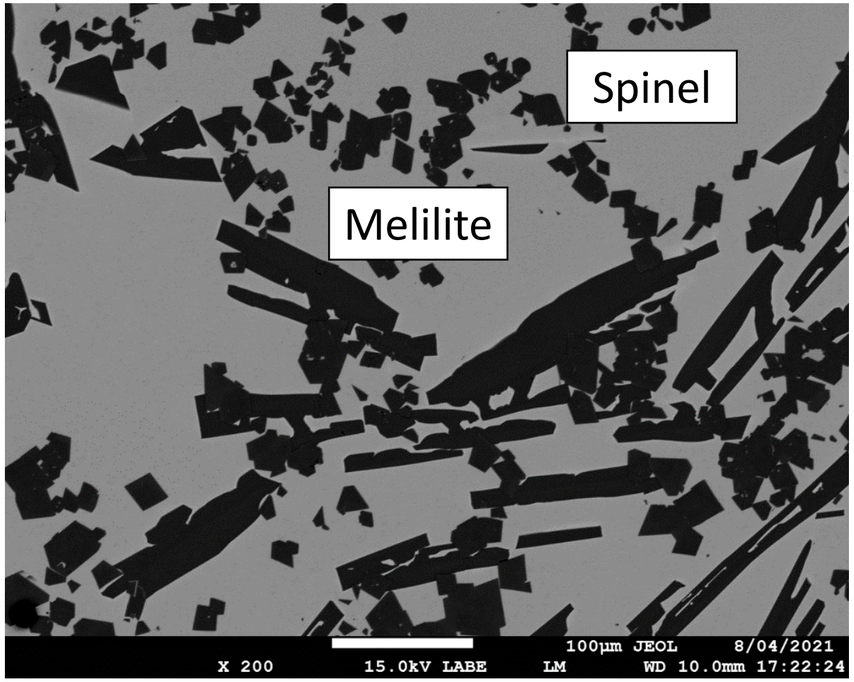
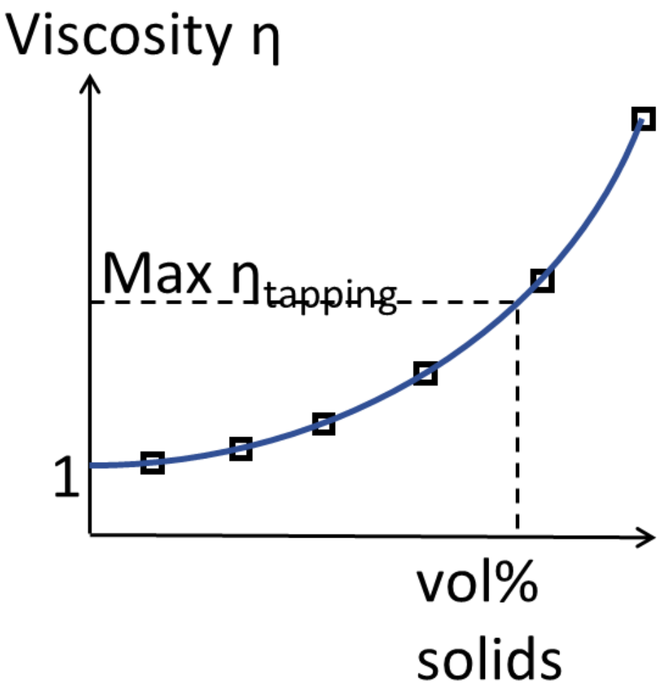
Slag suspension viscosity

Slag viscosity = resistance against flow

Depends on:
- slag structure
- temperature
- **presence of solids**





Vergote et al., Journal of rheology 67 (2023), 1159–1174
(Ghent University)

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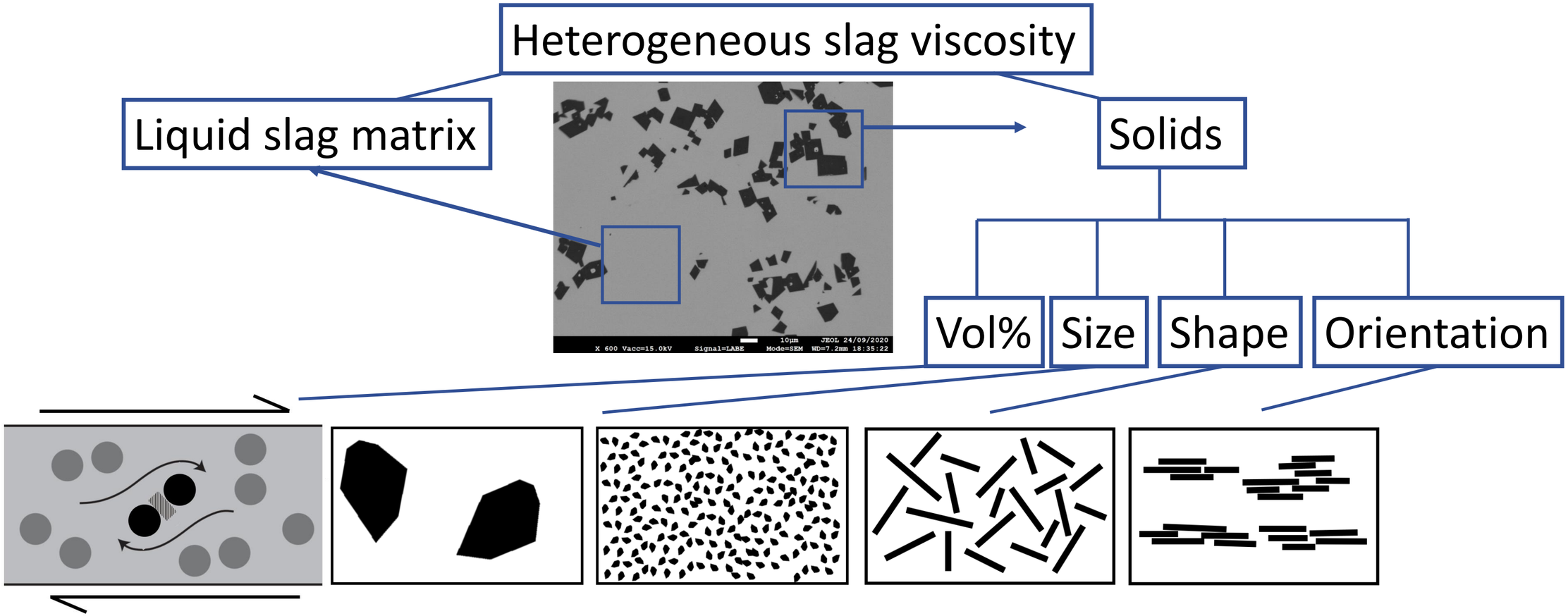
Heterogeneous (liquid + solid) slag viscosity



$\eta = \eta_{liquid} \times f_{solids}(\Phi_{solids}, \text{morphology, orientation})$

Various parameters, many neglected

→ Reproducibility slag suspension viscosity low

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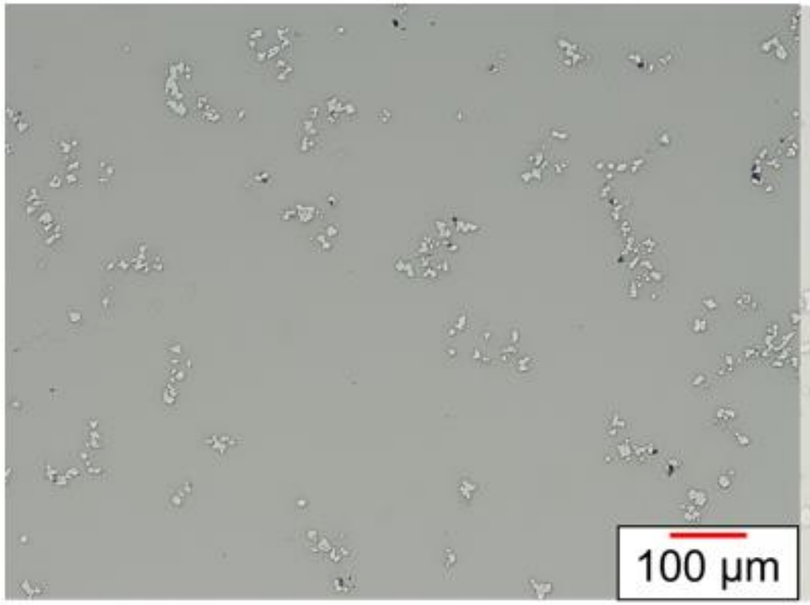
Methodology – slag system

Three datasets studied

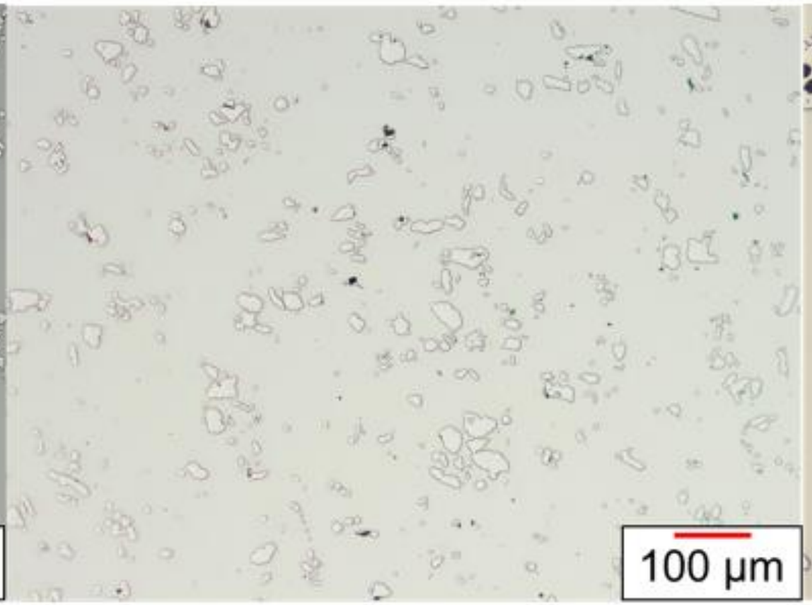
Spinel small



13 µm

0 – 7 vol%

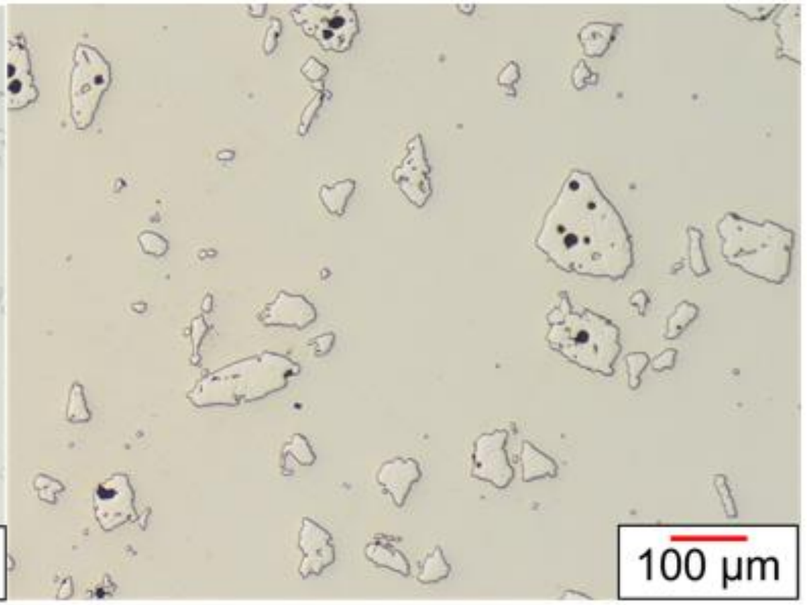
Spinel medium



34 µm

0 – 12 vol%

Spinel large



76 µm

0 – 16 %

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Vergote et al., Journal of rheology 67 (2023), 1159–1174
(Ghent University)

Results: spinel – effect of size

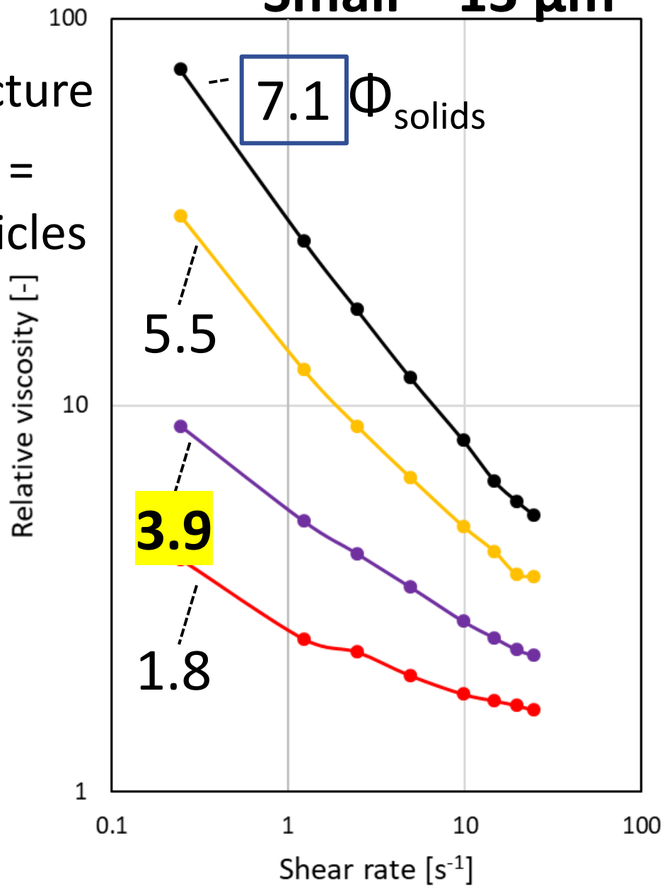
Vergote et al., Journal of rheology 67 (2023), 1159–1174
(Ghent University)

Larger spinel

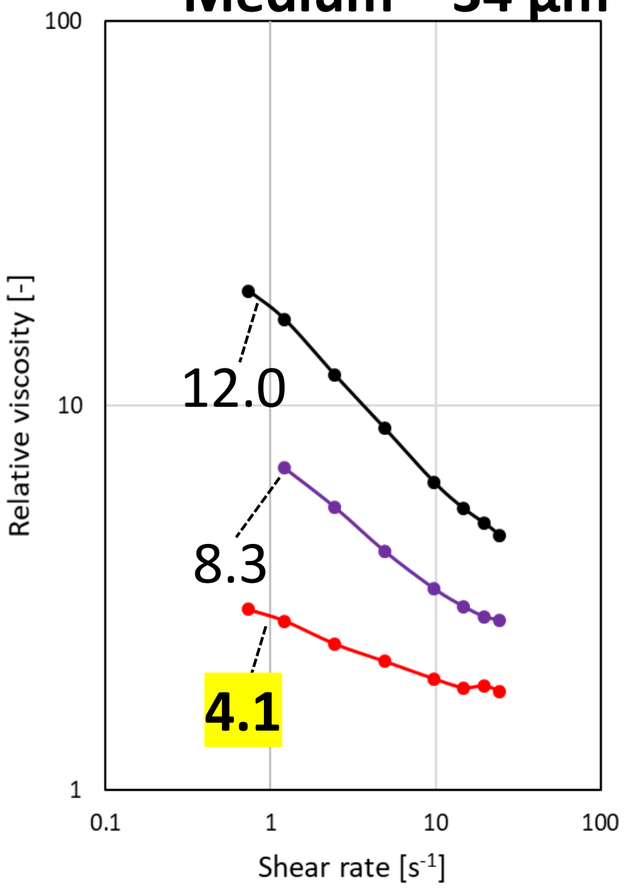
More structure

Φ_{solids} ↑ =
More particles

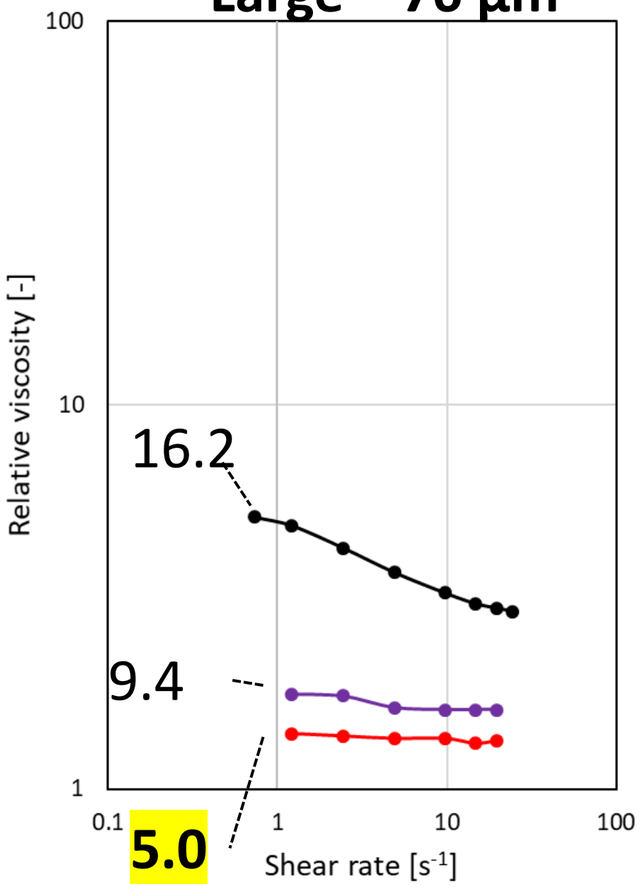
Small – 13 µm



Medium – 34 µm



Large – 76 µm



Strong internal structure → Weak internal structure

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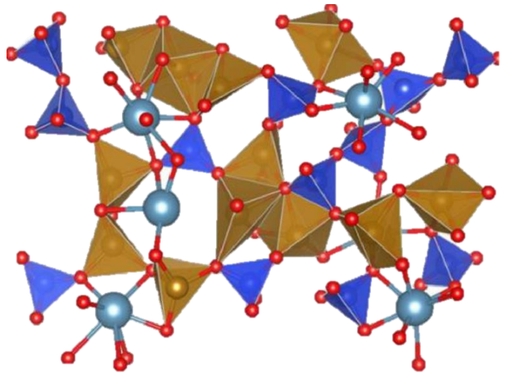
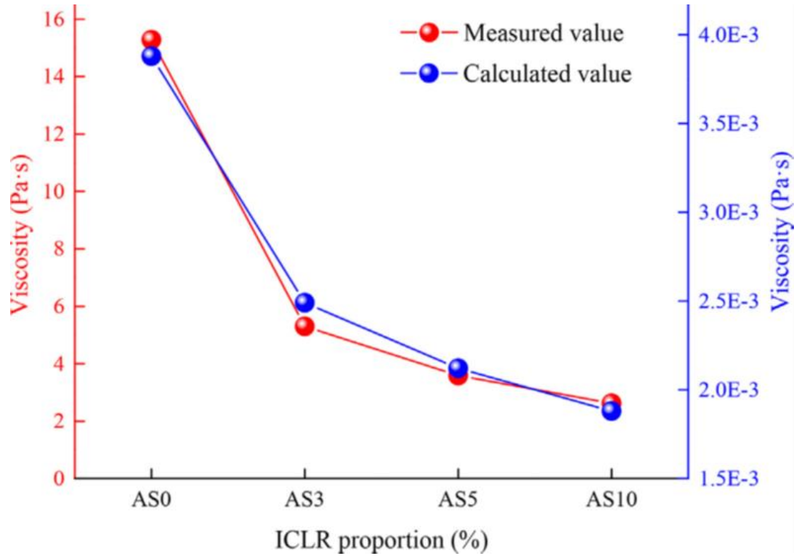
Opportunity: combination with molecular modelling

Simulation Output

Slag structure



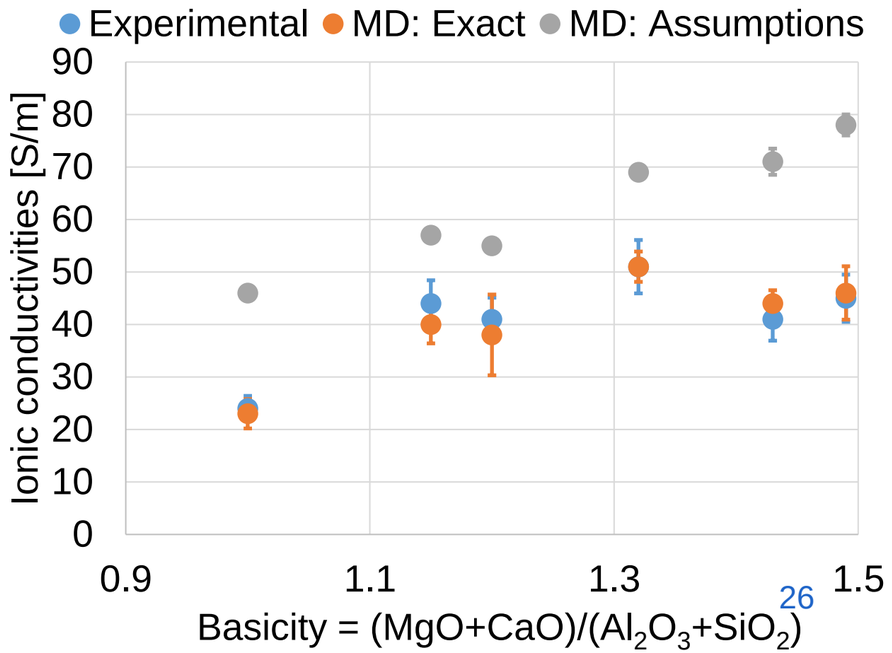


Zhang et al., Chemical Engineering Science 273 (2023) 118642

Thorough analysis gives physical slag properties:

- ✓ Diffusivity
- ✓ Viscosity
- ✓ Electrical Conductivity
- ✓ Surface tension

Mongalo et al., Journal of Non-Crystalline Solids Vol 452 (2016), P 194-202



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FACULTY OF ENGINEERING
AND ARCHITECTURE

Inge Bellemans

DEPARTMENT OF MATERIALS, TEXTILES AND CHEMICAL ENGINEERING
RESEARCH GROUP SUSTAINABLE MATERIALS SCIENCE

E Inge.Bellemans@ugent.be
T +32 9 331 04 21

Ghent University
@ugent
Ghent University

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