Green Hydrogen Steelmaking

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metallurgical competence center

Coordinated by

FFG Tirol UAR INNOVATION NETWORK SFG

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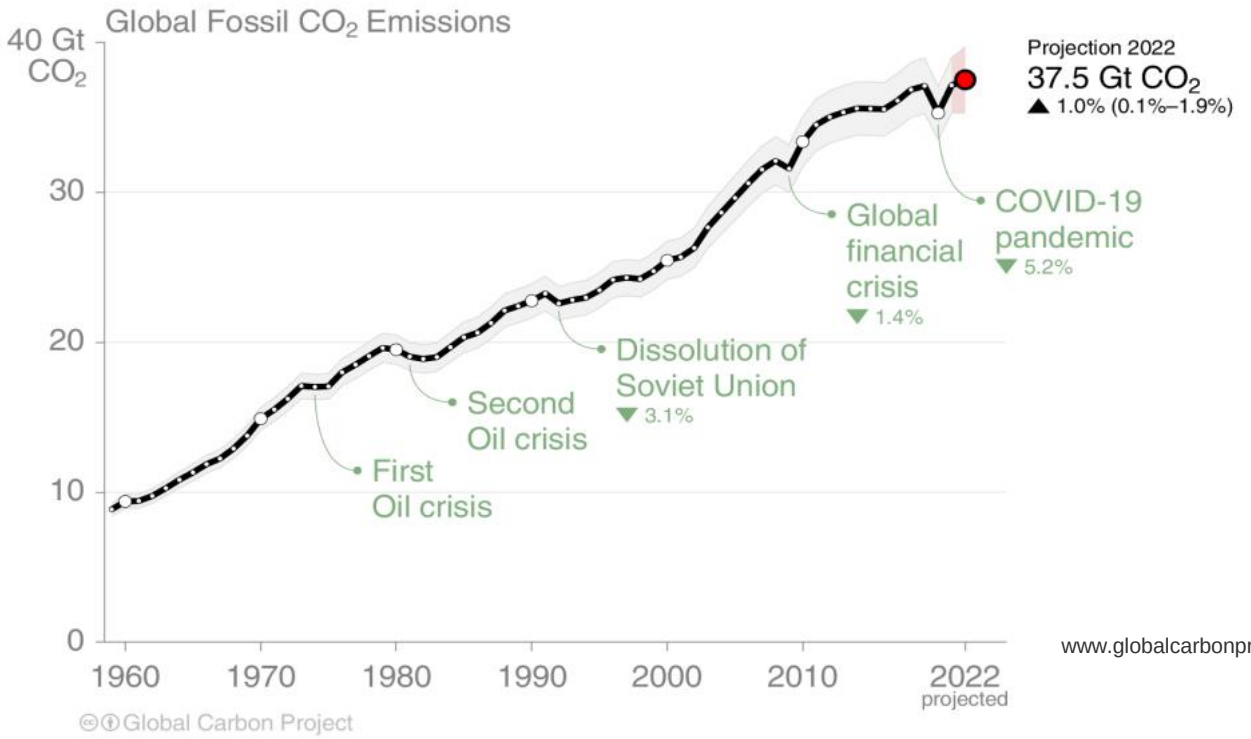
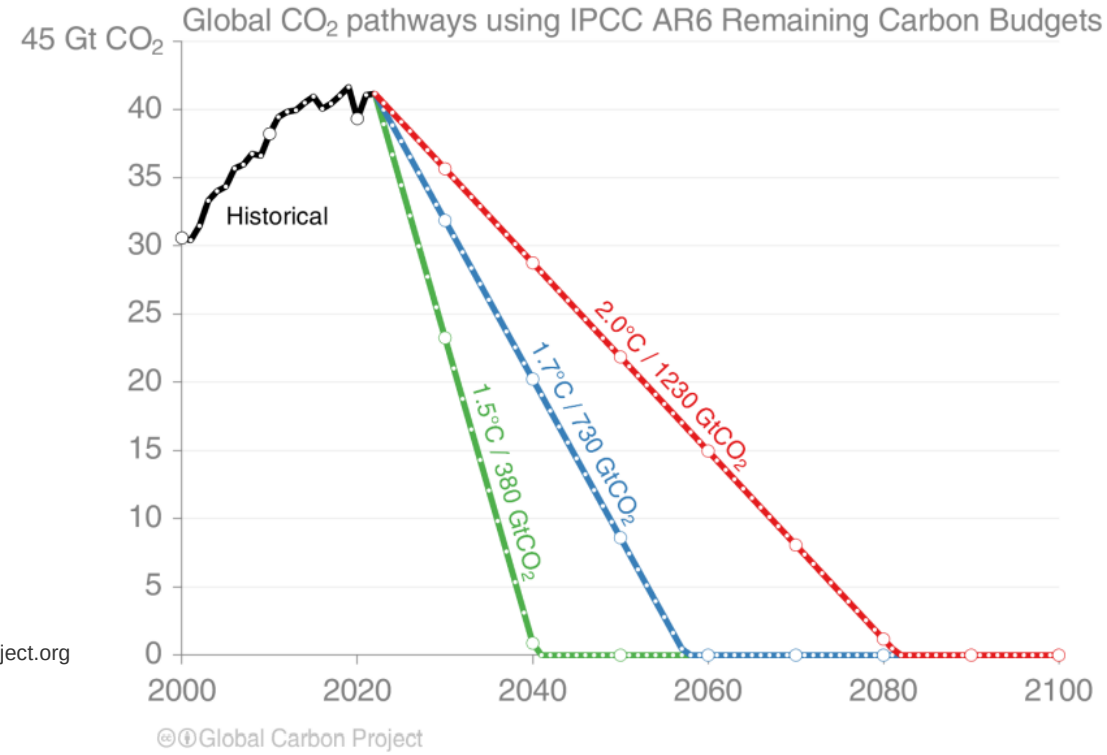
Climate goals

CO_2 emission scenarios



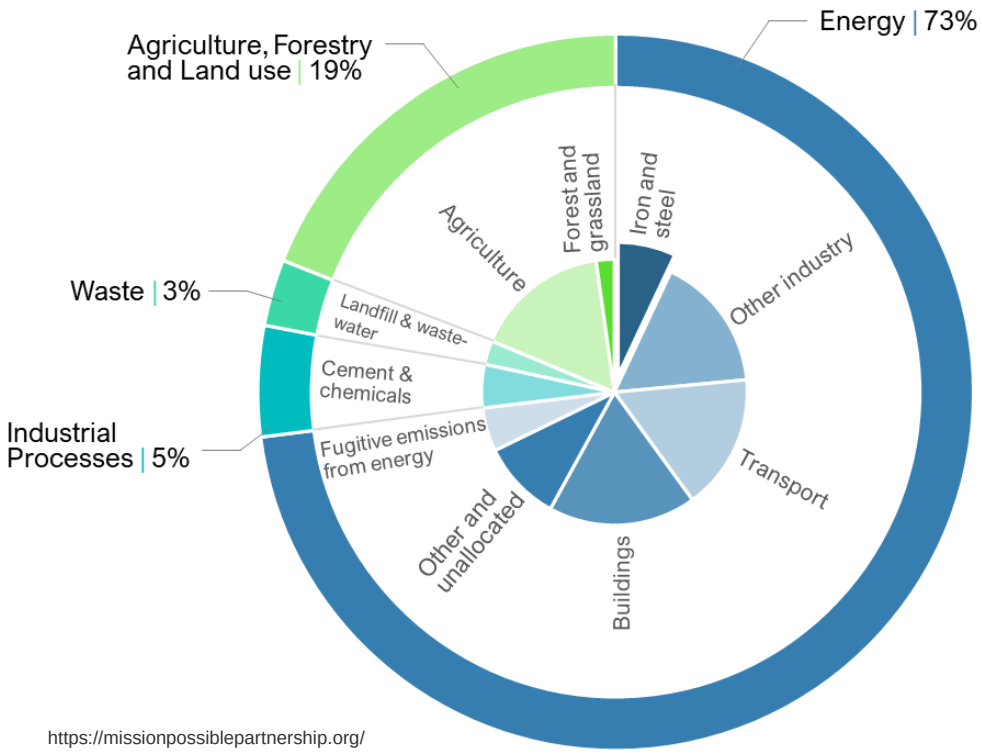
www.globalcarbonproject.org



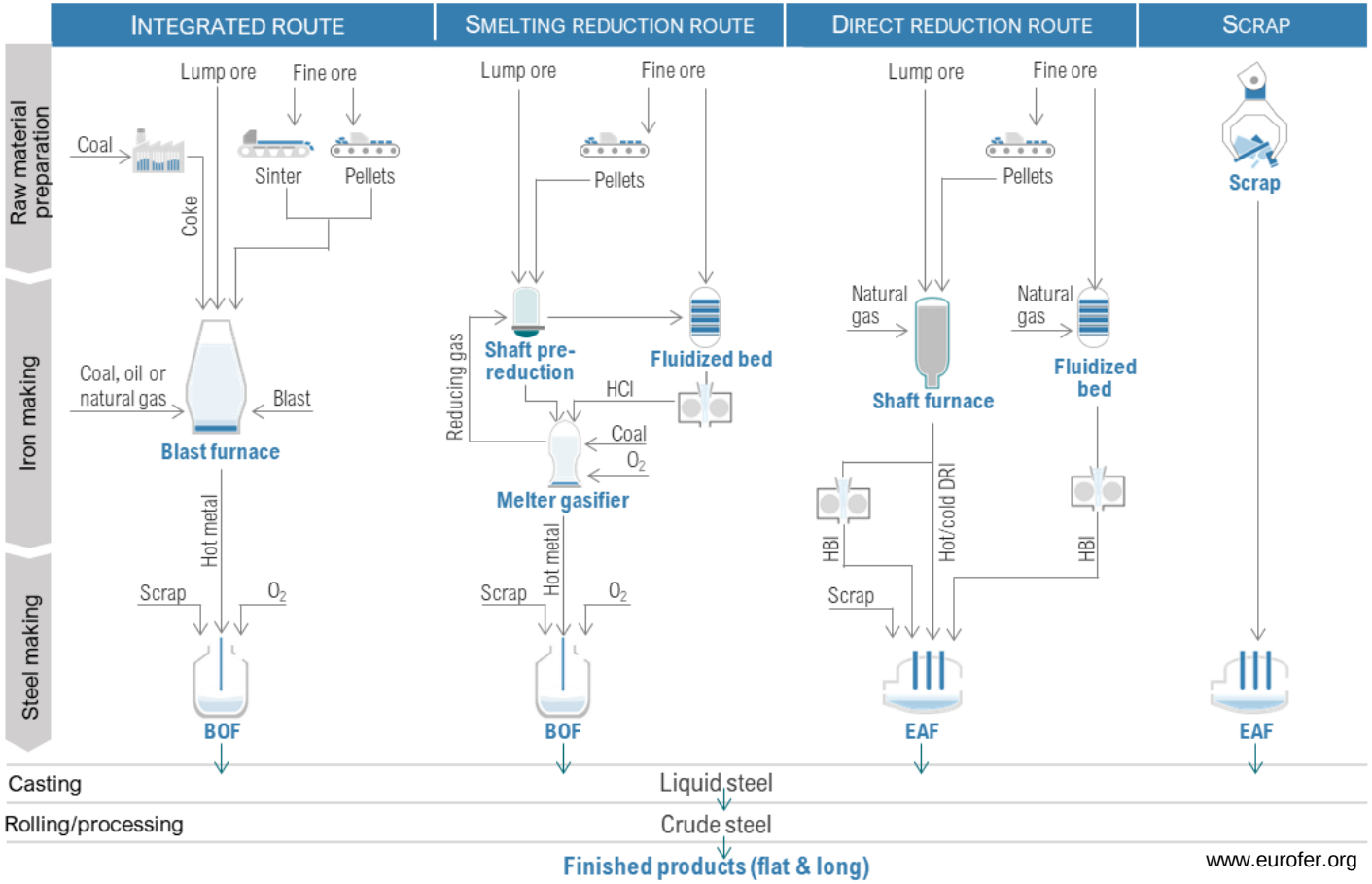
- EU Green Deal 2019: transform Europe into a continent with no net emissions of greenhouse gases in 2050
- Austrian government program 2020: 100% renewable electric energy in 2030, climate neutrality in 2040

How is steel going to be produced?

Classical steel production routes



https://missionpossiblepartnership.org/



- Iron and steel industry accounts for approx. 7% of global anthropogenic CO_2 emissions

$$Fe_2O_3 + 6CO = 2Fe + 3CO_2 + 3CO$$

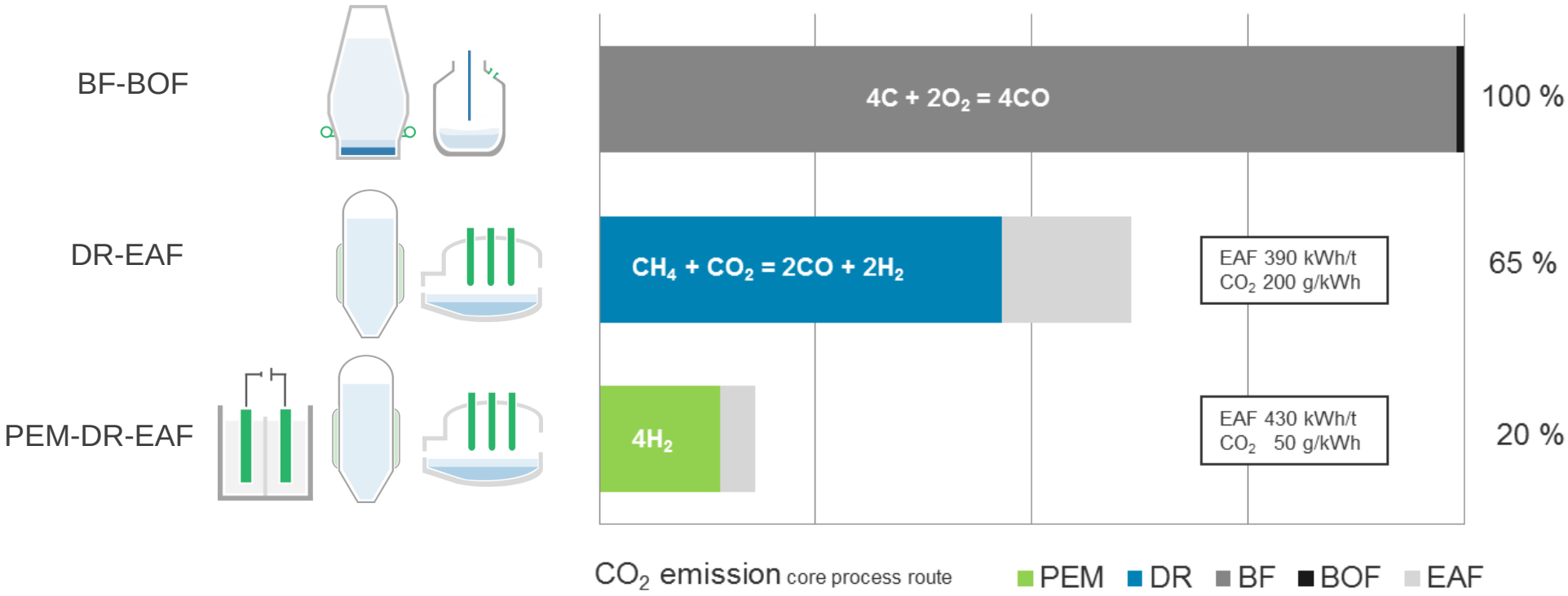
$$Fe_2O_3 + 6H_2 = 2Fe + 3H_2O + 3H_2$$

H_2 potential 10 %

60 – 100 %

Roadmap to climate neutral steelmaking

C, NG, and H_2 in integrated steel production



- Origin and availability of electric energy are essential for renewable H_2 production and use of ore based metallics (OBM) in the DR-EAF route
- Climate neutrality of scrap based EAF steelmaking without OBM is only depending on the origin of electric energy

Climate neutral hydrogen production

European flagship project H2Future

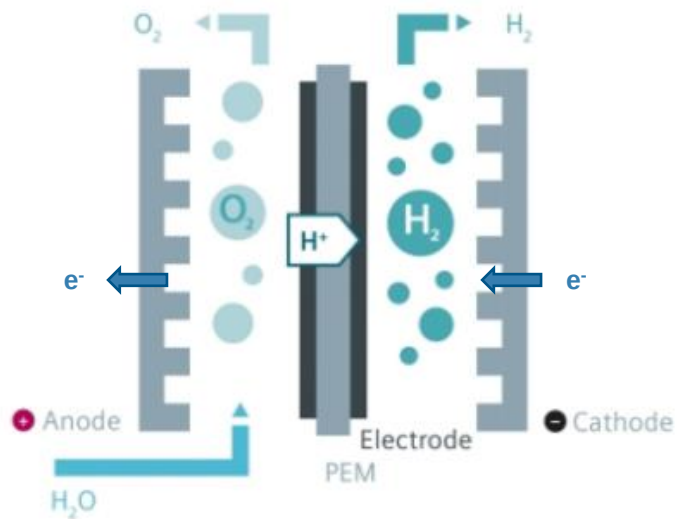
One of the biggest proton exchange membrane (PEM) electrolyser units in the world with 6 MW power and 1.200 m^3/h H_2 production at voestalpine Stahl Linz site for full scale demonstration of H_2 production and grid balancing

- Ambitious efficiency target at nominal power
- W_{el} = 48 - 51 kWh/kg
- η_{System} = 82 % - 77 %
- To demonstrate a CAPEX of < 1.000 €/kW for PEM technology

Project Budget: 17,8 M€

Total EU Funding: 12,0 M€ (70 % funding)

Project Duration: 5 years (2017-2021)



PEM reactions

Anode: $H_2O = 2H^+ + 0{,}5O_2 + 2e^-$

Cathode: $2H^+ + 2e^- = H_2$

Climate neutral hydrogen production

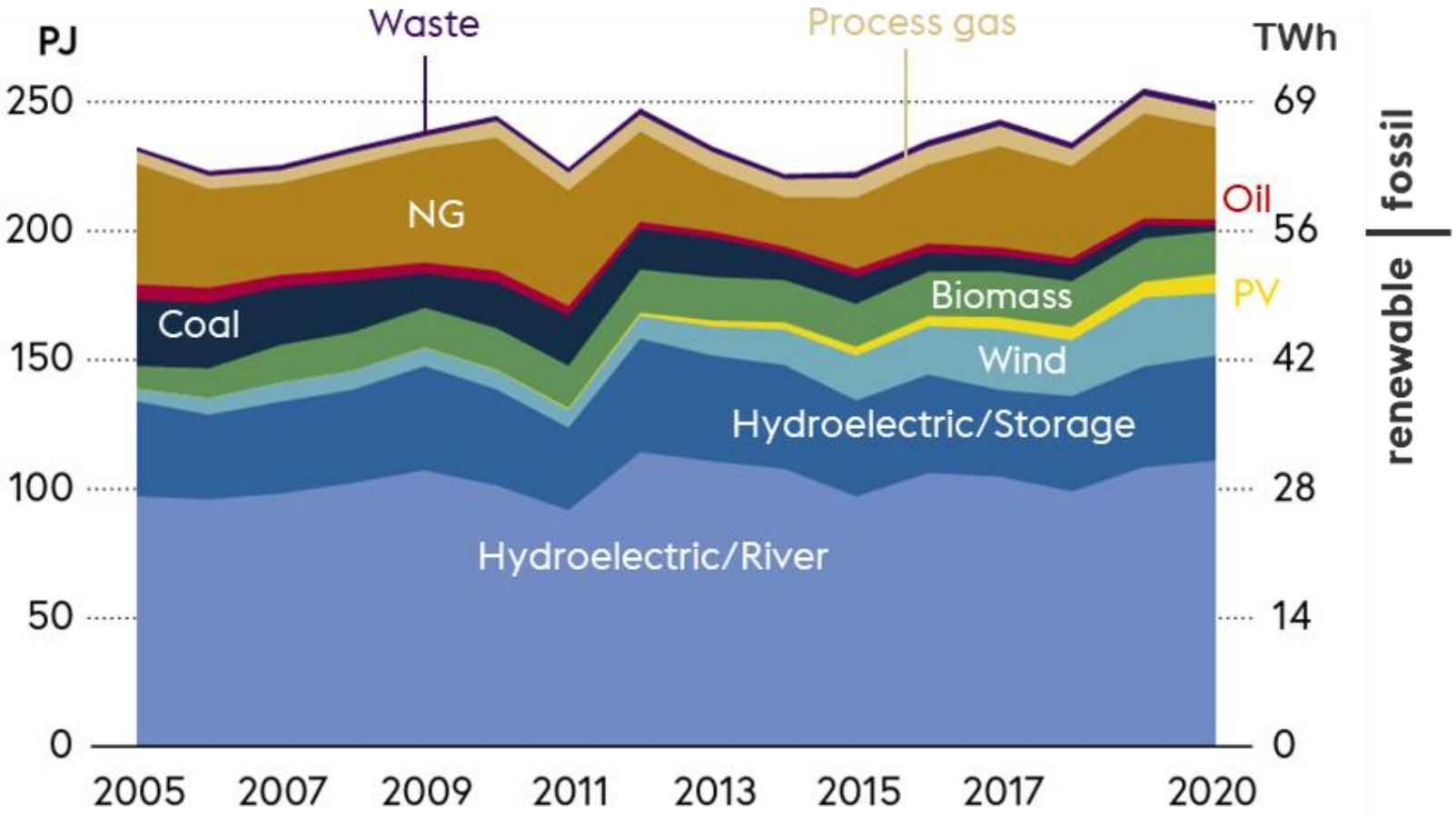
PEM demonstration plant Linz

- Stable operation tested from 1,5 MW to 9,0 MW
- Dynamic response for all kind of grid services
- Stack efficiency up to 83% at rated load
- H_2 purity 99,9%, O_2 purity 99,0%

Replacement of fossil energy

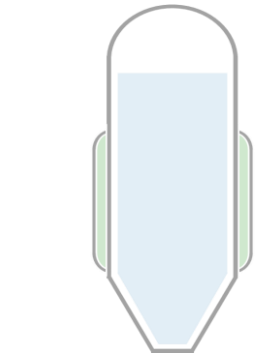
Electricity demand for climate neutral steelmaking

Electric energy production in Austria



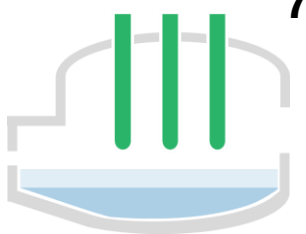
https://www.bmk.gv.at/themen/energie/publikationen/

Electric energy demand for 6,0 Mt steel/a



18 TWh_{el}
H_2 DRI

DRI/Scrap
75/25

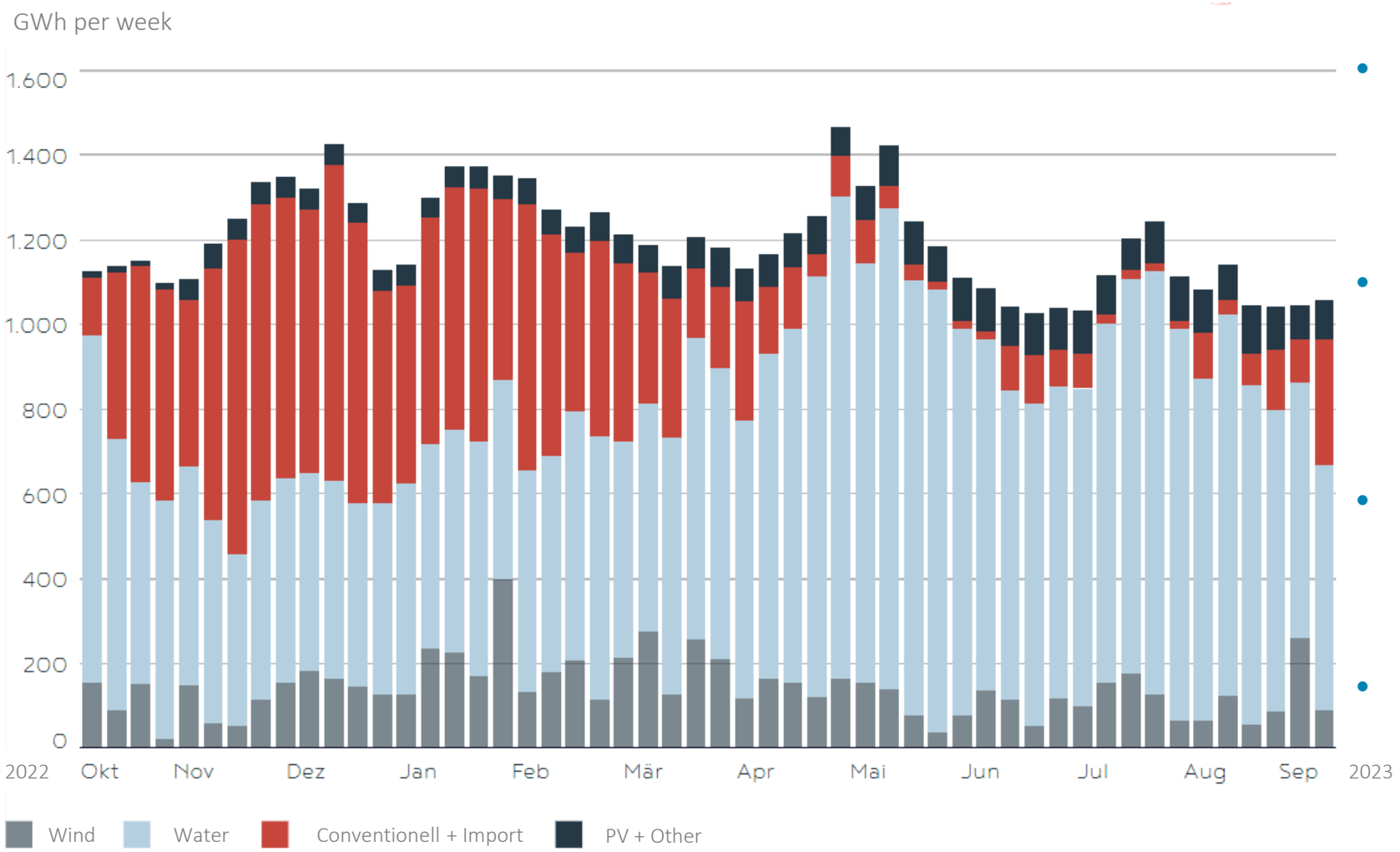


2,5 TWh_{el}
75/25

7,5 TWh_{el}
Downstream processes

Replacement of fossil energy

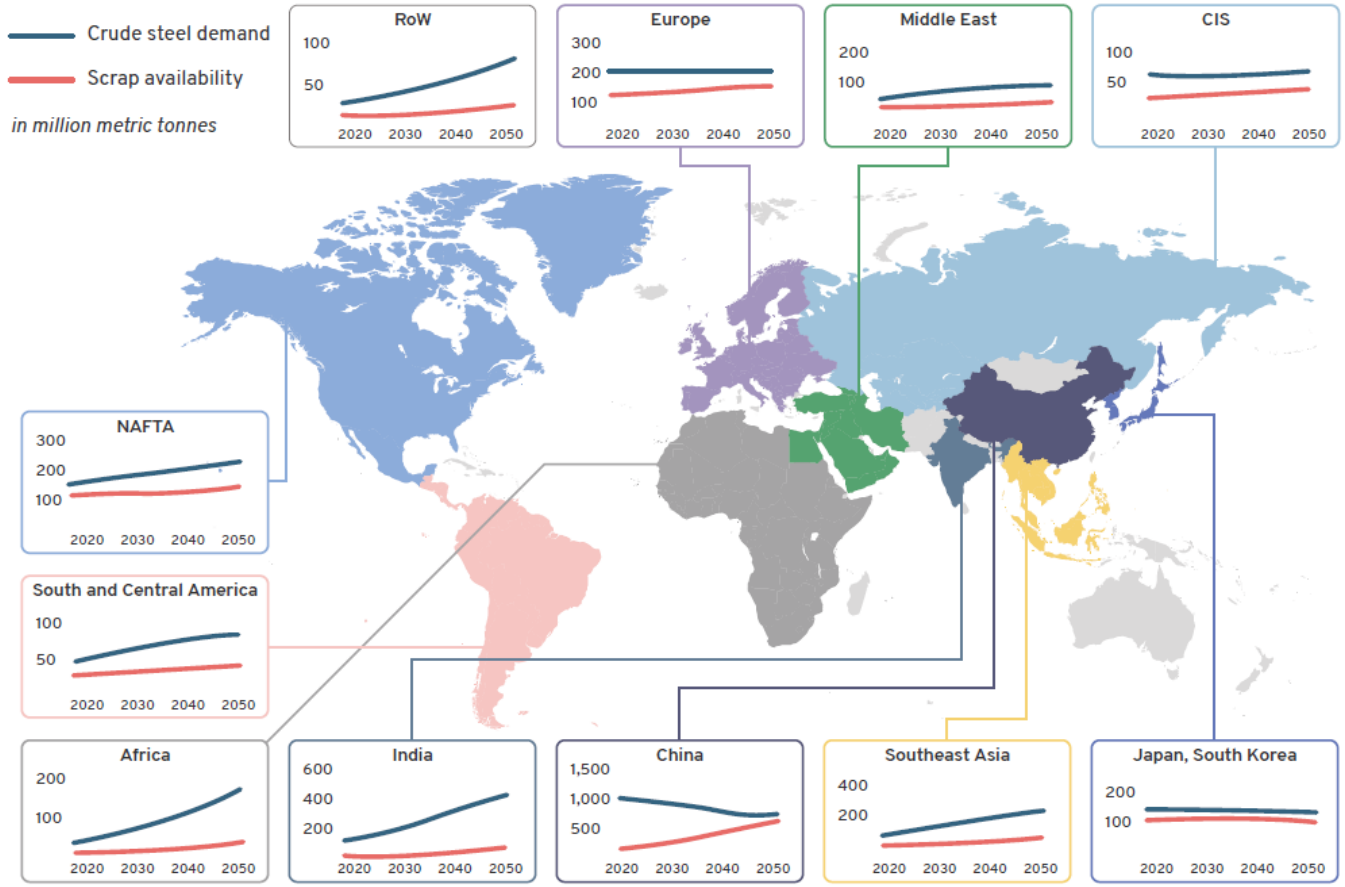
Electricity production Austria 2022/23



- Renewable electric energy could not fully cover the electricity demand also from May to September
- Up to 50 % import demand or NG power plant production necessary for 100 % supply from October to April
- 27 TWh of new renewable electric energy generation capacities with high seasonal fluctuation in 2030
- 100% renewable sources creates min. 10 TWh excess energy over 6 months in summer period

Technology development OBM

Global trend for scrap availability



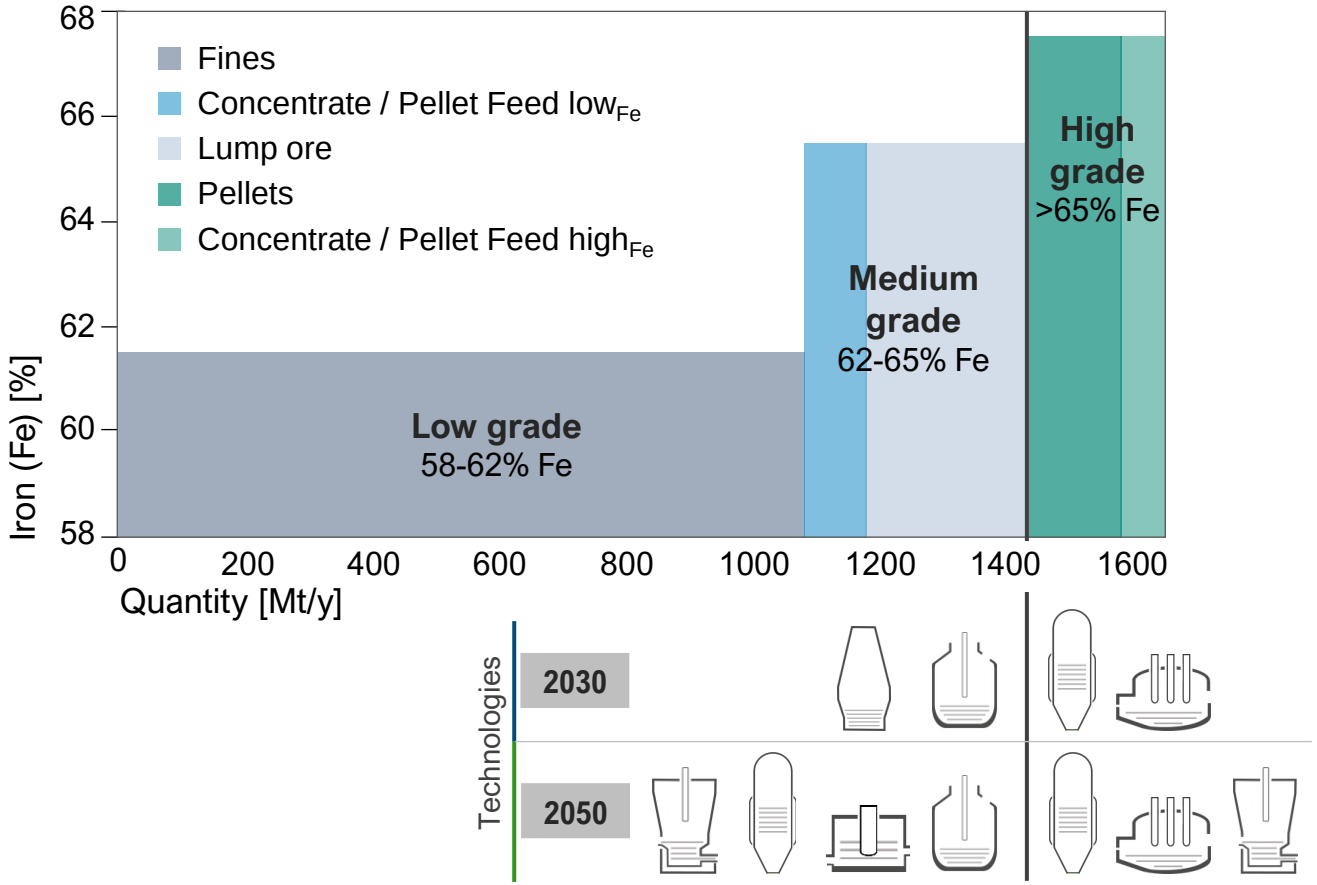
https://missionpossiblepartnership.org/

- Crude steel demand will be 30 % higher in 2050 than it is today
- Much of this growth will be in emerging economies with declining demand in China, Europe, Japan, and South Korea
- Contribution of scrap in the total steel charge will likely grow to 40 % in 2050 from 30 % than today
- Process technologies for OBM (ore based metallics) will have an important role in future CO_2 neutral steelmaking

Technology development OBM

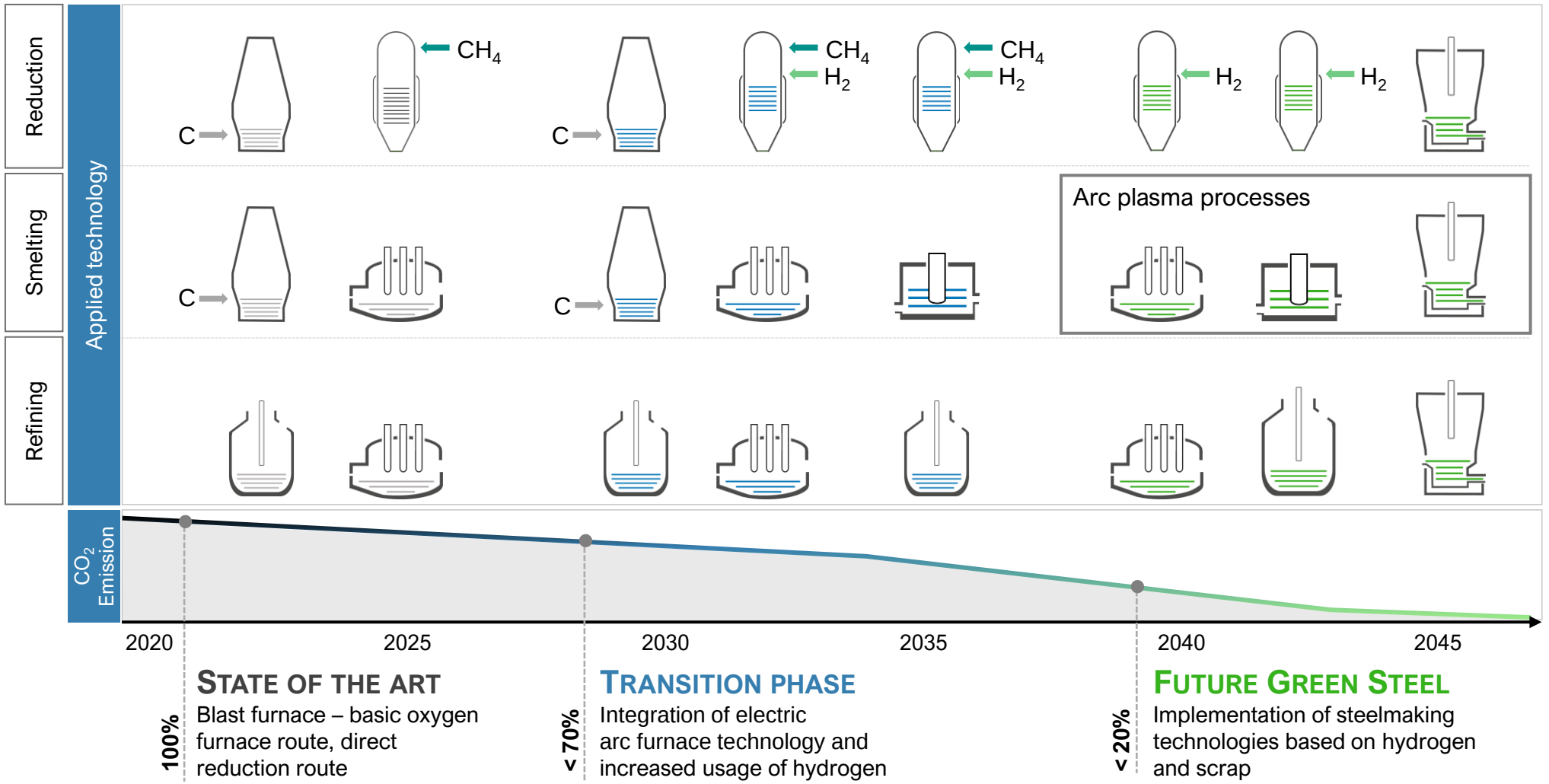
Iron ore qualities

- Global iron ore market is dominated by low and medium grade iron ores
- High grade sea born iron ores are available in limited quantities
- 75% of all beneficiated iron ores are fines



How is steel going to be produced?

Transition process towards green steel



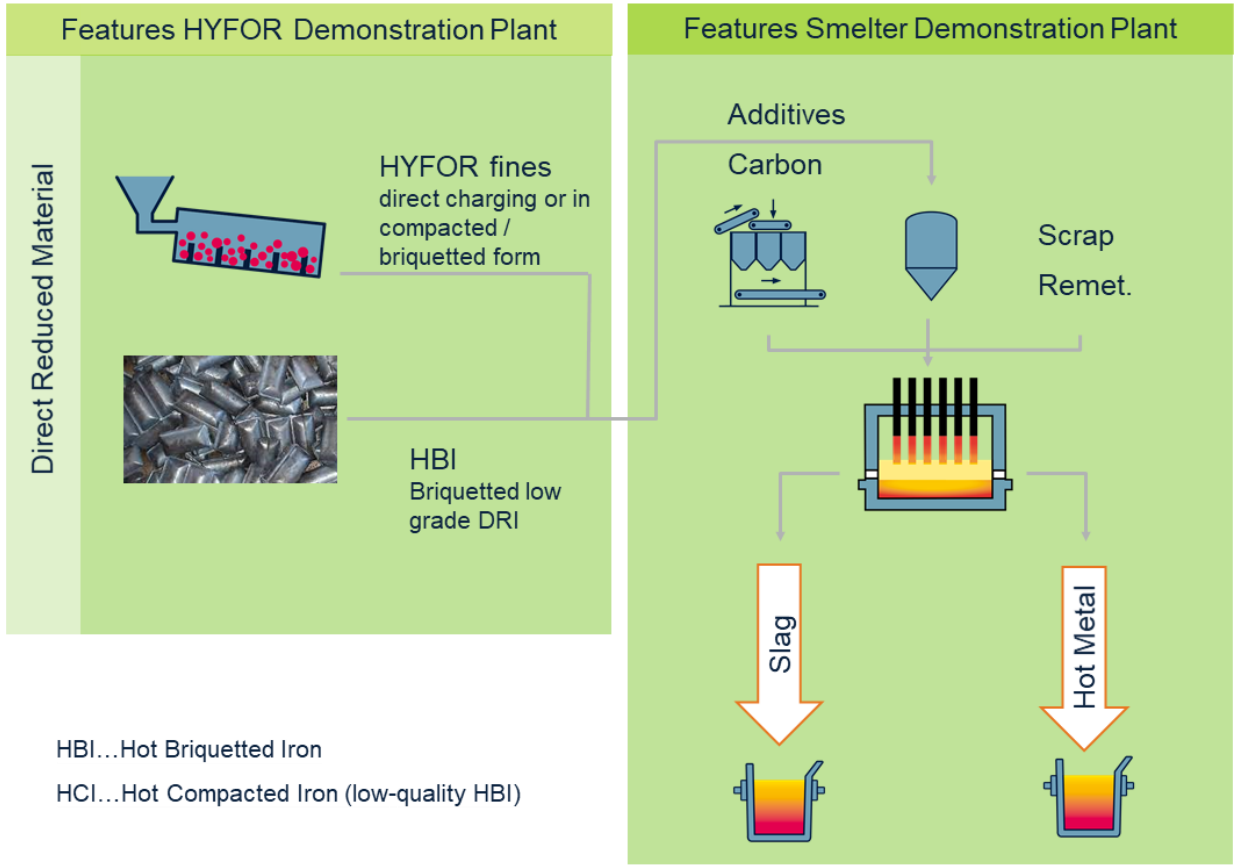
Technology development OBM

HYFOR DR process

- Test the performance of the HYFOR reactor and the preheating/oxidation cyclone under real operating conditions
- Direct reduction of magnetite/hematite iron ore fines with H_2 in fluidized bed reactor at 700 °C up to a metallization degree of 97 %
- Typical grain size: 100 % < 150 µm
  Max. grain size: < 500 µm (up to 1 mm possible)
- Batch operation with 800 kg ultrafine iron ore is equal to 200 kg DRI per hour
- Pilot plant at voestalpine Donawitz site as technical basis for next development phase

Technology development OBM

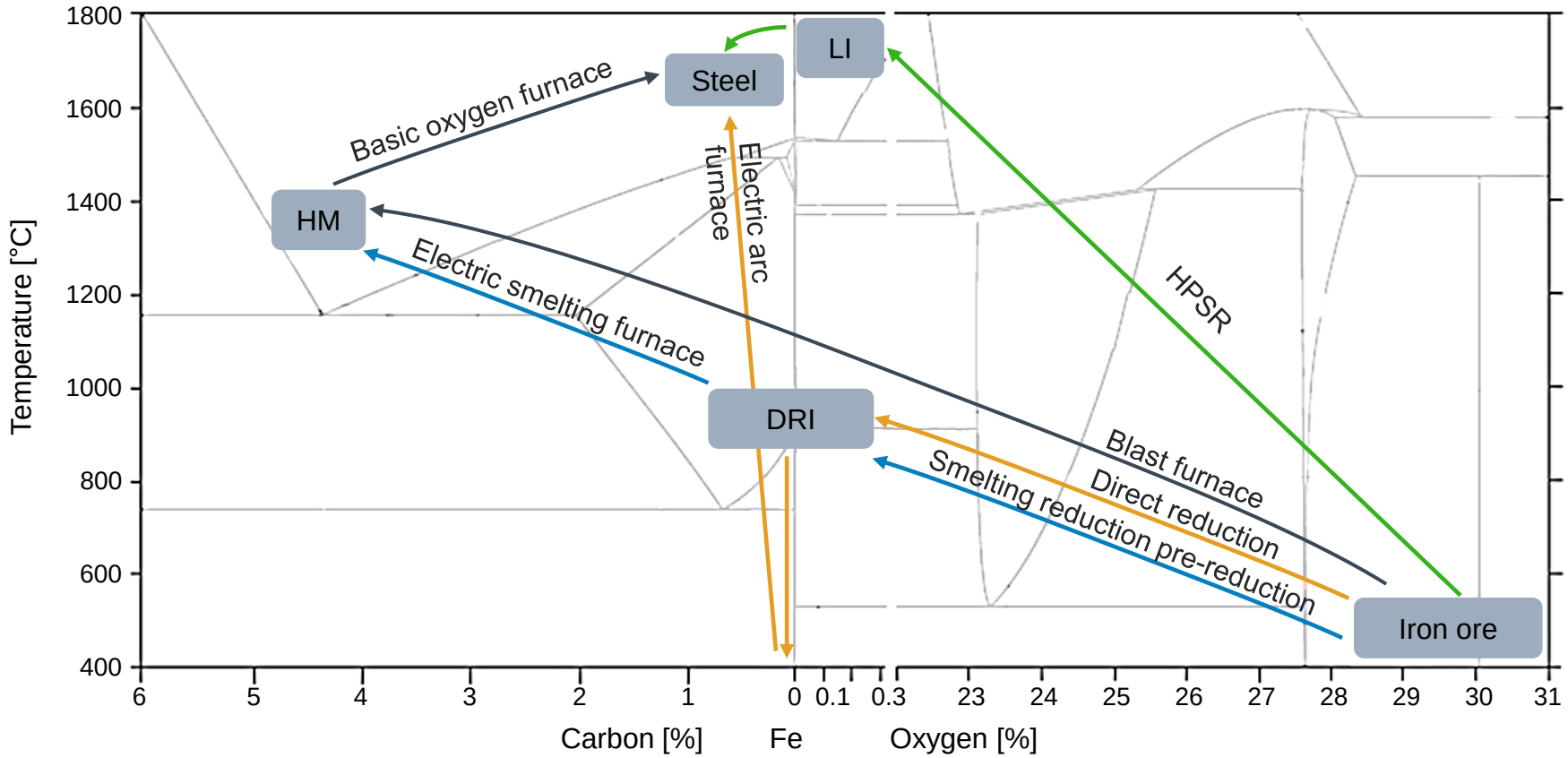
Combined HYFOR and Smelter process



- Continuous operation from preheating iron ores to hot metal (HBI) in longer campaigns
- Flexible Ore Basis - Utilization of multiple iron ore qualities (low to high-grades)
- Carbon addition – Based on bio-char and other carbon carriers
- Hot link of DRI fines to Smelter (alternatively HCI) and addition of HBI/Scrap
- Addition of slag forming materials → slag shall be utilized in the cement industry (cross-sectorial approach)
- Autonomous operation of Smelter part

Steelmaking process routes

From iron ore to crude steel



DRI … direct reduced iron
HM … hot metal (pig iron)
LI … liquid iron (steel-like liquid product)
HPSR … hydrogen plasma smelting reduction

Hydrogen plasma smelting reduction pilot plant

Process development Sustainable Steel (SuSteel)

- Fundamental research project for direct steelmaking from iron oxides with H_2 plasma smelting reduction (HPSR)
- Verify of process concept with batch operation in a DC electric arc furnace (EAF) with 250 kVA
- Upscaling of the technology from 100 g to 50 kg tapping weight
- Creating design parameters for an increased reactor size and continuous operation
- Demo plant for this breakthrough technology is located at voestalpine Donawitz site

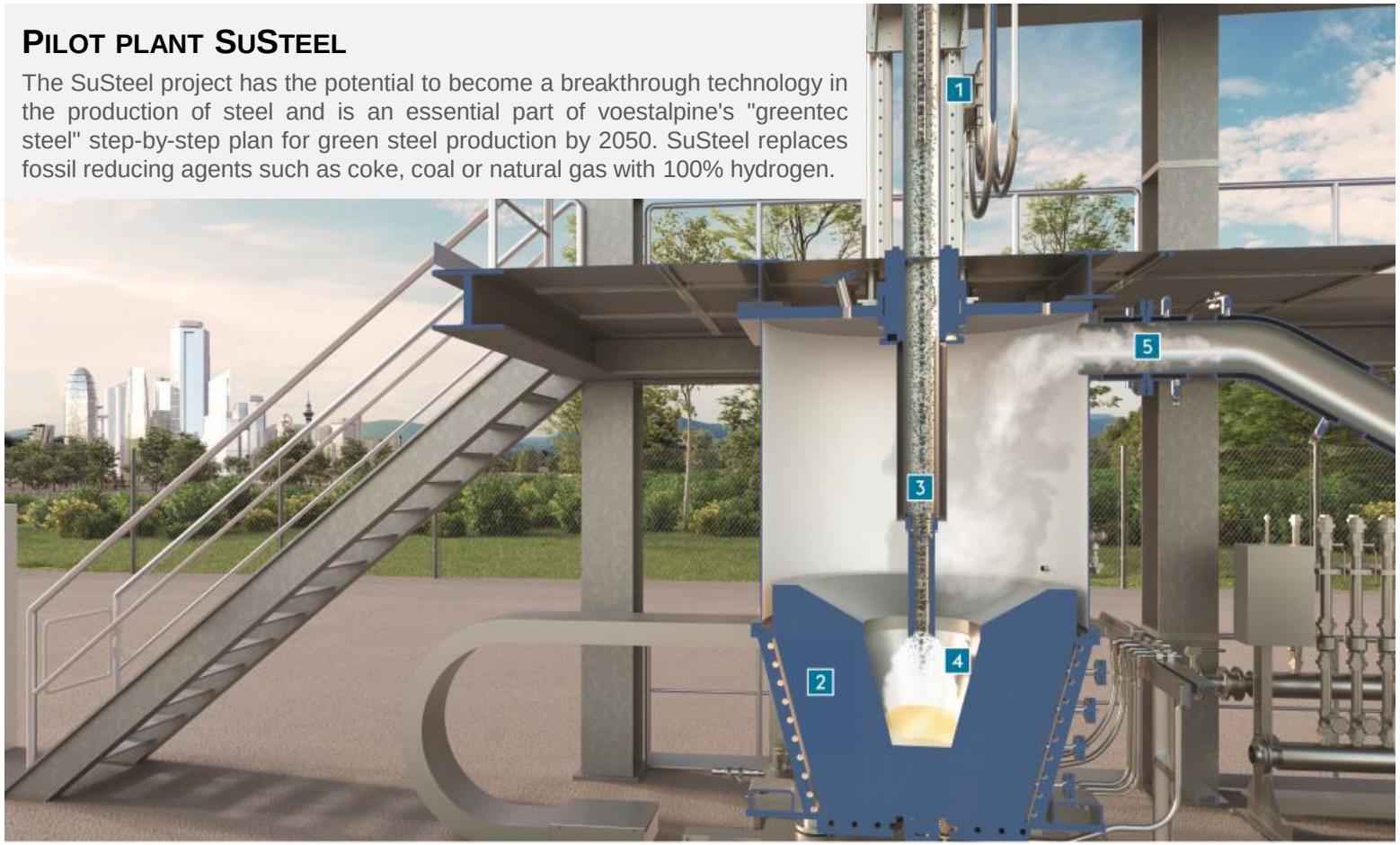
SuSteel pilot plant

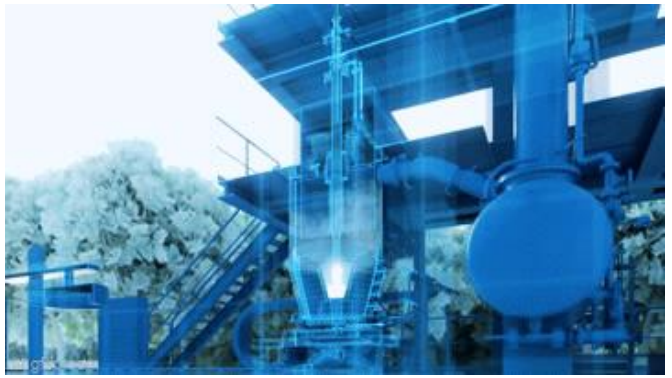
Process development SuSteel

HPSR process in detail

Pilot plant SuSteel

The SuSteel project has the potential to become a breakthrough technology in the production of steel and is an essential part of voestalpine's "greentec steel" step-by-step plan for green steel production by 2050. SuSteel replaces fossil reducing agents such as coke, coal or natural gas with 100% hydrogen.





1 **Hydrogen and iron ore supply**
Hydrogen and iron ore are fed to the plant.

2 **Electric arc furnace**
The DC electric arc furnace is the heart of the plant. The reactions take place in the transferred arc.

3 **Electrode**
Iron ore and hydrogen enter the reaction zone of the arc via a hollow electrode.

4 **Reaction zone**
Hydrogen is ionised into plasma and the iron ore is melted and reduced in one step. Crude steel is produced.

5 **End product: water vapour**
At the end of the process, only water vapour escapes. CO_2 emissions are fully avoided.

Process development SuSteel

Commissioning of the pilot plant

CHRONOLOGICAL DEVELOPMENT IN PICTURES

March 2021

May 2022

February 2023

April 2023

May 2023

MILESTONES

Plant
Plant erected

Trials
Stable trials

Production
First pure iron produced

Charging
Charging higher loads

Production
First blocks

Process development SuSteel

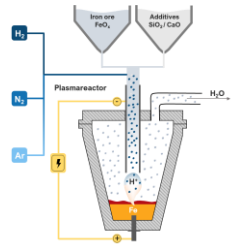
History and outlook to a continuous process

1998

First trials

Construction of a plasma smelting reactor in laboratory scale and first trials

2016 - 2019



SuSteel

Analysis of different concepts (plasma, feeding system, reactor geometry)

Construction of a demo plant at voestalpine

2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2023 | 2024 | 2025 | 2025+

TRL 5

2019 - 2023

Operational optimization of hydrogen plasma smelting reduction

Selection of suitable materials

Slag management

Conceptual design of the electrolysis system

2019 - 2023

Fundamentals of hydrogen reduction

Process variations to achieve economic optimization

Optimization of raw material input

Concept for upscaling and continuous operation

2022 - 2025

Sustainable steelmaking follow-up

Development of a semi-continuous production process of carbon-lean steel in one step (200 kg/h)

Concept for hydrogen supply

2023 - 2027

Continuous HPSR process development

Process variations to achieve economic optimization

Parameter evaluation for continuous operation

Design of a pilot plant layout

TRL 7

2025 – 2027+

SuSteel pilot engineering

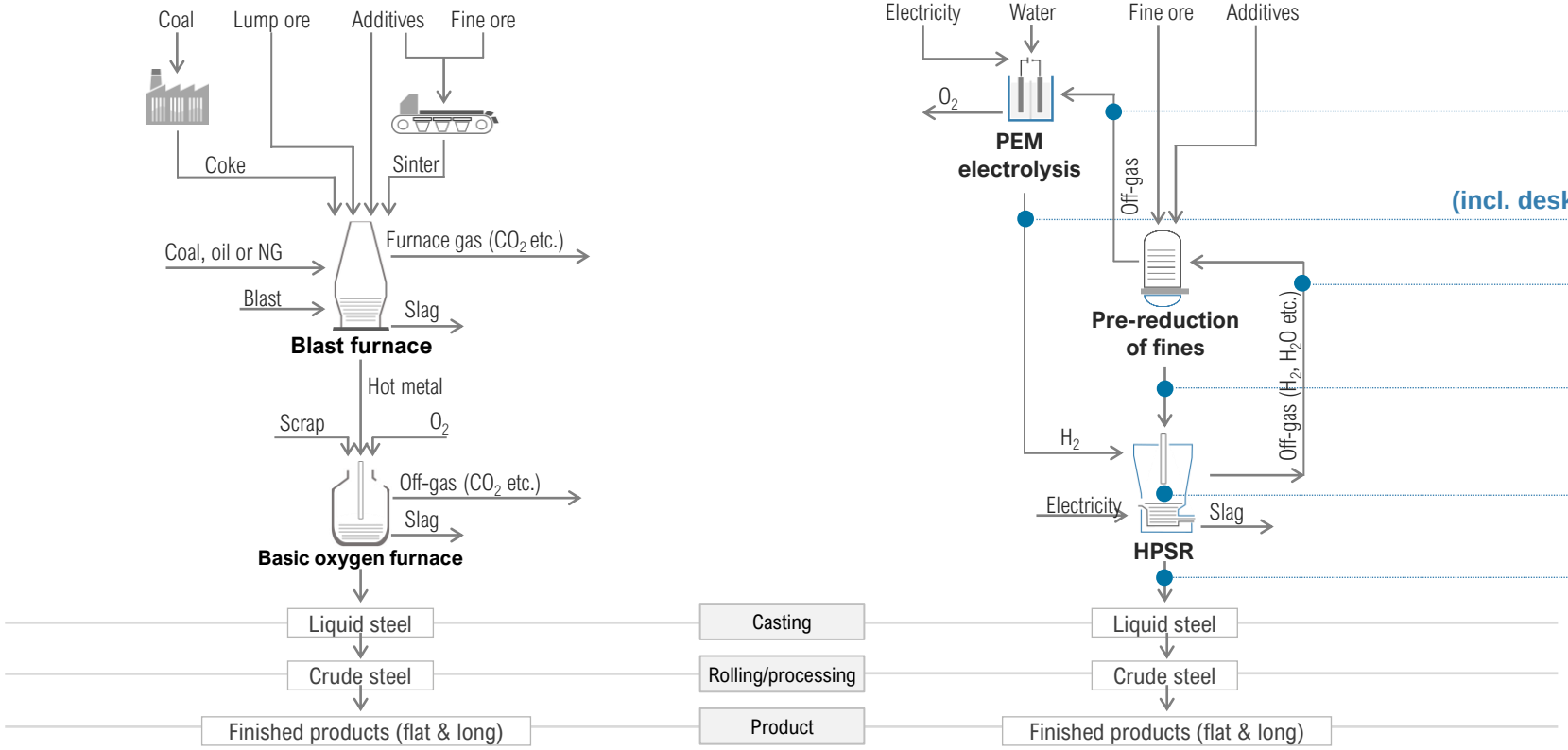
Basic engineering SuSteel pilot plant with >1t/h capacity

Process development SuSteel

Technological tasks for upscaling

INTEGRATED ROUTE (STATE OF THE ART)

Integrated route consisting of raw material preparation, blast furnace (iron making) and basic oxygen furnace (steel making)



HYDROGEN PLASMA SMELTING REDUCTION

HPSR route consisting of green hydrogen supply, pre-reduction of fines and HPSR

SuS-F

Objectives

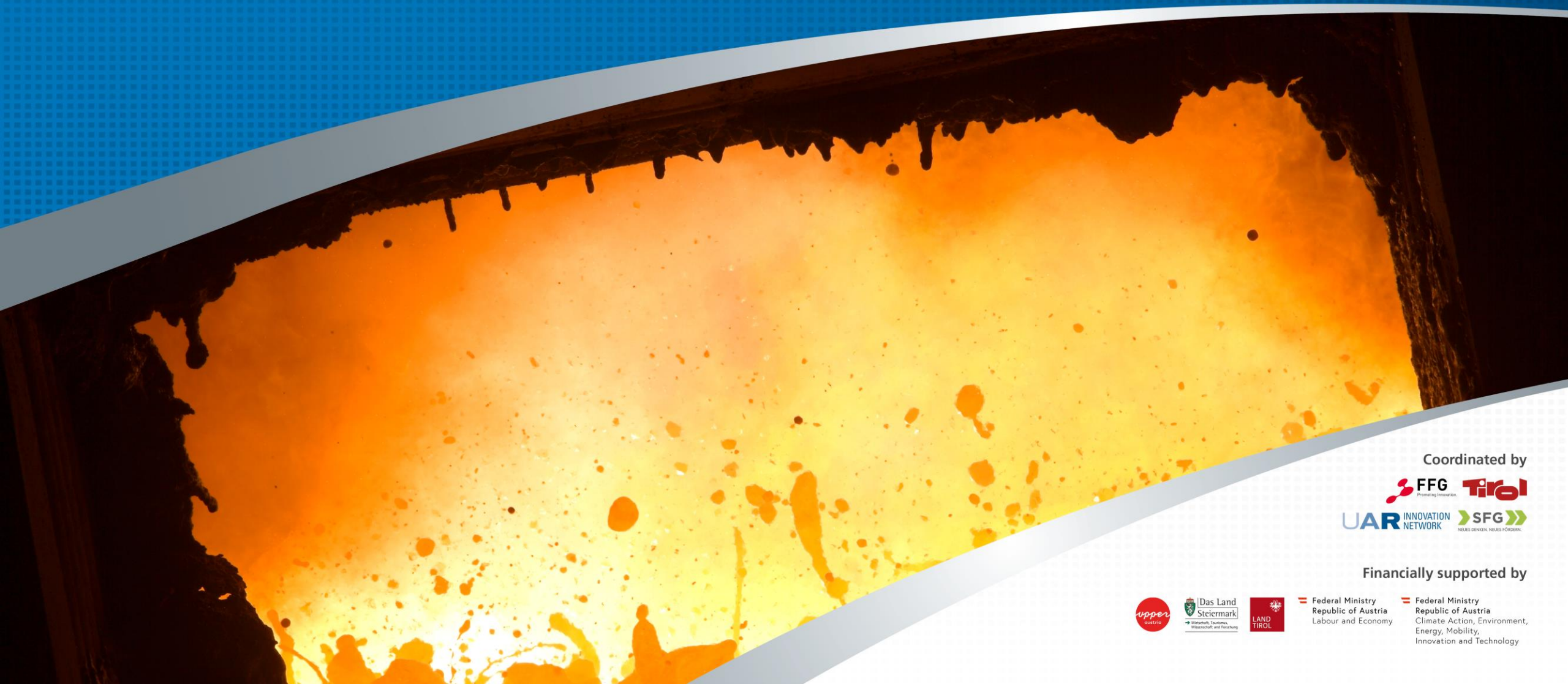
- Recycling of water
- Continuous supply of green hydrogen (incl. desktop study of integrated hydrogen production)
- Recycling & further use of off-gas
- Continuous feeding of ultra fine ore
- Automated and digitalized system
- Semi-continuous tapping of carbon lean steel
- Dissemination

Thank you! Questions?

Wels, November 15th, 2023

Michael Zarl, Thomas Buergler

metallurgical competence center



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