metallurgical competence center

Model-based Control of Electric-arc Plasma in the HPSR Process

for Zero-emission Iron-ore Reduction

Erwin K. Reichel

29.10.2024

ESTEP 2024
Annual Event

ESTEP
European Steel Technology Platform

20 years together

H2 FOR GREEN STEEL
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A CIRCULAR ECONOMY DRIVEN BY THE EUROPEAN STEEL

voestalpine
ONE STEP AHEAD.

PRIMETALS TECHNOLOGIES

Model-based Control of Electric-arc Plasma in the HPSR Process

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ESTEP Annual Event Linz, October 29th, 2024

Erwin K. Reichel

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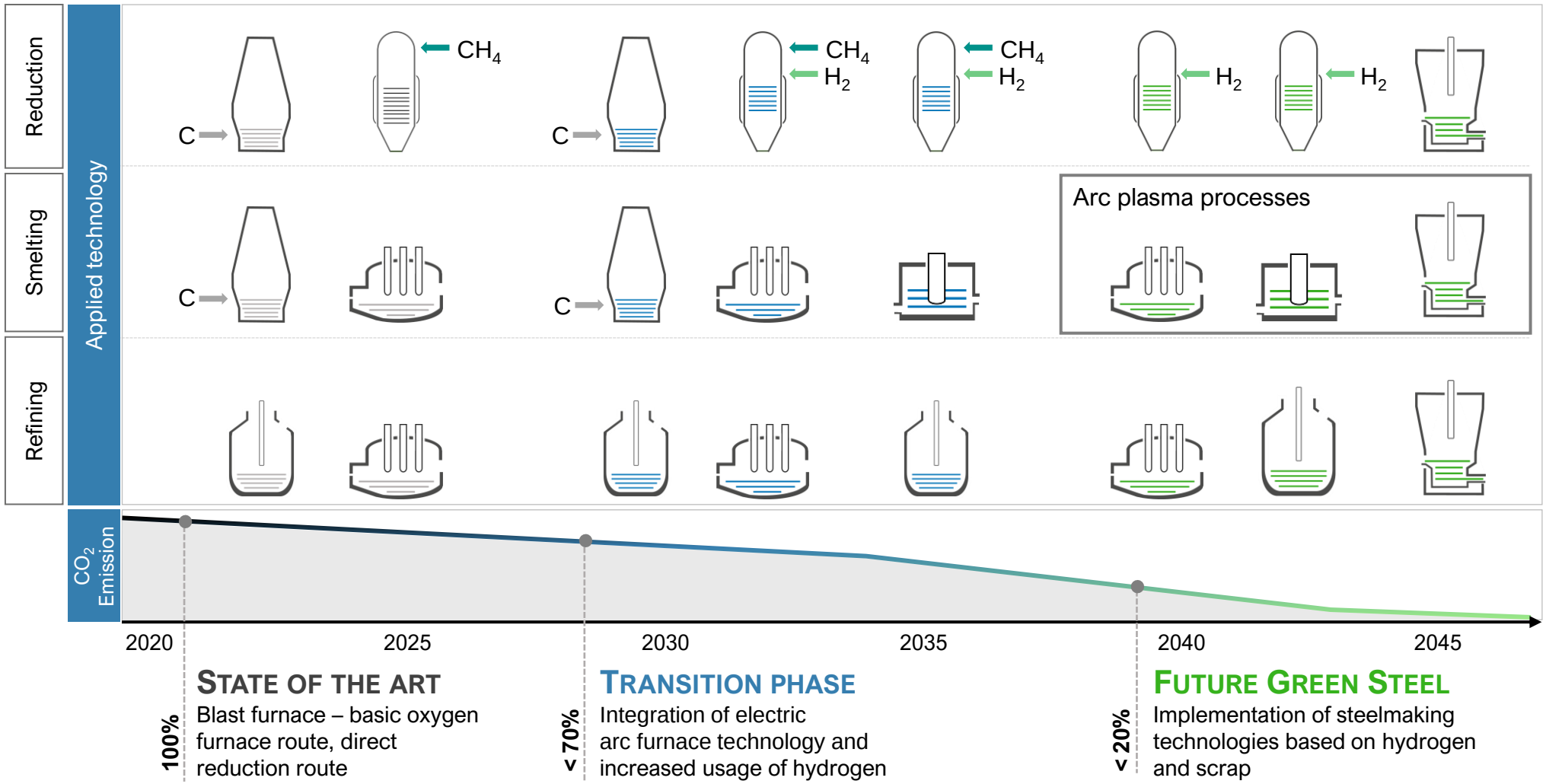
How is steel going to be produced?

Transition process towards green steel



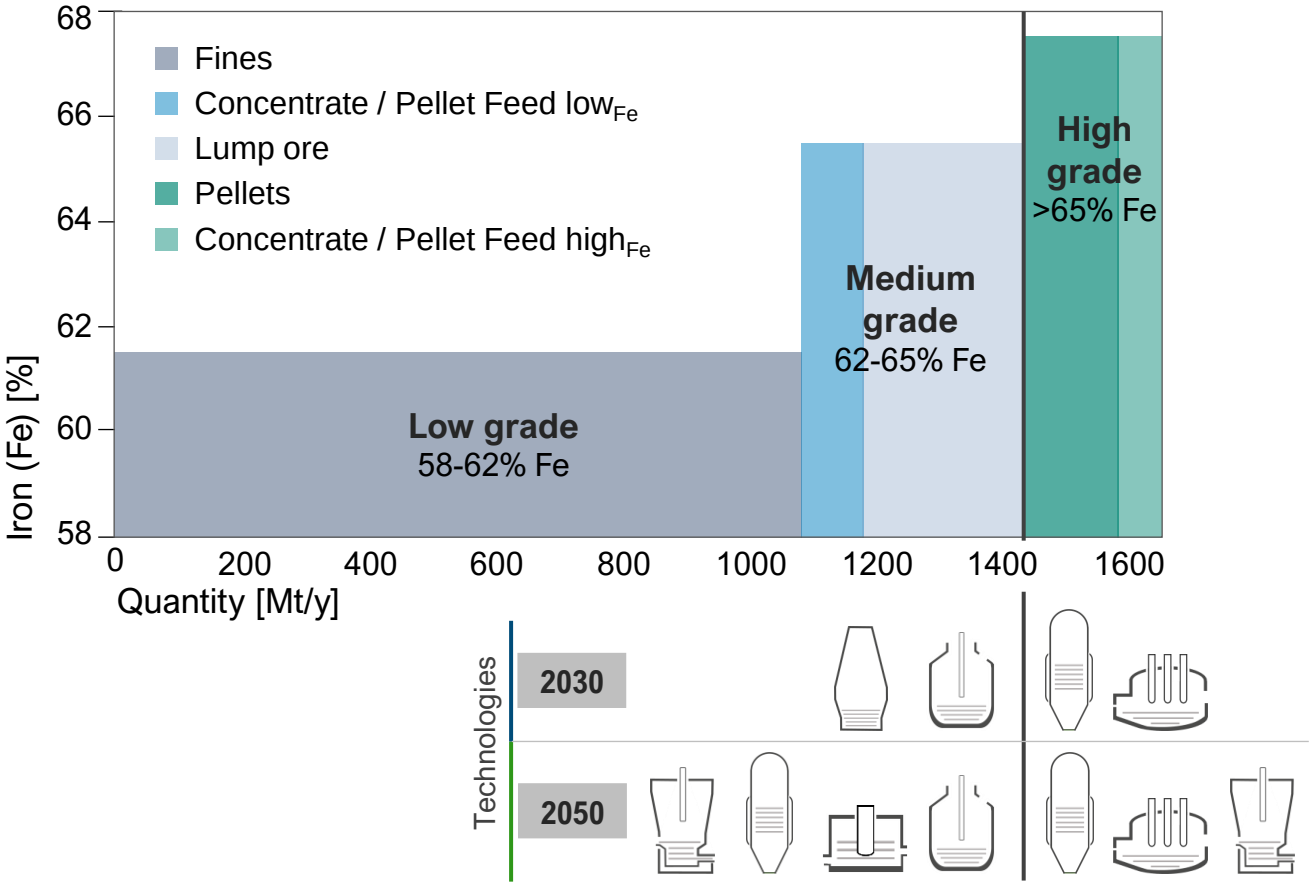
Why is the HPSR process fit for 2050

Iron ore qualities

Global iron ore market is dominated by low and medium grade iron ores

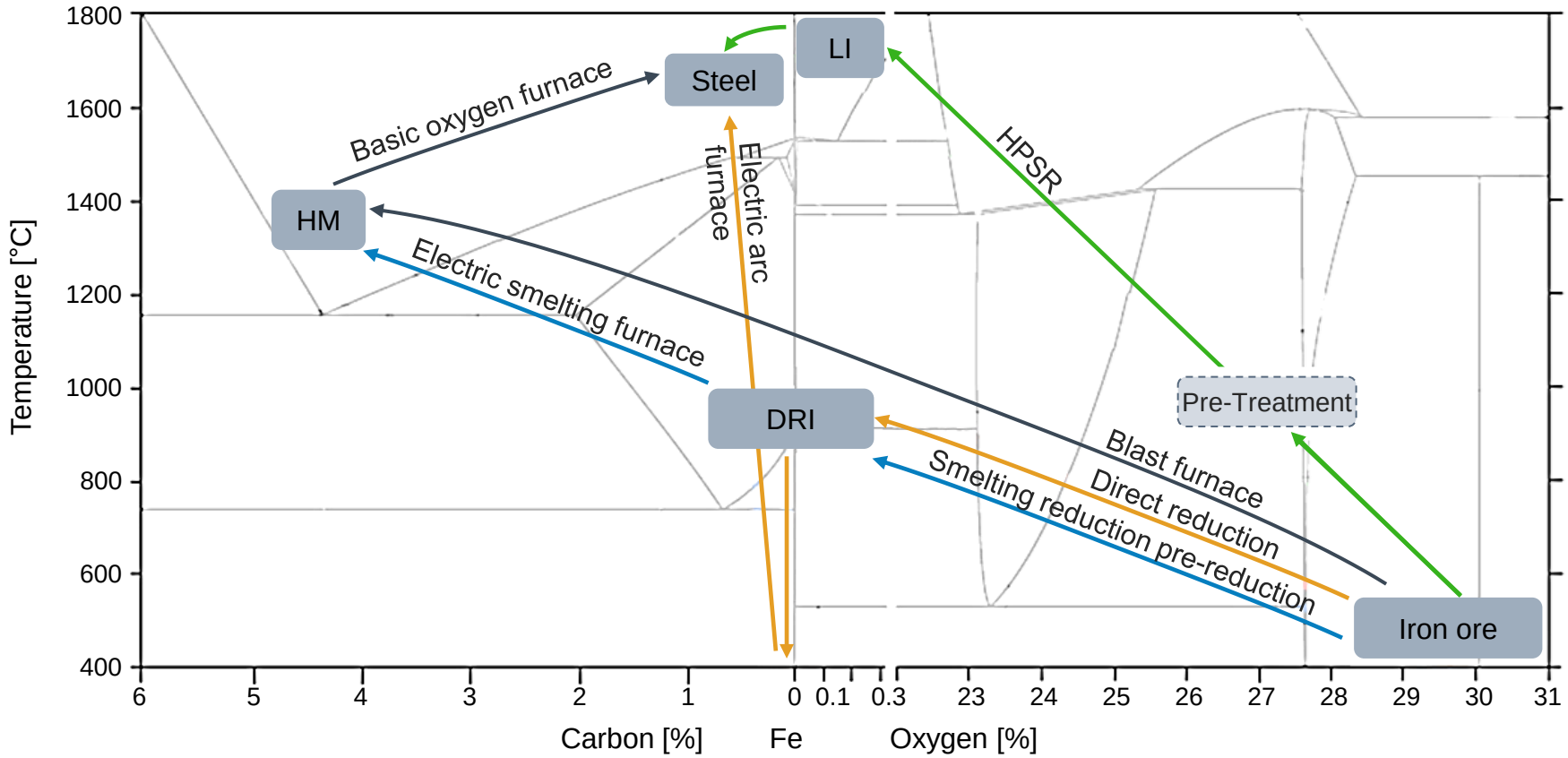
High grade sea born iron ores are available in limited quantities

75% of all beneficiated iron ores are fines



One step ahead with one step to steel

Steel making process routes



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

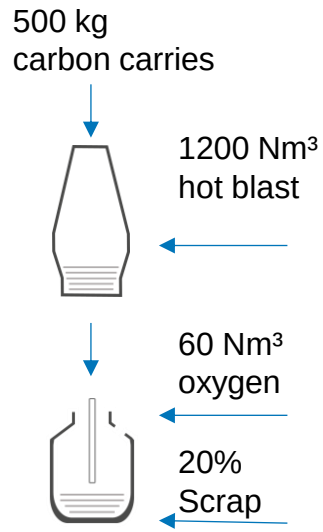
Comparison of steelmaking technologies

Energy demand per ton of liquid steel

Conventional steelplant

Electricity-based steelmaking

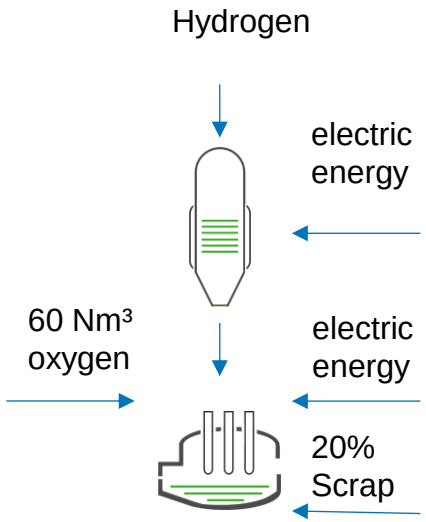
BF-BOF



Benchmark

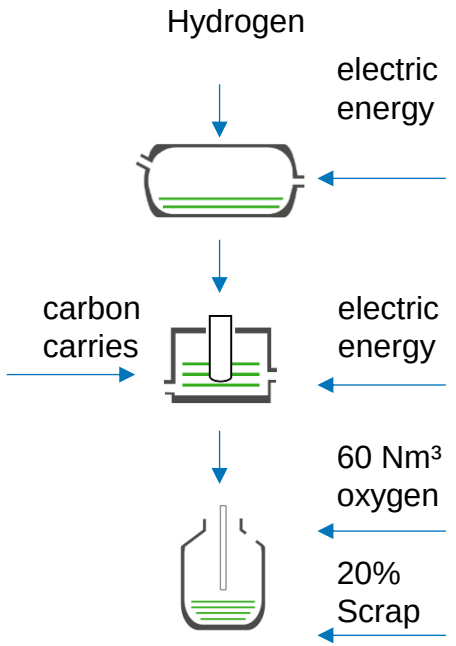
~4,5 MWh/t fossil energy

DR-EAF



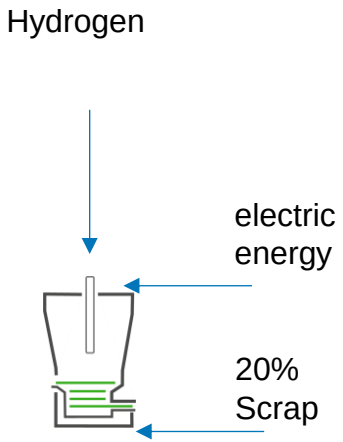
High-grade ore alternative

HYFOR-ESF



Low-grade ore alternative

HPSR



Potential single step process for low- and high-grade ores

<4 MWh/t renewable energy

The SuSteel project

Success story

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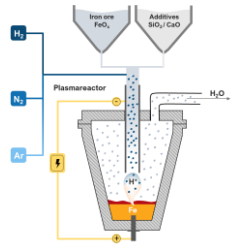
1998

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

2019 - 2023

Operational optimization of hydrogen plasma smelting reduction

Selection of suitable materials

Slag management

Conceptual design of the electrolysis system

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

2025 – 2027+

SuSteel pilot engineering

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

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

TRL 5

TRL 7

2019 - 2023

Fundamentals of hydrogen reduction

Process variations to achieve economic optimization

Optimization of raw material input

Concept for upscaling and continuous operation

2023 - 2027

Continuous HPSR process development

Process variations to achieve economic optimization

Parameter evaluation for continuous operation

Design of a pilot plant layout

2024+

PLASMARED

HELIOS

PlasmArc Green

LIGHTBOW

Expedition Zukunft - Wissenschaft

The SuSteel project

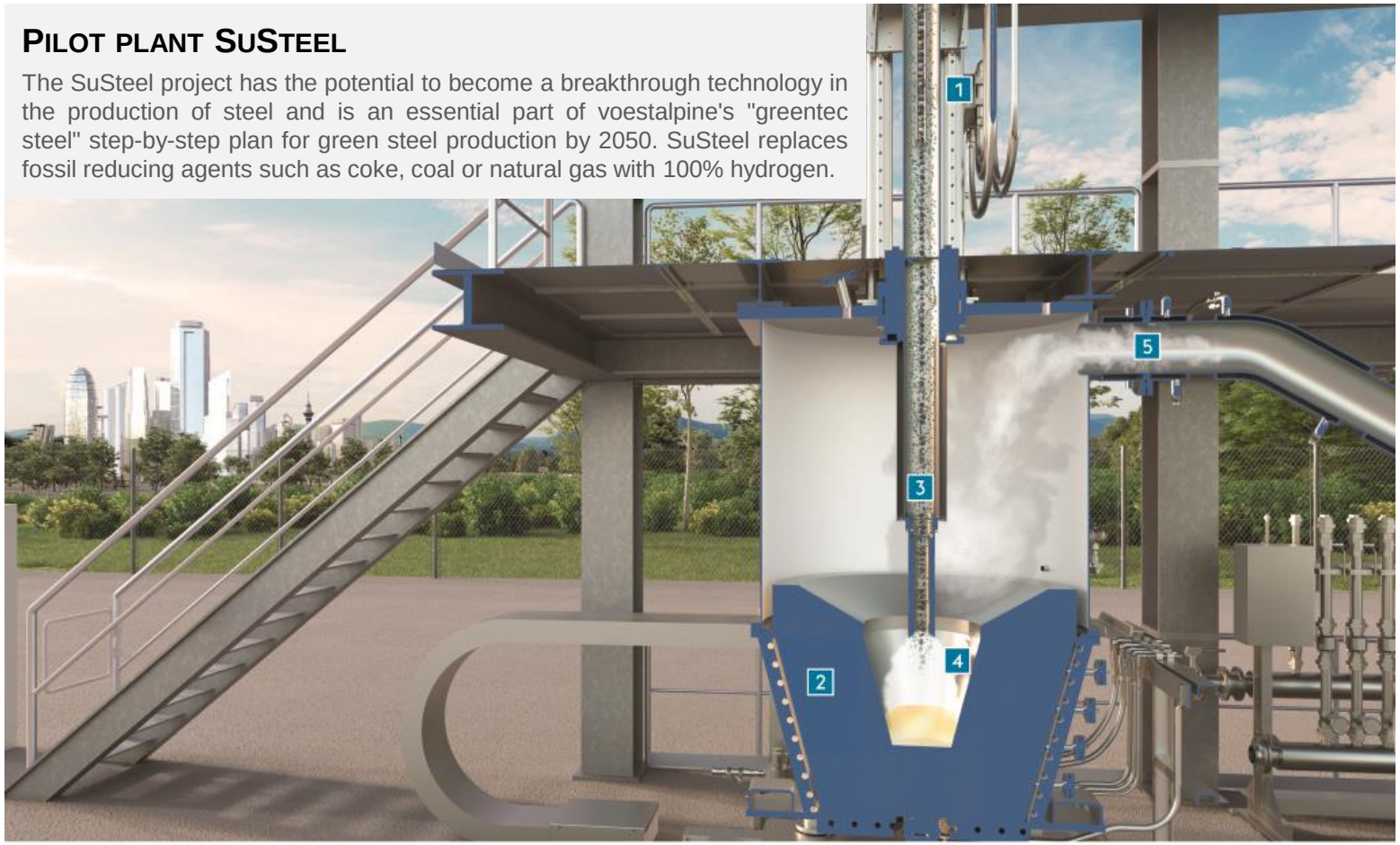
Demonstration plant voestalpine Donawitz site

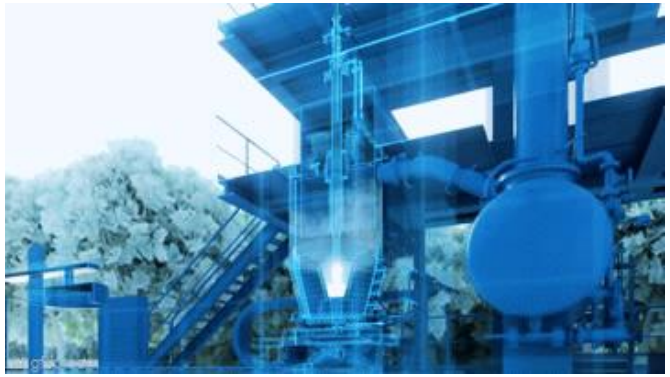
The SuSteel project

Demonstration plant voestalpine Donawitz site

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.

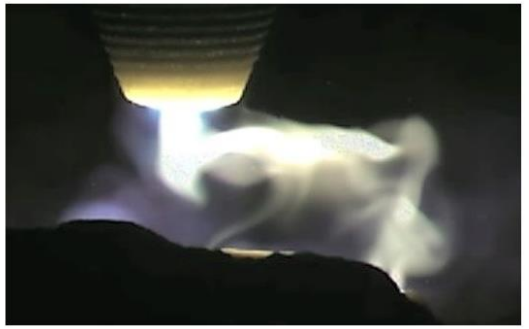
4 **Reaction zone**
Hydrogen is ionised into plasma and the iron ore is melted and reduced in one step. Crude steel is produced.

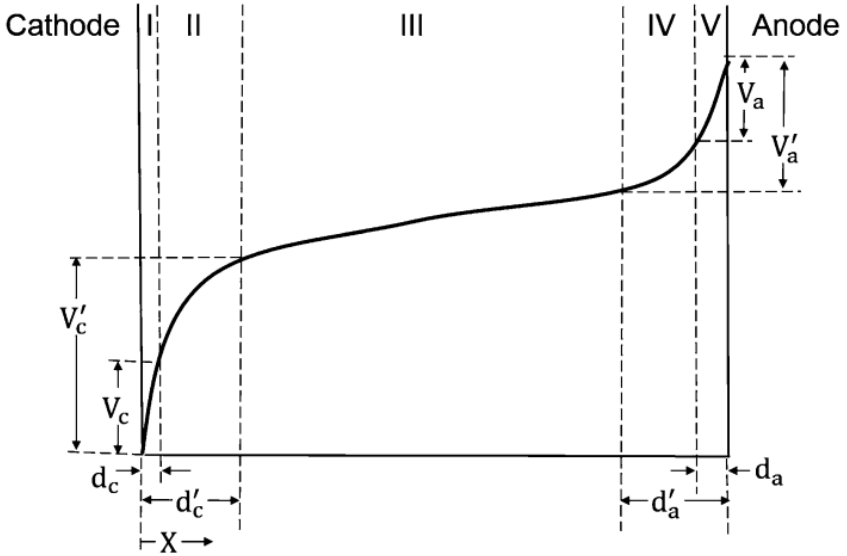
5 **End product: water vapour**
At the end of the process, only water vapour escapes. CO_2 emissions are fully avoided.

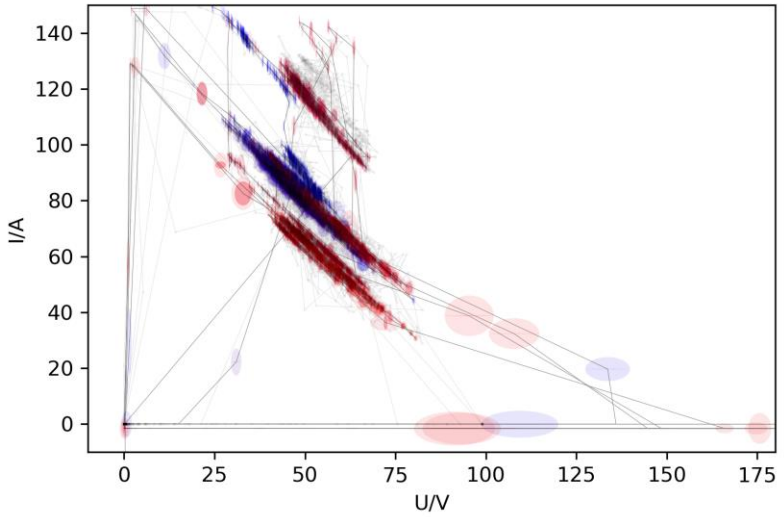
Hydrogen Plasma Smelting Reduction

Experimental and simulation approach

- Experiments
  - Energy/Material input/output
  - Logged sensor data (1s interval)
  - Gas analysis (1s-10s interval)
  - Video data: 25 fps
  - Voltage/current data: 100 kS/s
- Analysis
  - Reduction rate
  - Electrical model
  - Final product, electrode wear

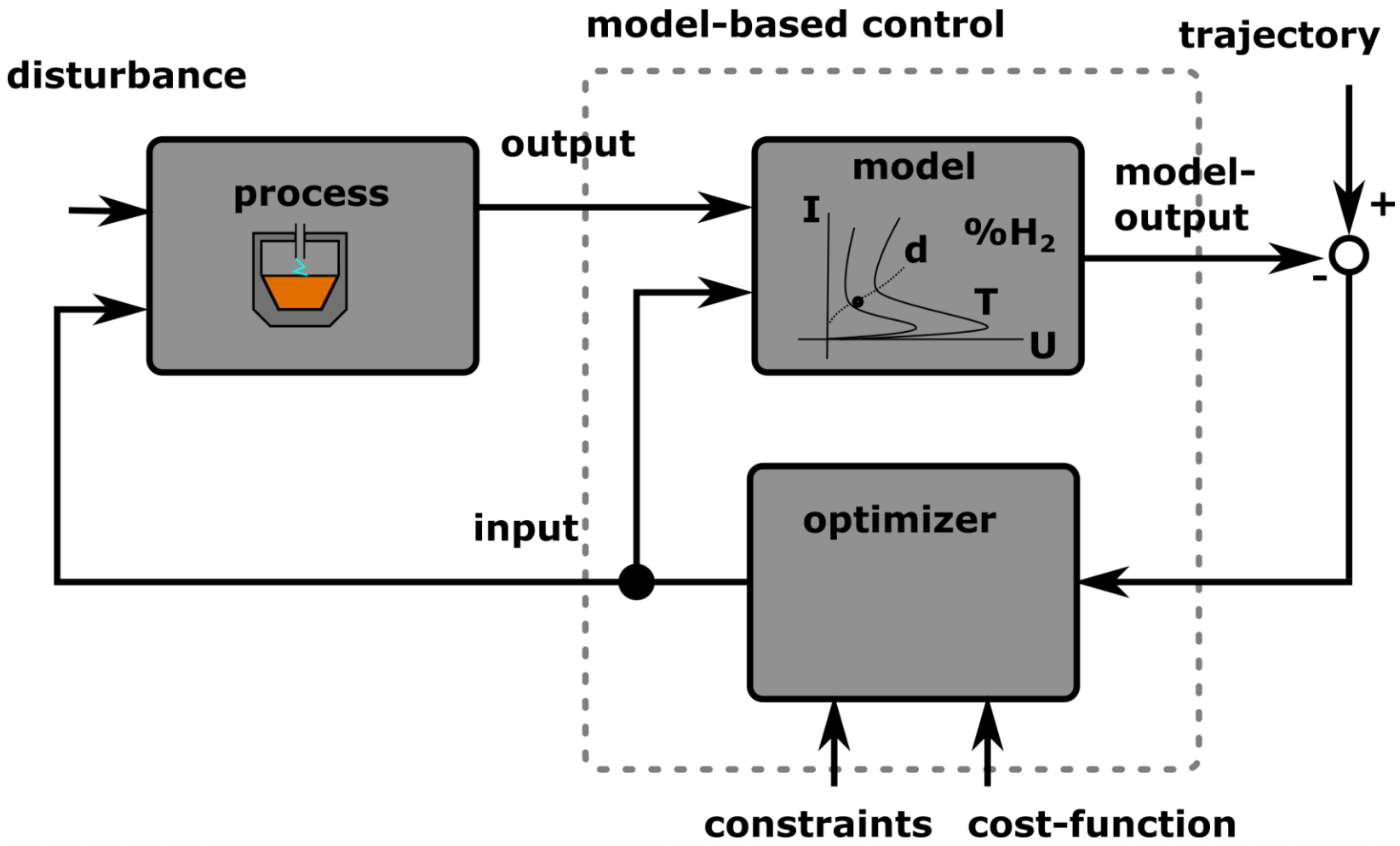






Hydrogen Plasma Smelting Reduction

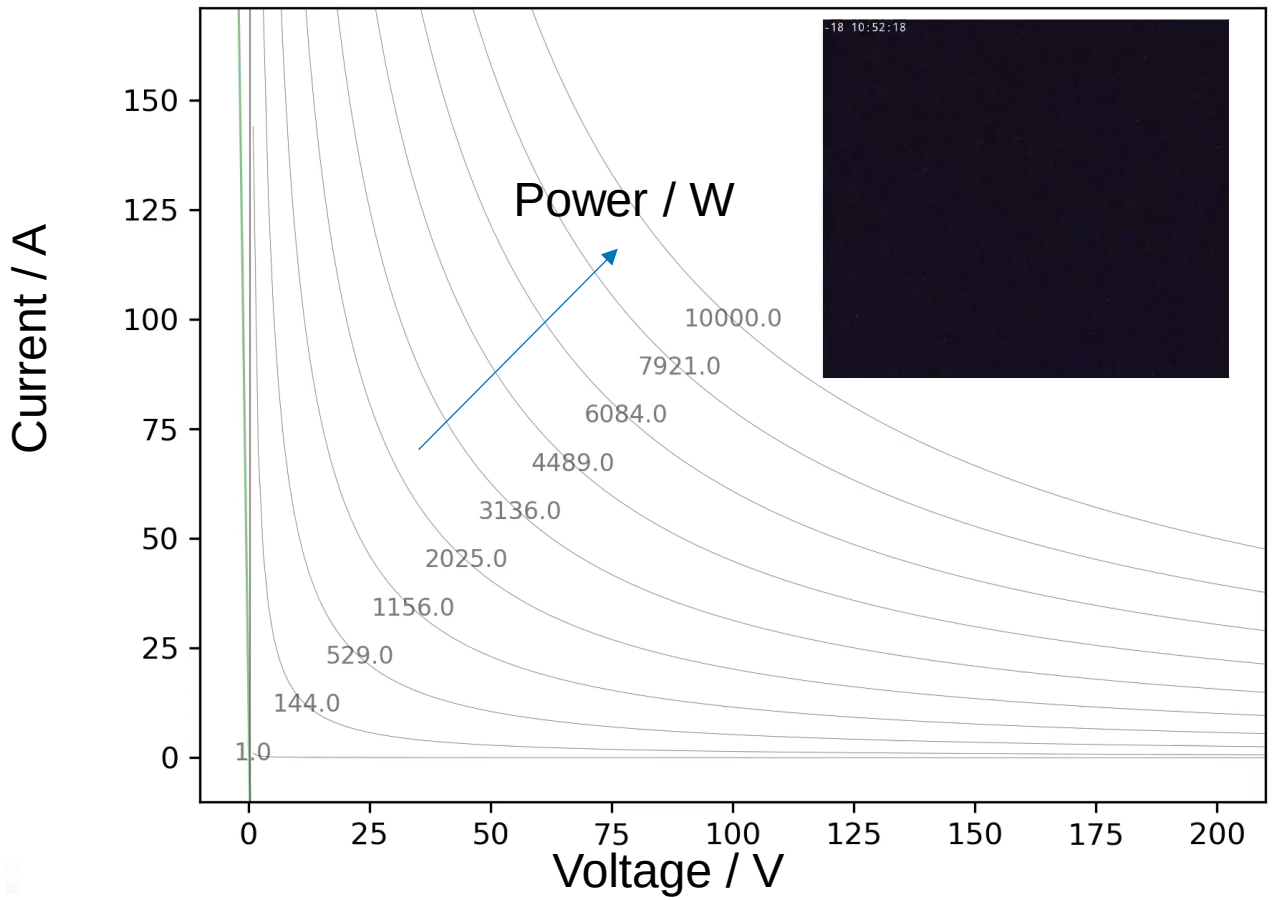
Model-based control of electric arc plasma



Hydrogen Plasma Smelting Reduction

Electric arc plasma model

Electrode meaurements 100 kSamples/sec



current-voltage model with parameters:

- electrode distance / geometry
- gas composition
- temperature
- flow rate
- material properties

virtual sensors for:

- reduction rate / H_2 utilization
- energy efficiency
- electrode consumption
- ionization

Next steps and related projects

What's up next?

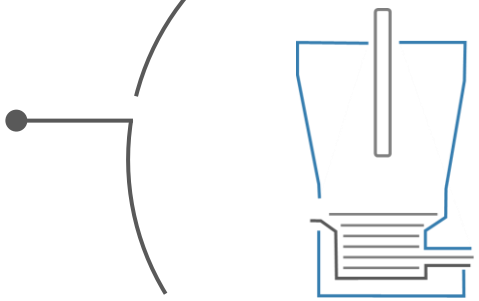
metallurgical competence center

Budget total

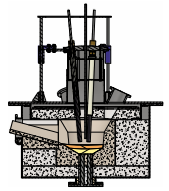
ZEROSTEEL
Novel technologies in the whole value chain including biomass gasification and integrating hydrogen
5,0 Mio.€

plasmarc4GREEN PlasmArc Green
Fundamental development of simulation methods
3,9 Mio.€

SuS-F
Continuous operation in a fully integrated environment
6,7 Mio.€

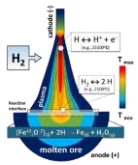


Project 2.1
Further development of the HPSR process, refractory concepts and simulations
1,3 Mio.€



MKO
Development of a multi cathode furnace for the HPSR process
500 k €

HELIOS
Instrumentalization and advanced measurements
2,7 Mio.€



Green CO_2-free steelmaking route based on H_2-plasma technology
6,1 Mio.€

LIGHTBOW
Expedition Zukunft - Wissenschaft
Electrical modelling and implementation of a model-based control system for arc plasma stabilization
471 k €

Fund granted ---- Proposal

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Questions?

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ESTEP

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Test facilities: HPSR reactors

- Crucible type with central cathode
- Hollow graphite cathode conveys process gas (and solid fines)

Laboratory	.	Demonstration
~200 g	Batch Size (continuous also possible)	50-200 kg
3-8 kW 30-80 V 50-130 A	Power Voltage Amperage	100-250 kW 80-220 V 500-1500 A
H_2, Ar, N_2, CH_4 2-8 L/min	Gas Flowrate	H_2, Ar, N_2 300-2000 L/min
5-30 mm	Arc length	50-300 mm
+100-200 mbar	Pressure	+150 mbar