Co-funded by
the European Union

Hy4Smelt

Deliverable 2.2 – Definition of Key Performance Indicators

0 Document Information

Deliverable Title	Definition of Key Performance Indicators
Number of Deliverable	D2.2
WP/Task related	WP2, Task 2
Distribution/Confidentiality	PU Public
Date of Delivery	31/07/2025
Number of Pages	11
Person Responsible for Document	Norbert Bauernfeind
Author(s)	Johannes Gabl
Reviewers	Daniel Spreitzer (PTAT), Christoph Thaler (VAS), Andreas Pfeiffer (PTAT), Christoph Prietl (PTAT)

Document Version	Effective date	Description/Changes
1.0	31/07/2025	First issue

This project has received funding from the Research Fund for Coal and Steel RFCS-2024-CSP-Big Tickets for Steel of the European Union under Grant Agreement no. 101193416

Disclaimer: This report contains a preliminary list of KPIs which are defined at the start of the project, but which may change throughout the course of the project given development and operation of the plant. This may lead to adjustment of both the number and character of KPIs.

Table of Contents

List of Tables

1 Introduction

Hy4Smelt is a research project with a TRL 7 – 8 industrial-scale demonstration plant for hot metal production in a sustainable process with green hydrogen, electricity and secondary carbon carriers (Biochar). Besides sustainability, a focus of Hy4Smelt is the processability of iron ore ultra-fines of all qualities, enabling highest flexibility in input material selection. This is possible because of the groundbreaking combination of novel technologies HYFOR and Smelter. The document "Deliverable 2.1 – Hy4Smelt use case specification" [1] gives an overview of the input materials and main process parameters. HYFOR is a fluidized bed process that enables reduction of ultra-fine iron ores with hydrogen. The Smelter is a continuous electric smelting process under reducing atmosphere enabling processing of direct reduced iron at lower metallization degrees and higher gangue content than electric arc furnaces. This outstanding flexibility is the basis for the process design and coalesces in the key performance indicators (KPIs) below.

1.1 Purpose of this Document

KPIs are a vital tool to monitor and judge the performance of the system. For each core component multiple technical and operational KPIs are selected. Therefore the entire system can be evaluated but also each process step can be evaluated independently of the other. The Hy4Smelt plant is, for the purpose of this document, split into the following components:

- HYFOR: Ore preparation (drying, grinding, pre-heating, depending on ore type pre-oxidation or calcination), direct reduction of the iron ore (HYFOR) including direct reduced iron (DRI) briquetting and DRI product quality
- Smelter: The electrical smelting of DRI as well as additives, including product handling (hot metal and slag granulation) and product quality

The KPIs and the overview table are adapted from ISO 22400 [2]

1.2 Abbreviations, Acronyms, Units,

Table 1: Abbreviations

Abbreviation	Meaning
KPI	Key Performance Indicator
HYFOR	Hydrogen based Fine Ore Reduction
Smelter	Electric Smelting Furnace
DRI	Direct Reduced Iron
CO_2	Carbon Dioxide
TRL	Technology Readiness Level
PEM	Proton Exchange Membrane
HBI	Hot Briquetted Iron
GHG	Greenhouse Gas

BF	Blast Furnace
PSA	Pressure Swing Adsorption
Ca	Calcium
Fe	Iron
FeO	Iron oxide
Fe_{met}	Metallic iron content
Fe_{tot}	Total iron content
Si	Silicon

Table 2: Units

Unit	Meaning
°C	Temperature in Celsius
m^3	Cubic metres
Nm^3	Norm cubic metres
h	hours
%	percent
t	tonnes
mg	milligrams

2 Overview of all KPIs

KPI ID	Scope	Description	Range/target and unit	Trend (value is better if…)	Method of verification/calculation
KPI 1	HYFOR	Replacement of conventionally fossil reducing gas with green hydrogen from PEM electrolysis	100 %	Higher	By design only green hydrogen from on-site PEM electrolysis is used.
KPI 2	HYFOR	Maximum hydrogen flow	1500 Nm³/h	plant design	Hydrogen flow measurement at H2FUTURE [3] plant
KPI 3	HYFOR	Metallisation degree depends on the target application. For the use in the Smelter the target metallisation is 85 %. This can be tailored to an optimum economic equilibrium of reducing work through hydrogen in HYFOR and carbon in the Smelter. For the production of HBI a metallisation of 93 % is required to achieve the briquette density.	85 % respectively 93 %	Depends on downstream process and economic considerations.	Wet chemical analysis (Zimmermann Reinhardt) of final product and calculation: $$Metallisation\ (\%) = \frac{Fe_{met}}{Fe_{tot}}$$
KPI 4	HYFOR	Material losses in HYFOR reactors	< 0.1 %	Lower	Closed system by design with internal dust recycling. Dust load in the off-gas can be measure on demand
KPI 5	HYFOR	Utilisation of hydrogen for reduction of iron oxide	> 75 %	Higher	Measurement of reducing gas composition upstream and downstream fluidised bed reactors and calculation of hydrogen utilisation caused by reduction. Additionally, calculation of material balance through measurement of

					DRI output and reduction degree. This includes gas recycling via PSA.
KPI 6	HYFOR	Utilisation of hydrogen in plant	> 95 %	Higher	Bleed gas from HYFOR loop will be used as fuel for ore drying.
KPI 7	HYFOR	DRI production capacity. The production of DRI depends, amongst others, on the iron ore type, hydrogen flow and temperature. Generally around 550 – 670 Nm^3 hydrogen are expected per tonne of DRI, resulting in the target production.	1.8 – 2.6 t/h	Higher at fixed hydrogen consumption	Material balance, level measurement and solid flow rate.
KPI 8	Smelter	Share of pre-reduced iron carrier showcasing the production of hot metal from primary resources (iron ores) of all grades and not requiring scrap or HBI.	80 – 100 %	-	Hot DRI and other iron carriers can be charged independently different systems, allowing a precise control of the input material mix.
KPI 9	Smelter	Demonstration of utilisation of secondary carbon carriers i.e. Biochar as a replacement of fossil carbon	Up to 100 %	Higher	See D2.1 [1] use-case 3. Biochar with adequate properties will be secured for Smelter operation.
KPI 10	Smelter	Hot metal carburisation	Above 3,0 %	Higher	Measurement via glow-discharge optical emission spectroscopy
KPI 11	Smelter	FeO concentration in slag	< 1 %	Lower	XRD for total iron; wet chemical analysis for Fe^{2+} and Fe^{3+} detection
KPI 12	Smelter	Hot metal production rate	1.7 – 2.4 t/h	Higher at fixed hydrogen consumption	Weight measurement and detailed mass balance calculation
KPI 13	Smelter	Slag production rate	0.1 – 0.7 t/h	Depends on input material mix	Weight measurement and detailed mass balance calculation

KPI 14	Smelter	Glass content of Smelter slag	> 85 %	Higher	Chemical analysis of slag (X-ray diffraction, polarised light microscopy)
KPI 15	Hy4Smelt	Utilisation of 6 different iron ore types as specified in the D2.1	6 iron ores	-	As defined in D2.1 [1]
KPI 16	Hy4Smelt	TRL Level at end of Project	TRL 7 – 8	Higher	
KPI 17	Hy4Smelt	Demonstration of reduction of Scope 1 CO_2 emission of entire process compared to BF hot metal production.	> 90 %	Higher	Calculation of detailed mass and energy balance with operational data, see Innovation Fund, Annex C: Methodology for calculation of GHG emission avoidance

3 Additional description of KPIs

KPIs 1 & 2: The HYFOR gas loop will be fed exclusively with green hydrogen from the H2FUTURE [3] PEM electrolysis plant. No natural gas or fossil based (grey or other) hydrogen is used.

KPI 3: The nominal production capacity of the H2FUTURE [3] plant is 1200 Nm^3/h which is applicable for most use cases in Hy4Smelt, see D2.1 [1]. By utilising on-site hydrogen storage capabilities this hydrogen flow rate can be increased to 1500 Nm^3/h for up to 36 hours to test the Hy4Smelt system at higher production loads.

KPI 4: The HYFOR reactors and gas loop are by design a closed system. Environmental emissions limits are set by the authorities and must be lower than 10 mg/m^3 which is less than 0.1% of the material throughput and will be measured on demand in the off-gas.

KPI 5: Minimisation of losses and optimisation of reduction

KPI 6: The bleed gas from the HYFOR gas loop after heat-exchange, recycling with pressure swing adsorption contains approximately 40 – 50 % hydrogen (~250 Nm^3/h) which will be used to dry the iron ore before the optional grinding and subsequent pre-heating.

KPI 7: The hot DRI production will be verified through multiple means and data acquisitions such as hot metal production, hydrogen flow, level and flow sensor, a detailed mass- and energy balance.

KPI 8: The higher the share of pre-reduced iron carriers the higher the energy demand in the Smelter and the addition of carbon as reducing agent.

KPI 9: Carbon in the Smelter has two applications. The first is the remaining reduction of the iron oxides in the DRI to metallic iron with the additional effect of the formation of a reducing atmosphere. The second one is the carburisation of the hot metal with additional adjustment possible through injected carbon.

KPI 10: The target hot metal carburisation above 3.0 % for smooth refining in the basic oxygen furnace.

KPI 11: FeO in slag should be as low as possible due to two main reasons. First, it is a loss of yield which should be minimised. Second, it causes a black/dark discolouration when used as a binder in the cement and construction sectors. The lower the FeO content the more applications in the cement sector are possible.

KPI 12: A detailed mass balance calculation, a digital twin and multiple flow- and level sensors and weighing of the product will allow verification of this KPI regarding production quantity.

KPI 13: The slag production rate depends on the used type of iron ore, target slag basicity and the addition of other iron carriers such as HBI and scrap. See D2.1 [1] for the individual slag rate per use-case. Some of the produced slag will be wet granulated towards KPI14 while the rest will be collected in slag pots and integrated into the material handling system of the on-site existing steel mill.

KPI 14: The slag properties, including glass content, are relevant for further use in other sectors, such as cement or construction. The goal is to produce a Smelter slag with similar characteristics as BF slag. Therefore, analysis of slag granulation and derived latent hydraulic properties (mortar prism strength, hydration heat, concrete properties/durability) will be performed to evaluate the slag as a secondary cementitious material. Furthermore, the glass content (amorphous non-crystalline fraction) comprising elements, such as Si or Ca) being a significant factor to evaluate the performance of the Smelter slag as a replacement material for cement, is quantified. The glass content is an important indicator regarding the latent hydraulic properties (ability of the slag to form Ca-Si-hydrates after contact with water, which are required for the strength of cement-based materials).

KPI 15: 6 different iron ores are selected within the Hy4Smelt RFCS project to showcase the operation and processability over a wide range of input materials. This ranges from low grade sideritic and haematitic sinter feed to high grade magnetitic pellet feed, and therefore over a wide range of iron content and particle size. Full details of the chemical ore composition are given in D2.1 [1].

KPI 16: It is expected that due to the automation, digitalisation, continuous operation and system design analogous to an industrial plant that the TRL is higher than 7. However, due to a production capacity lower than an industrial scale plant the TRL is smaller than 8, hence final TRL will be 7-8.

KPI 17: The reduction of CO_2 emission at Scope 1 is limited by the availability of green hydrogen produced by PEM electrolysis with sustainable electric power. Once the required quantities of energy and chemical reducing agents (hydrogen, carbon) are available, a net-zero CO_2 emission can be achieved with the electrodes being last technological challenge. However, the C-sink of secondary carbon carriers (i.e. Biochar) in the iron compensates the electrode consumption. The Scope 2 and 3 emissions need to be replaced by renewable processes for a full GHG emission free value chain, which, while it is monitored within the project, is outside of the scope of Hy4Smelt.

4 Conclusion

The KPIs presented here are aligned with the grant agreement and are the main basis for the technical and performance evaluation of the system. After construction Hy4Smelt will be operated for multiple continuous campaigns split over 3 years to test and optimise all relevant parameters to achieve all KPIs. This is necessary for the successful exploitation of the technology. It should be noted that this resulting list of KPIs is preliminary and may change throughout the course of the project given development in thinking related to the operation of Hy4Smelt, leading to adjustment of both the number and character of PIs

5 References

[1] Hy4Smelt Deliverable 2.1 – Hy4Smelt use case specification

[2] International Standard ISO 22400, “Automation systems and integration — Key performance indicators (KPIs) for manufacturing operations management”

[3] H2FUTURE PEM Electrolysis plant, https://www.h2future-project.eu/en, accessed 18.07.2025