H2AL

DECARBONISING ALUMINIUM RECYCLING WITH HYDROGEN

D2.1 – Report on the system's requirements, specifications, and KPI baseline.

VERSION 4.0

Clean Hydrogen Partnership

Co-funded by the European Union

Deliverable Nature:	Document, report
Version:	0.0
Date:	June 20th, 2024
Keywords:	Requirements, specifications, KPI

Executive Summary

The H2AL Report on Project Requirements, Specifications, and KPIs has been developed to collect the requirements and specifications to feed and guide the activities within WP3-WP6. This deliverable reports the requirements and specifications of the demonstration site to compare today's scenario with the scenario after the modification to 100% H2 combustion. The relevant KPIs will be defined, modified, and assessed throughout the project.

The requirements and systems specifications of HTAs will be analyzed, and KPIs will be cross-checked with other HTA industries to compare and allow the application of the project results to other sectors different from the aluminum industry.

Document Information

Project Number	HORIZON – JTI – CLEANH2 101137610	ACRONYM	H2AL
Full Title	Full-scale Demonstration of Replicable Technologies for Hydrogen Combustion in Hard to Abate Industries: The Aluminium use-case		
Project URL	https://h2al.ulb.be		

Date of Delivery	Contractual	M6	Actual	M6 – June 30th, 2024

Author	Iban Vicario	Affiliation	TEC

Reviewers	
Name	**Affiliation**
Jörg Weiss	GWI
Alessandro Parente	ULB
Ivan Vaiani	NIP
Inma Suarez	2a
Iban Vicario	TEC

Version Log			
Date	**Rev. No.**	**Author**	**Change**
20 June 2024	v0.0	Iban Vicario	Initial Version
26 June 2024	V1.0	Jörg Weiss / Alessandro Parente	V1
27 June 2024	V2.0	Ivan Vaiani	V2
27 June 2024	V3.0	Inma Suarez	V3
28 June 2024	V4.0	Iban Vicario	V4

Table of Contents

Abbreviations

2a	2a S.P.A.
BER	BlueEnergy Revolution
CMM	Calibration, verification, and performance testing
DI	Density Index
E	Elongation
EAA	European Aluminium Association
EC	European Commission
GHI	Guinea Hornos Industriales
GWI	Gas-und Wärme-Institut Essen e.V.
HPDC	High-Pressure Die Casting
HTAI	Hard-To-Abate Industries
KER	Key Exploitable Results
KPI	Key Performance Indicator
LHV	Low Heating Value
NA	Not Applicable
NG	Natural Gas
NIP	Nippon Gases Italia
ULB	Université Libre de Bruxelles
RINA	Registro Italiano Navale
TEC	Tecnalia Research & Innovation
UTS	Ultimate Tensile Strength
YS	Yield Strength

1. Introduction

The demonstration site at 2A requires a comprehensive characterization in terms of processes involved in their product range (including their existing combustion equipment/technology), refractory materials relevant to KPI and quality indicators, laboratory facilities, measurement and control systems, current data/knowledge management structure and control structures of the line.

We aim to characterize the requirements and specifications of the Aluminium Foundry industry in general – including variants of industrial processes based on different heating processes (e.g., natural gas, electricity) and other types of furnaces (e.g., rotary furnace, reverberatory furnace, melting tower), including the different technologies and processes to spread the solutions to HTAIs (Hard-to-Abate Industries). The best available technologies for different HTAIs will also be assessed to surpass the lack of actual data with a novel fuel such as hydrogen. Based on these evaluations, concepts for developing new burners and retrofitting the furnaces with improved properties designed explicitly for H_2 will be employed in WP3.

A KPI revision will be held over the project in parallel with sister projects (HyInHeat, H2Glass, HyTecHeat, GreenHeatEAF, TWINGHY, and HyDreams).

The key objective is to collect the requirements and specifications to feed and guide the activities within WP3-WP6. The specific objectives are:

1) Collect the requirements and specifications of the demonstration site (2A).

2) Characterize current processes subject to conversion to 100% H_2 combustion, by carrying out a technology baseline analysis in the aluminium industries and differences from other HTAIs.

3) Define the KPIs to compare the AS-IS with the TO-BE scenario demonstrated in H2AL.

4) Define the relevant KPIs and methodologies to characterize the quality of the product (i.e., aluminium).

In summary, this deliverable reflects our commitment to collect the requirements and specifications to feed and guide the activities within WP3-WP6.

2. Technology baseline analysis and KPI definition

The demonstration site at 2a has been characterized, defining a technology baseline and KPI definition.

2.1 Technology baseline analysis

2a is a privately owned aluminum global die-casting foundry specializing in the development and production of automotive and industrial components It is one of the largest companies specializing in the production of aluminium die-castings on the Italian market and has the largest press on the market, capable of supplying die-castings up to a finished product.

The company's growth has been, and continues to be, characterized by investment in research and technology. This has enabled the company to produce innovative die-cast components using the latest high-performance aluminium alloys through state-of-the-art technology.

2a produces components cast, machined, heat treated, painted, and assembled of any dimension, from the smallest to the largest in the market. The diecasting production cells go from 220 tons up to 4,500 tons. Many aluminum alloys are employed, going from primary (from electrolysis) to secondary (recycled).

A wide range of aluminium alloys, from primary to secondary alloys, are used. Most aluminium alloys used are recyclable and therefore environmentally friendly with low CO2 emissions. Great attention is thus paid to the environment from a sustainability perspective. This is achieved by complying with regulations, maximizing the use of energy resources, and carefully managing the entire waste cycle.

2.1.1Process involved in the product range

2a is an enterprise that produces High-Pressure Die Casting (HPDC) parts. 2a covers the whole process, starting from the production of aluminium HPDC components: from the melting of the alloy to the diecasting, the trimming, the finishing, the machining, the coating, the assembling, and the testing.

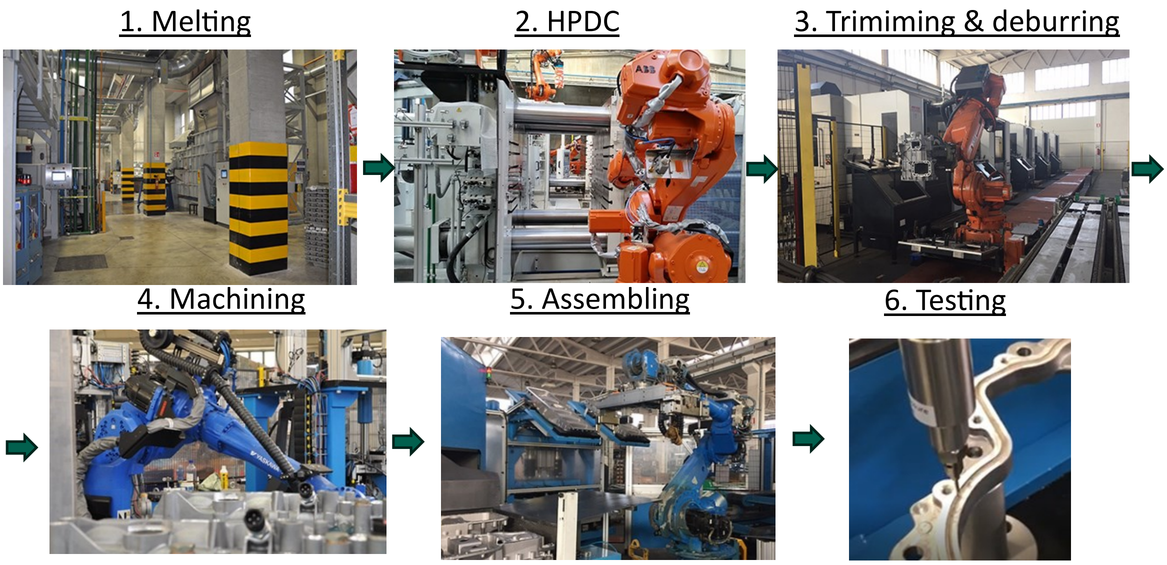

Figure 1: Schematic process description of 2a

The diecasting production cells from 220 tons up to 4,500 tons are employed to produce five types of components:

- Powertrain components.
- Structural components.
- Chassis components.
- Assembled components.
- Telecom / Domotic components.

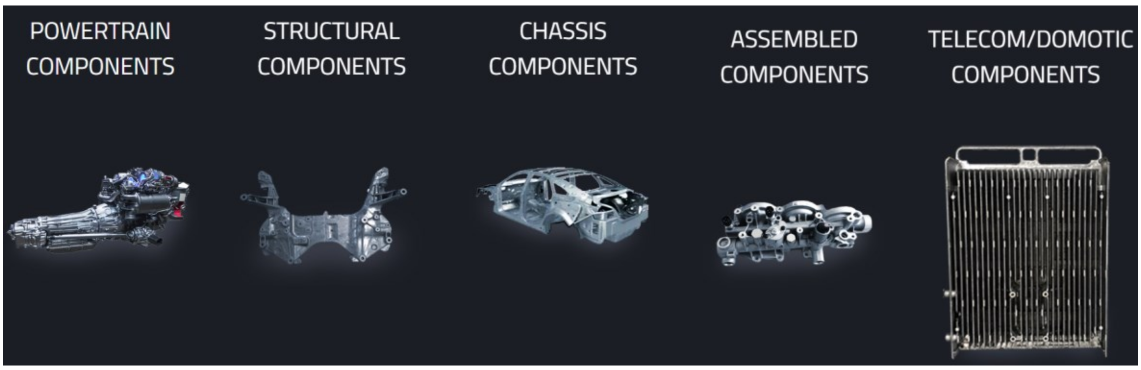

Figure 2: Components produced at 2a

2.1.2Laboratory facilities

A well-equipped laboratory enables 2a S.P.A. to test and certify all stages of the process with a range of laboratory equipment for the characterization of aluminum alloys, both in terms of mechanical properties and chemical composition. The company's facilities are capable of testing and certification at all stages of the process:

- Spectrometers
- Microscopic analyses.
- Hardness and fatigue testing.
- CT scans & X-ray.
- Non-liquid testing
- Standard CMM.
- Online measuring stations.
- 3D scanner.
- Casting simulation/FEM analysis
- Cleanliness laboratory
- Leakages control stations.

Figure 3 shows some of the most important control systems.

Dimensional control | Metallography | Laboratory furnace | RX tomography

Figure 3: Main laboratory facilities at 2a

Thanks to modern aluminium alloy die-casting plants, 2a manufactures high-tech components for a wide range of sectors, including automotive and telecommunication Using state-of-the-art aluminium alloy die-casting equipment, 2a manufactures high-tech components for a wide range of industries, including automotive and telecommunication.

The high technological and quality standards of 2a's equipment and machines ensure minimal dimensional tolerances and high surface quality on die-cast parts.

With the available equipment, 2a can assure the quality and performance of the produced HPDC cast parts.

2.1.3 Current industrial processes, with their needs and constraints

Currently, 2a has 20 machines ranging from 220 to 4,500 t, representing the biggest Italian HPDC foundry. The space is minimal inside the installation due to the large number of machines, furnaces, and peripherals.

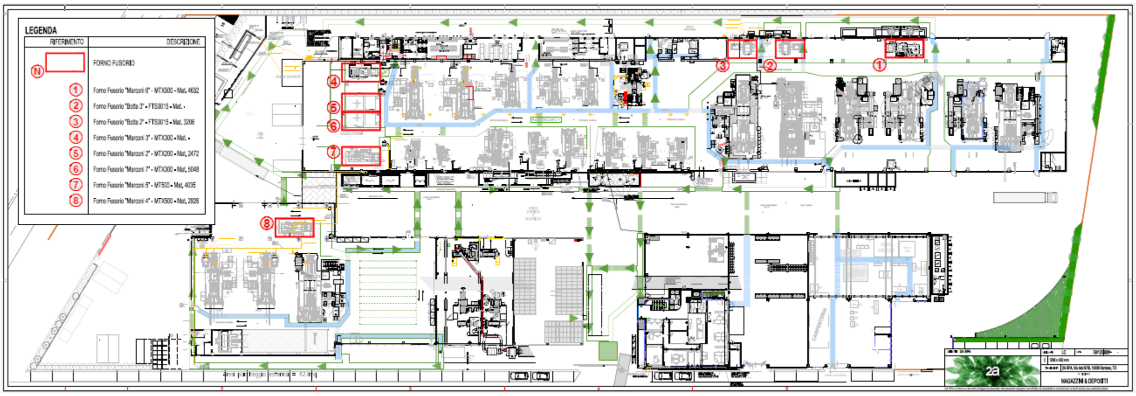

Figure 4: General location plant scheme of 2a

To feed those HPDC machines, 8 melting and holding furnaces are employed, with different aluminium alloys depending on the final part. In the following table, we can observe the main characteristics of the furnaces.

Table 1: Characteristics of furnaces installed at 2a

NUMBER	NAME	MODEL	POWER
1	MARCONI 6	MTX500	3372 kW
2	BOTTA 3	FTS3015	900 kW
3	BOTTA 2	FTS3015	900 kW
4	MARCONI 3	MTX300	3372 kW
5	MARCONI2	MATX 200	1163 kW
6	MARCONI 7	MTX 300	3372 kW
7	MARCONI 5	MT500	2442 kW
8	MARCONI 4	MTX 500	3372 kW

The furnaces rely on natural gas (NG) for the melting and holding operations, with high CO2 emissions rates.

Each furnace has several different power burners. For example, the MTX500 furnace selected for the project has 3 NG + air burners of 1 MW in the melting area and 1 NG + air burner of 0.2 MW. Figure 5 shows the layout of the selected furnace.

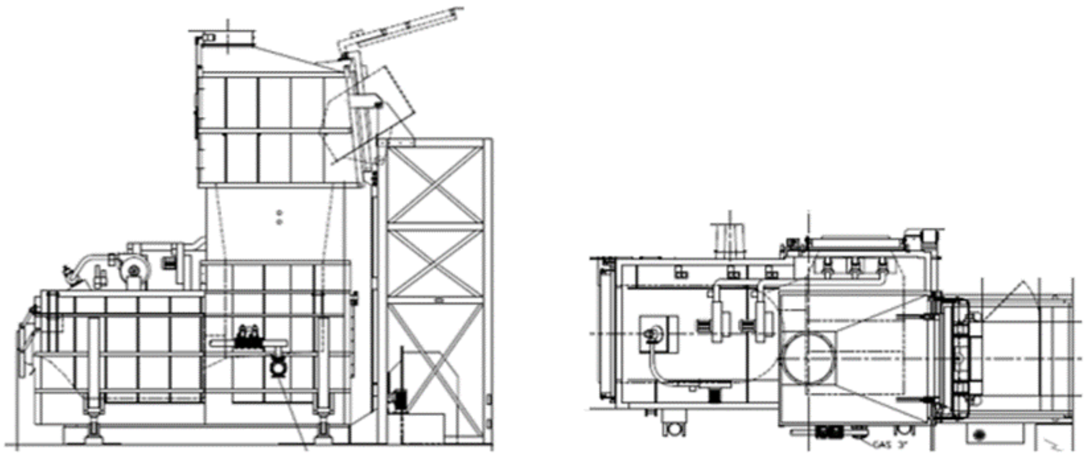

Figure 5: General location plant scheme of 2a..

The large number of burners and the limited space make using H_2 + O_2 oxy-combustion systems challenging, especially concerning the supply of oxygen and hydrogen to the furnace. Hydrogen can be supplied directly by tube-trailer trucks in combination with storage tanks. However, there are some furnaces where there is no space to implement the supply of these gases. Because of that, a preliminary study has been performed to define the furnace that can be retrofitted and the areas where the auxiliary equipment and the tanks could be installed. Figure 6 shows the selected surface, the area for the delivery trucks, the oxygen tank, and 2 hydrogen tanks.

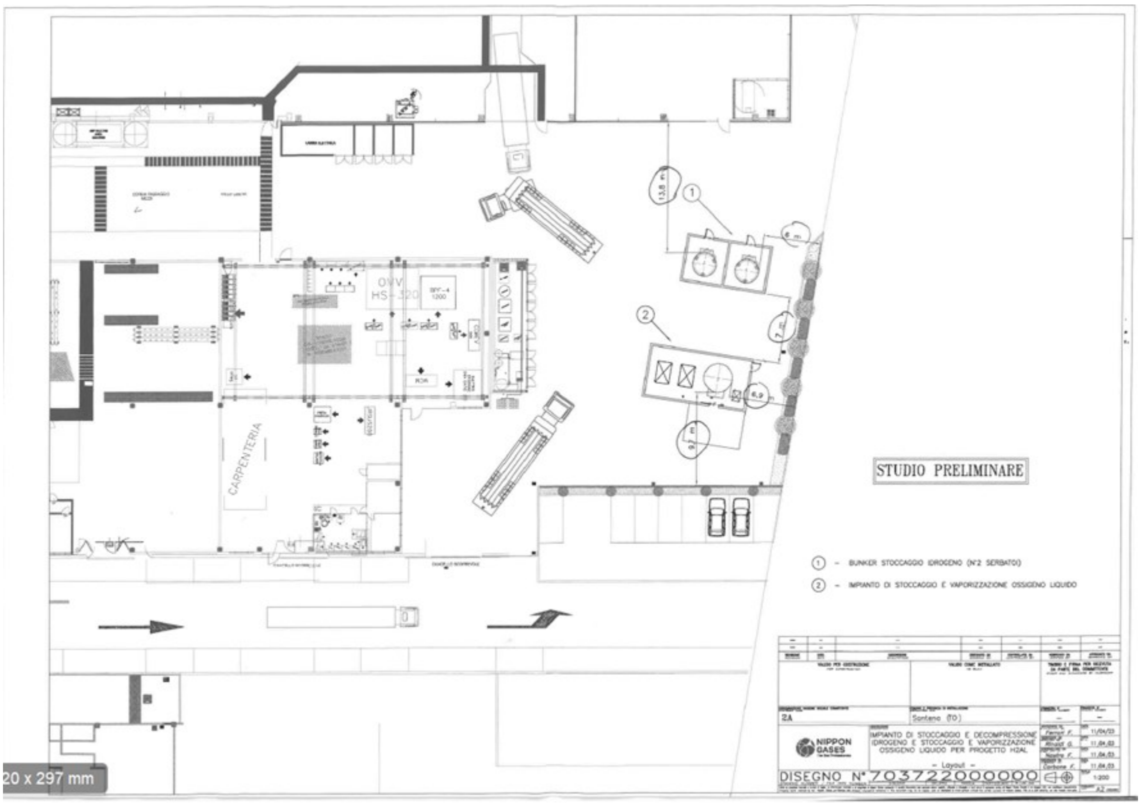

Figure 6: Preliminary study of the area for the H2 and O2 supply.

Using the H_2+O_2 oxy-combustion promotes atmospheres in the furnace with high water vapor percentages (up to 100%). The effect of this atmosphere on the furnace refractories is unknown. However, they can lead to an accelerated degradation of the refractories or, even worse, to a catastrophic failure. In both cases, appropriate refractories should be selected or developed for insulating the furnace. In Figure 7, we can observe the scheme of the chosen furnace, with the different types of refractories in different furnace areas.

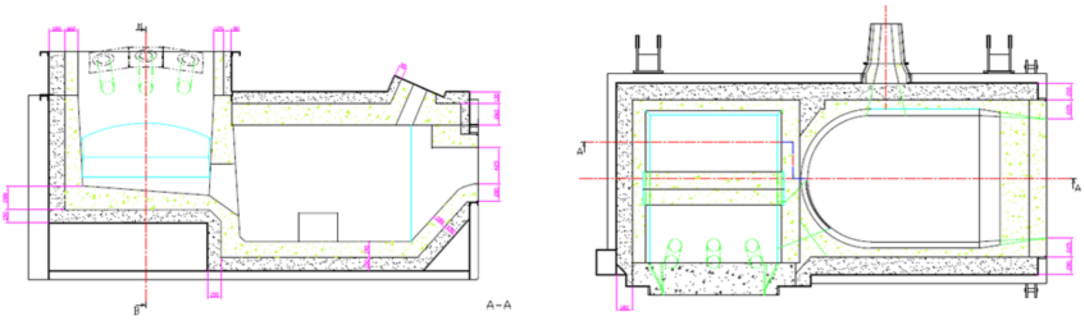

Figure 7: Scheme of refractories in the selected furnace.

There are 4 primary refractory materials in the furnace:

- Seven Cast 59. Andalusite-based low cement castable.
- Seven Cast 80. Bauxite-based low cement castable.
- Seven Cast A 84. Bauxite-based low cement castable.
- Seven Gun A 73. Bauxite gunning Material.

The specifications of every refractory material are included in the annexes.

The most significant uncertainty is the need for more legislation concerning the industrial use of H_2. New standards and laws for the industrial use of H_2 are under development. To overcome this problem, BER, NIP, and EAA are analyzing the standards, and the operation design will be based on the legal requirements of Italian law.

Once the furnace is retrofitted, it must be certified by a furnace constructor based on Italian legislation or by an external certification enterprise. In that way, the equipment can operate with H_2+O_2 combustion. The furnace to be retrofitted was constructed by an Italian furnace manufacturer (Marconi) that will not certify the furnace after the modifications. An agreement is being negotiated between 2A and RINA to certify the furnace after the retrofitting of the furnace.

2.1.4Measurement and Control Systems

The parameters of the production of HPDC parts at 2a are controlled and registered, ensuring traceability of the produced parts from the aluminium composition to the final characteristics of the parts.

The composition of every aluminium charge is controlled by analyzing the alloy composition by ICS, and all the data are registered and stored.

Figure 8: Registration of an alloy composition.

The alloy is melted in the furnace. The temperature is carefully controlled to ensure that the metal is at the optimum level to avoid localized overheating and excessive temperature, which can lead to oxidation of the aluminium alloy, a severe problem in the production of die-cast components.

Another source of the problem is porosity caused by hydrogen in solution in the molten metal, which is one of the most common defects observed in foundries. Hydrogen in the molten metal can come from a variety of sources, including:

- The furnace atmosphere, due to incomplete gas combustion,
- Ambient humidity or wet tooling, a cause of extreme reactivity where water decomposes and releases hydrogen into the melt,
- turbulent motions,

It is, therefore, essential to monitor and control the level of hydrogen to minimize the amount of scrap/rejected components. 2A controls the gas content through the degassing process, removing some of the hydrogen in the molten metal and thus limiting the formation of defects in the castings. This treatment injects nitrogen gas (N_2) into the melt from a rotary degassing unit. The N_2 gas bubbles collect hydrogen as they float to the surface, and then the hydrogen-saturated bubbles leave the melt, reducing the hydrogen content.

The melt degassing technique is focused on removing hydrogen and the entrapped oxide bi-film from the melt. The method used to measure hydrogen and oxide bi-film content is the Reduced Pressure Test (RPT), which involves solidifying the melt in two conical steel cups, one in the air (atmospheric pressure) and the other under partial vacuum (80 mbar). The quality of the melt is then assessed by calculating the density index (DI) using equation 1 (**Eq. 1**), where ρ_{air} and ρ_{vac} are the density of the sample solidified in air and under vacuum, respectively. The density index increases with the amount of hydrogen and oxides in the melt.

$$DI \frac{\rho_{air}-\rho_{vac}}{\rho_{air}} * 100 \qquad \textbf{Eq.1}$$

Figure 9: Degassing unit @ 2a

Another analysis used to indicate the potential porosity to be generated in the casting is the cutting of the RPT specimens. This visual test assesses the internal porosity aspect developed during solidification.

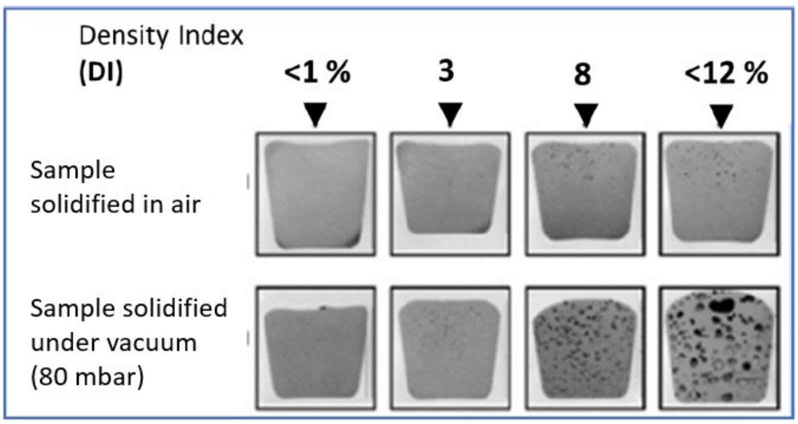

Figure 10: Porosity of RPT samples

Once the molten alloy has degassed, it is transferred to the holding furnace. The aluminium liquid is poured slowly into the holding furnace to avoid violent disturbance of the molten metal. This reduces the area of contact between the alloy and the air, reducing the oxidation of the aluminium liquid.

Once the alloy is poured into the machine furnace, the main parameters of the injection curve (pressure, speed, plunger position) are recorded. Also, some peripherals log other data, such as temperatures, vacuum pressure… In Figure 11 we can observe the relationship between different peripherals and the obtained data. In the high-pressure die-casting process, it is necessary to maintain the die temperature within a specific specified range to ensure that the casting solidifies progressively from the outside to the running systems to reduce porosity, improve mechanical properties, and increase die life. Therefore, the temperature of the mould is regulated by heating /cooling a fluid (water or diathermic oils) inside cooling channels within the die, which is measured using an IR camera.

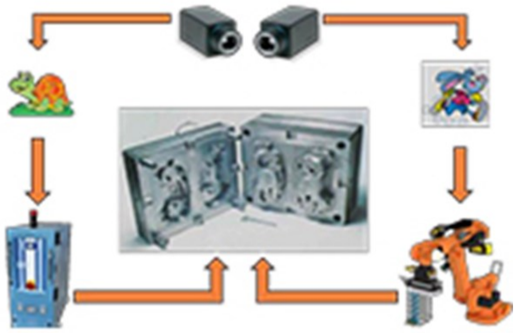

Figure 11: Logging of an alloy composition.

In Figure 12, we can appreciate the data collected by the machine, furnace, and thermal cameras.

Figure 12: Logging of an alloy composition.

Two different marking systems are employed to ensure complete traceability of the parts: point marking and QR adhesives. Laser marking is also being investigated to produce QR directly from the HPDC cellule. In Figure 13, we can observe two examples of part marking and tracking.

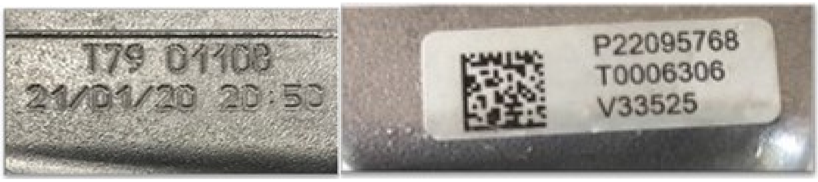

Figure 13: Point marking and QR control adhesive.

2.1.5 Data/knowledge management structure and control structures of the line

All 2a equipment are connected to a central station, enabling 2a to collect all working data and constantly measure our performances.

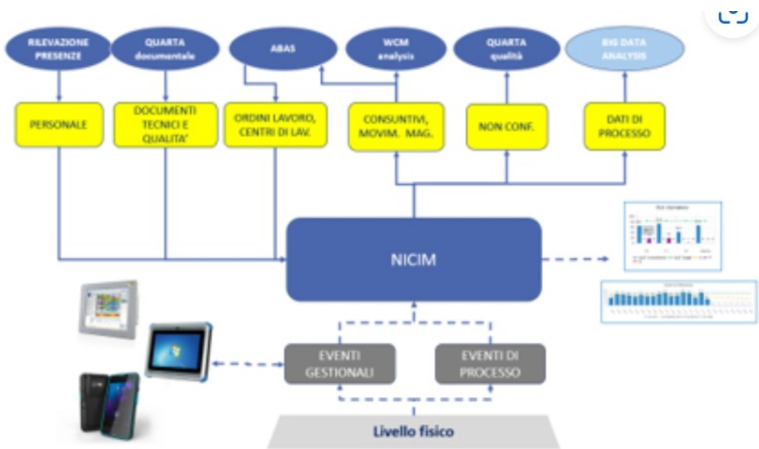

Figure 14: Data management structure.

All the data is stored, and it can be analyzed if necessary.

2.2 KPI definition and base KPIs

KPI stands for "**key performance indicator,"** a quantifiable performance measure over time for a specific objective. KPIs provide targets for teams to shoot for, milestones to gauge progress, and insights that help people across the organization make better decisions. From finance and HR to marketing and sales, key performance indicators help every business area move forward at the strategic level.

The KPIs will be determined to **define the baseline scenario of the use case** and, in the demonstration stage, to evaluate the impact of the new process based on H2 +O2 combustion.

H2AL's KPIs are **in line with the KPIs** defined in the Strategic Research and Innovation Agenda (SRIA) of Clean Hydrogen Europe and other representative SRIA as SPIRE, Processes4Planet (P4P), and Best Available Techniques (BAT) for the foundry and steel-making industry [1].

In CLEAN HYDROGEN PARTNERSHIP, there are 4 main areas to be measured by KPIs:

1. Availability.
2. Lifetime.
3. Efficiency.
4. Total cost of ownership.

In PROCESSES4PLANET INTERVENTION LOGIC, there are 3 main areas to be covered by the KPIs:

1. Climate.
2. Circularity.
3. Competitiveness.

A first draft for the **classification of the different KPIs** is proposed:

1. Energy Efficiency.
2. Material Efficiency.
3. Atmospheric Emissions.
4. Generated waste/by-products.
5. Final properties.
6. Competitiveness.

Every general classification has its own KPIs. A description of every KPI definition is enclosed below.

1. **Energy Efficiency**.

Energy efficiency is the capacity to obtain the best results in any activity using the least possible energy resources. It allows us to reduce the consumption of any energy and the potential environmental impacts associated with it. This applies from the generation of this energy to its final consumption. Energy efficiency is using less energy to perform the same task or produce the same result.

For the KPIs related to energy efficiency, the energy consumptions that can be measured have been defined, and within these, fuel consumption (furl/gases) and electricity consumption, obtaining each separately and finally the sum of both to obtain the overall efficiency. To make them comparable, the same unit of measurement has been defined, kWh consumed per tonne of molten metal, and they refer to the complete cell for obtaining injected castings, including the melting furnace and the injection cell. We analyze each of the 3 KPIs defined below:

- **KP1: Direct specific energy consumption** (fuels/gases) [kWh/tmetal]:

The specific thermal energy consumption is due to the contribution of solid (Biochart, carbon…), liquid fuels (diesel, fuel oil, petrol...), and gaseous fuels (N.G., H2...). The specific thermal energy consumption is calculated as the sum of the total energy contributed by each fuel/gas and refers to the unit of a tonne of metal processed.

$$\textit{Specific thermal energy consumption} = (\Sigma\, m_i * LHV_i) / t_{metal} \qquad \textbf{Equation 1}$$

Where:

m_i (kg) = quantity of every solid-liquid fuel/gas used (Biochart, diesel, NG, H2…).

LHV_i (kWh/kg) = lower heating value of the employed fuel.

t_{metal} = tonne of metal processed.

The calculation is made with the LHV value because it represents the lowest efficiency of thermal fuels. If accurate data is provided, the LHV value can be substituted by the real average heating value of every fuel.

- **KP2: Direct specific power consumption (electricity)** [kWh/tmetal]:

The total specific consumption of electrical energy that corresponds to all furnaces, transformation, and auxiliary equipment involved in the production process of a part.

- **KP3: Direct Direct total energy consumption** [kWh/tmetal]:

The total consumption of electrical energy that corresponds to all furnaces, transformation, and auxiliary equipment involved in the production process of the final part. It corresponds to the sum of KP1 and KP2:

$$KP3 = KP1 + KP2 \qquad \textbf{Equation 2}$$

2. **Material Efficiency.**

Material efficiency is about getting the most value from the materials we use and reducing waste to achieve a sustainable future.

During the production of a die-cast part, it is necessary to start from a larger quantity of material, because losses occur, e.g. due to dross production or evaporation of certain elements. In the case of producing a part, the calculation includes the losses in melting, holding, and transforming the metal into an injected part.

The four defined KPI's are:

- **KPI4: Specific metallic charge materials** [kg/tmetal]:

The specific metallic charge materials account for the total weight of metallic charge materials (scraps, alloys, returns, alloying / modifying metallic elements, etc.) related to the metal output (the metal introduced into the injection machine).

- **KP5: Specific non-metallic charge materials** [kg/tmetal]:

The specific metallic charge materials account for the total weight of non-metallic charge materials (fluxes, slag formers, salts...) related to the metal output (the metal introduced into the injection machine).

- **KPI6: Specific gases** (m^3/tmetal):

The specific gases account for the total volume of gases ($N2$, Ar…) employed in the process (degasification, de-drossing…) related to the metal output (the metal introduced into the injection machine).

- **KPI7: Metallic yield** [kg/tmetal]:

The metallic yield is the ratio between the mass flow of inlet material and the mass flow of output material, related to the metal output (the metal introduced into the injection machine).

- **KPI8: Recyclability (2nd life) of employed materials** [%]:

The recyclability ratio is the total percentage of the material that can be recycled, avoiding landfilling. It includes metallic scraps, turnings, and drosses.

3. **Atmospheric Emissions**.

Atmospheric emission means the release of pollutants into the air, which may result from various activities such as power generation, industry, and transport. These emissions contribute to air pollution and can have harmful effects on human health and the environment.

In the case of HPDC, emissions cannot be only related with melting and holding operations, but also to the emissions in the casting cellule. The results in this case are obtained from the focus of the melting and holding furnace, as it's the one where most of the emissions are generated.

- **KPI9: Direct CO2 emissions** [kg/tmetal]:

The Direct CO2 emissions are related to the specific scope 1 CO2 emissions of the processes referred to the unit of a tonne of metal processed.

- **KPI10: Direct NOx emissions** [mg/MWh]:

The Direct NOX emissions are related to the measured emissions of the processes expressed in mg/MWh. This unity has been selected by the consortium because it allows comparing the obtained values from different combustions systems in the same unities.

- **KPI11: Carbon monoxide (CO) emissions** [ppm]:

The Carbon monoxide emissions are related to the measured emissions of the processes expressed in ppm.

- **KPI12: Oxygen (O2) emissions** [ppm]:

The Oxygen emissions are related to the measured emissions of the processes expressed in ppm.

- **KPI13: Gases produced in the process: Decomposing non wetting additives in refractories, organics, …** [ppm]:

The Gases produced in the process are related to the measured emissions of the processes expressed in ppm.

4. **Generated waste/by-products**.

The high-pressure die-casting process produces different wastes and by-products. These can be solid or liquid. The waste and by-products cannot be used directly in the high-pressure die-casting process, so they are sent to recyclers or authorized waste managers.

Among the main by-products are those that can be recycled and recovered, such as slag or refractories, from which new metal or new refractories can be obtained.

Depending on the facility, there are several different types of furnaces, fluxes, and salts, so final waste and by-products can vary slightly between different enterprises.

- **KPI14: Specific white dross production** [kg/tmetal]:

The specific white dross production is related to the metal output (the metal introduced into the injection machine). White dross involves the dross produced in the melting and holding furnace, the degassing unit, and the machine furnace.

- **KPI15: Specific black dross production** [kg/tmetal]:

The specific black dross production is related to the metal output (the metal introduced into the injection machine). Black dross involves the dross produced in the melting processing of aluminium with rotary furnaces that employ salts, especially for recovering complex aluminium drosses or scraps.

- **KPI16: Specific dust production** [kg/tmetal]:

The specific dust production is related to the metal output (the metal introduced into the injection machine). The dust is generated principally during the melting operation and collected in bags from the filter.

- **KPI17: Specific scrap/returns/swirls production** [kg/tmetal]:

The specific scrap/returns/swirls production is related to the metal output (the metal introduced into the injection machine).

In any injection, there is a part of it that cannot be used as the final part and generates an internal scrap (returns) that is consumed internally. A mixture of about 70% ingot / 30% returns is employed at 2a. In parallel, some parts are discarded because their quality is not good enough (scrap). They can be the first parts of a series or parts with defects.

Some parts are machined to obtain the final dimensions. In this machining process, swirls are produced.

- **KPI18: Specific refractory waste production** [kg/tmetal]:

The specific refractory waste production is related to the metal output (the metal introduced into the injection machine).

The furnaces and ladles are covered with different refractories that must be replaced once consumed.

- **KPI19: Total specific solid waste production** [kg/tmetal]:

The specific solid waste production is related to the metal output (the metal introduced into the injection machine). It’s calculated as the sum of generated solid waste. In this case, it would be the sum of all the KPIs from KPI14 to KPI19, plus the rest of the solid waste (normally, they are few negligible compared to the rest, so they are omitted).

$$KP19 = KP14 + KP15 + KPI16 + KPI17 + KPI18 \qquad \textbf{\textit{Equation 3}}$$

- **KPI20: Total specific liquid waste production** [m^3/tmetal]:

The specific liquid waste production is related to the metal output (the metal introduced into the injection machine).

It covers principally the spent glycol water and the spent spraying lubing+water liquid.

5. **Final properties**.

The products produced must meet a series of requirements agreed with the customers. Different properties are controlled and registered depending on the customer and the final product and application.

This KPI includes all the requirements that assure that one injected part complies with the required quality.

Dimensional measures, the percentage of internal porosity, external and internal dimension defects, and microstructural and mechanical properties can be included in this KPI.

The selected characteristics are defined below with their measurement units/standards.

- **KPI21: Microstructural and physical properties** (H2 percentage – Density Index (DI), internal porosity, Quality index, mechanical properties, Y.S. (MPa), UTS (MPa); E (%)), corrosion…):

Some of the main properties are described below:

- Internal porosity[1]: Based on ASTM E 505 standard, different grades of porosity are defined for a specific part in other areas, depending on the functionality of the part. In 2a, the most employed value is a requirement of the porosity Level of 2 &3.
- Density index: The density index correlates with the density of a sample measured in air and water, and after degassing its value must be <1, being a value of the total gas (H2) trapped in the aluminium sample.
- Mechanical properties[2]: Based on EN 1706:2020 (E) standard, minimum Y.S. (MPa), UTS (MPa); E (%) values are defined for a defined alloy. In the case of the EN-AC 46000 alloy, Y.S. (MPa) > 140, UTS (MPa) >240; E (%)>1 are the established limits.

[1] ASTM E 505 standard.

[2] Alloy EN-AC 46000. EN 1706:2020 (E) standard.

6. **Competitiveness**.

A competitive economy is an economy whose sustained rate of productivity can drive growth and, consequently, income and welfare. Economic competitiveness has long been one of the key political priorities of the European Union (EU).

The definition of the KPIs allow to measure competitiveness and its effect on employment, exports and the companies that bet on it. Improved competitiveness will enable companies to improve their products/processes and compete in an increasingly complex market.

The KPIs defined are mainly based on the competitiveness KPIs developed by the Basque Government (Spain), as they are broader than those currently used in general and can be employed to compare with other developments.

- **KPI22: Significant new products or substantially improved existing products as a result of the project.**

This KPI Includes all products directly linked to the European Commission-funded projects as developed foreground, further developments of technologies, clustering, and standardization.

- **KPI23: Significant new processes or substantially improved existing processes as a result of the project.**

This KPI includes all processes directly linked to the European Commission-funded projects as developed foreground, further developments of technologies, clustering, and standardization.

All elements directly related to the project and knowledge gained outside the project's scope that is linked to the project results should be included.

In addition, added value activities such as further technology development, standardization, and partnership shall be included.

- **KPI24: Number of new companies created about the project's results.**

The KPI includes the number of new companies created because of the project's development.

- **KPI25: Expected number of patents derived from the project's activities**:

The KPI includes the number of patents derived from the activities developed in the project.

- **KPI26: Expected number of registered Intellectual Property (trademarks, industrial models, copyrights, etc.) derived from the project's activities.**

The KPI includes the expected number of registered intellectual property derived from the activities developed in the project.

- **<u>KPI27: Number of new jobs and job profiles [#]. Includes new skills identified by the project and new job profiles created.</u>**

The KPI includes the number of new jobs and job profiles. It includes new skills identified by the project and new job profiles created by its development.

The KPI includes the new competencies needed to realize the innovation to be developed in the project and the new job profiles required to develop the project.

The new job must be different from the current job in terms of jobs to be developed, tasks, and competencies.

- **<u>KPI28: CAPEX and OPEX reduction through the innovations [€].</u>** Monitor CAPEX reduction per process (referring to BAT) compared to original CAPEX. Same for OPEX.

The determination of the reduction of CAPEX per process (referring to the best available technology) compared to the original CAPEX and OPEX due to the project's development.

- **<u>KPI29: Expected impact on exports because of the project.</u>** Indicate the annual increase in exports (in M€).

The KPI includes the expected impact on exports because of the project. It consists of the annual increase in exports (in M€) created by the project's development.

The tables below show the defined KPIs and the obtained values:

Energy Efficiency	
KPI1: Direct specific energy consumption (Solid-liquid fuels/gases) [kWh/tmetal][3] The specific thermal energy consumption due to the combustion of fuels/gases.	189,9
KPI2: Direct specific power consumption (electricity) [kWh/tmetal] * The specific electric energy consumption for all equipment and auxiliaries involved in the process.	142,9
KPI3: Direct total energy consumption [kWh/tmetal] * The total specific energy consumption defined by KPI3 = KPI1 + KPI2	2.301

Material Efficiency	
KPI4: Specific metallic charge materials [kg/tmetal] Total weight of metallic charge materials (scraps, alloys, returns, alloying / modifying metallic elements, etc.) to the metal output.	3,8
KPI5: Specific non-metallic charge materials [kg/tmetal] Total weight of non-metallic charge materials (carbon, slag formers, salts, etc.) to the metal output.	7,3
KPI6: Specific gases (m3/tmetal). Total m3 of employed gases (metal treatment…) to metal output.	0,1
KPI7: Metallic yield [kg/tmetal] Ratio between the mass flow of inlet material and the mass flow of output material.	96,2
KPI8: Recyclability (2nd life) of employed materials (%): The percentage of recyclability of generated solid and liquid residues (metal returns, drosses, refractories, water…)	99,0

Atmospheric Emissions	
KPI9: Direct CO2 emissions [kg/tmetal] The specific scope 1 CO2 emissions of the processes	577
KPI10: Direct NOx emissions [mg/MWh] The specific NOx emissions of the processes.	18,7
KPI11: Carbon monoxide (CO) emissions [ppm]. Indicator for combustion efficiency for furnaces using natural gas[4].	2,8

[3] "kWh" refers energy input from fuel, based on the net calorific value at 15 °C /15 °C, 1 atm (ISO standard). "tmetal" refers to the metal fit for sale or use in the industry.
[4] From Foundry BATs.

KPI12: Oxygen (O2) emissions [ppm]. Indicator for combustion efficiency for furnaces using oxy-combustion*.	N.A.
KPI13: Gases produced in the process: Decomposing non-wetting additives in refractories, organics, …[ppm)	8,8

Generated waste/by-products	
KPI14: Specific white dross production [kg/tmetal]	28
KPI15: Specific black dross production [kg/tmetal]	N.A.
KPI16: Specific dust production [kg/tmetal]	0,024
KPI17: Specific scrap / returns / swirls production [kg/tmetal]	6,3
KPI18: Specific refractory waste production [kg/tmetal]	0,78
KPI19: Total specific solid waste production [kg/tmetal]	3,43
KPI20: Total specific liquid waste production [m3/tmetal], including oil, glycol water, lubing agents, spent lubing water…	0,47

Quality / Properties	
KPI21: Microstructural and physical properties (H2 percentage– Density Index (DI), internal porosity[5], Quality index, mechanical properties[6], Y.S. (MPa), UTS (MPa); E (%)), corrosion…	DI after degassing: 0.8 Porosity Level: 2 &3 UTS: 141 Mpa YS: 272 Mpa E: 5.1%

[5] ASTM E 505 standard.

[6] Alloy EN-AC 46000. EN 1706:2020 (E) standard.

Competitiveness	
KPI22: Significant new products or substantially improved existing products as a result of the project [#] Includes all products directly linked to the European Commission-funded projects as developed foreground, further developments of technologies, clustering, and standardization.	1
KPI23: Significant new processes or substantially improved existing processes as a result of the project [#] Includes all processes directly linked to the European Commission-funded projects as developed foreground, further developments of technologies, clustering, and standardization.	1
KPI24: Number of new companies created in relation to the project's results.	0
KPI25: Expected number of patents derived from the project's activities.	2
KPI26: Expected number of registered Intellectual Property (trademarks, industrial models, copyrights, etc.) derived from the project's activities.	0
KPI27: Number of new jobs and job profiles [#]. Includes new skills identified by the project and new job profiles created.	10
KPI28: CAPEX and OPEX reduction through the new innovations [€] Monitor CAPEX reduction per process (referring to BAT) compared to original CAPEX. Same for OPEX.	N.A.
KPI29: Expected impact on exports because of the project. Indicate the annual increase in exports (in M€)	5

3. Requirements and systems specifications of HTAIs

To pave the way for future replication of the H2AL concept in other HTAIs and to systematically assess the replication potential and impacts of our approach in other HTAIs, an analysis of the requirements specifications of heat production systems in other HTAIs. Contacts with other consortia from sister projects targeting other HTA beyond the aluminium were instrumental in identifying these requirements.

An event has been prepared on the 31st of October in Linz (Austria) during the ESTEP Annual Conference, which will be held from the 29th to the 31st of October to **join sister projects** (HyInHeat, H2Glass, HyTecHeat, GreenHeatEAF, TWINGHY, HyDreams, and H2AL). All the projects will focus on demonstrators, NOx emissions, the use of digital tools, and KPIs.

3.1 Requirements and systems specifications of HTAs

Hard-To-Abate (HTA) industries are carbon-intensive industries with few clear, viable low-emission alternatives, such as road freight, steel and cement making, chemicals, aviation, and deep-sea shipping, and account for roughly one-third of global CO_2 emissions. Far from distracting society from ongoing climate action, the pandemic coincided with a rapid escalation of pressure on multiple fronts, as appointed by Deloitte [2]. The main factors from the analysis are listed below:

• **Financiers and investors are increasingly demanding companies address emissions**. Influence is being applied by individual investors, some of whom are taking on activist roles and pushing for stronger climate action, and investor-led initiatives which are rapidly growing both in size and influence. Climate Action 100+, an investor-led initiative to act on climate change, has enlisted in 2023 more than 700 investors, engaged across 33 markets and representing more than half of all global assets under management [3]. More than 170 focus companies signed a pledge with the Net Zero Investors Initiative, which was formed in December 2020; signatories have committed to supporting the goal of net-zero greenhouse gas emissions by 2050 or sooner and include some of the world's largest asset managers with approximately $68 trillion in assets managed by investors participating in the initiative. Hard-to-abate industries are not exempt. • **Popular sentiment appears to have shifted**. 53% of the 73,000 people surveyed in 77 countries, representing 87 percent of the world's population globally surveyed by the UN Development Program in 2024, indicated that climate change was a "global emergency" [4]. That rising concern extends to consumers. In one recent study, more than 60% of respondents said that "companies have the opportunity, due to the pandemic, to be more thoughtful about how they incorporate sustainability into their business models moving forward [4].

• **Activist pressure seems to be mounting**, primarily led by the youth climate movement. The climate strikes in 2019 and 2020, attended by millions, helped push the issue higher on the global agenda [6], and other highly visible actions from various groups have captured global attention and galvanized many opinions.

- **Employees are an increasingly vocal and expectant stakeholder group across all geographies** [7]. While workforce activism appears more noticeable for some sectors, such as technology, it seems to expand across the board [8]. Nearly 40% of millennials cite employer sustainability as a factor in deciding where to work; a recent Gallup survey shows that seven in US job seekers care at least somewhat about a potential employer's environmental record [9].

- **The regulatory environment is growing more stringent**. Emissions requirements, clean energy standards, carbon pricing, border adjustments, and more are becoming increasingly commonplace, not only in Europe but in major markets in Asia and North America [10]-[12]. Climate reporting and disclosure is also evolving quickly, with efforts underway to rationalize different standards and create an authoritative standard-setting body under the umbrella of the IFRS Foundation[13]-[14].

3.2 Contacts with other consortia

A direct contact has been established with the European project HYINHEAT. A comparison between both project's KPIs has been performed. The latter is shown in the following tables.

H2AL	HYINHEAT
Energy Efficiency	
KPI1: Direct specific energy consumption (solid-liquid fuels/gases) [kWh/tmetal]* The specific thermal energy consumption due to the combustion of fuels/gases.	KPI1: Direct specific energy consumption (fuels) [kWh/tmetal] The specific thermal energy consumption due to the combustion of fuels.
KPI2: Direct specific power consumption (electricity) [kWh/tmetal]* The specific electric energy consumption for all equipment and auxiliaries involved in the process.	KPI2: Direct specific power consumption (electricity) [kWh/tmetal] The specific electric energy consumption for all equipment and auxiliaries involved in the process.
KPI3: Direct total energy consumption [kWh/tmetal]* The total specific energy consumption defined by KPI3 = KPI1 + KPI2	KPI3: Direct total energy consumption [kWh/tmetal] The total specific energy consumption defined by KPI3 = KPI1 + KPI2

H2AL	HYINHEAT
Material Efficiency	
KPI4: Specific metallic charge materials [kg/tmetal]* Total weight of metallic charge materials (scraps, alloys, returns, alloying / modifying metallic elements, etc.) to the metal output.	KPI6: Specific metallic charge materials [kg/tmetal] Total weight of metallic charge materials (scraps, alloys, wire materials, etc.) in relation to the metal output.
KPI5: Specific non-metallic charge materials [kg/tmetal]	KPI7: Specific non-metallic charge materials [kg/tmetal]

Total weight of non-metallic charge materials (slag formers, salts, etc.) to the metal output.	Total weight of non-metallic charge materials (carbon, slag formers, salts, etc.) in relation to the metal output.
KPI6: Specific gases (m3/tmetal). Total m3 of employed gases (metal treatment…) to metal output.	
KPI7: Metallic yield [kg/tmetal] Ratio between the mass flow of inlet material and the mass flow of output material.	KPI8: Metallic yield [kg/tmetal] Ratio between the mass flow of inlet material and the mass flow of output material.
KPI8: Recyclability (2nd life) of employed materials (%): The percentage of recyclability of generated solid and liquid residues (metal returns, drosses, refractories, water…)	

H2AL	HYINHEAT
Atmospheric Emissions	
KPI9: Direct CO2 emissions [kg/tmetal] The specific scope 1 CO2 emissions of the processes	KPI4: Direct CO2 emissions [kg/tmetal] The specific scope 1 CO2 emissions of the processes
KPI10: Direct NOx emissions [mg/kWh] The specific NOx emissions of the processes.	KPI5: Direct NOx emissions [kg/tmetal] The specific NOx emissions of the processes.
KPI11: Carbon monoxide (CO) emissions [ppm]. Indicator for combustion efficiency for furnaces using natural gas*.	
KPI12: Oxygen (O2) emissions [ppm] .Indicator for combustion efficiency for furnaces using oxy-combustion*.	
KPI13: Gases produced in the process: Decomposing non-wetting additives in refractories, organics, …[ppm]	

H2Al	HYINHEAT
Generated waste / by-products.	
KPI14: Specific white dross production [kg/tmetal]	KPI9: Specific slag production [kg/tmetal]
KPI15: Specific black dross production [kg/tmetal]	KPI10: Specific scale production [kg/tmetal]
KPI16: Specific dust production [kg/tmetal]	KPI11: Specific dust production [kg/tmetal]
KPI17: Specific scrap / returns / swirls production [kg/tmetal]	KPI12: Specific scrap production [kg/tmetal]
KPI18: Specific refractory waste production [kg/tmetal]	KPI13: Specific refractory waste production [kg/tmetal]
KPI19: Total specific solid waste production [kg/tmetal]	KPI14: Total specific solid waste production [kg/tmetal]
KPI20: Total specific liquid waste production [m3/tmetal], including oil, glycol water, lubing agents, spent lubing water…	

H2Al	HYINHEAT
Quality / Properties	
KPI21: Microstructural and physical properties (H2 percentage – Density Index (DI), internal porosity[7], Quality index, mechanical properties[8], Y.S. (MPa), UTS (MPa); E (%)), corrosion…	

[7] ASTM E 505 standard.
[8] Alloy EN-AC 46000. EN 1706:2020 (E) standard.

H2AI	HYINHEAT
Competitiveness	
KPI22: Significant new products or substantially improved existing products as a result of the project [#] Includes all products directly linked to the European commission funded projects as developed foreground, further developments of technologies, clustering and standardization.	KPI15: Significant innovations developed [#] Includes all items directly linked to the P4P projects as developed foreground, further developments of technologies, clustering and standardization.
KPI23: Significant new processes or substantially improved existing processes as a result of the project [#] Includes all processes directly linked to the European commission funded projects as developed foreground, further developments of technologies, clustering and standardization.	
KPI24: Number of new companies created in relation to the project's results.	
KPI25: Expected number of patents derived from the project's activities.	
KPI26: Expected number of registered Intellectual Property (trademarks, industrial models, copyrights, etc.) derived from the project's activities.	
KPI27: Number of new jobs and job profiles [#] Includes new skills identified by the project and new job profiles created.	KPI17: Number of new jobs and job profiles [#] Includes new skills identified by the HYINHEAT project and new job profiles created.
KPI28: CAPEX and OPEX reduction through the new innovations [€] Monitor CAPEX reduction per process (referring to BAT) compared to original CAPEX. Same for OPEX.	KPI20: CAPEX and OPEX reduction through the new innovations [€] Monitor CAPEX reduction per process (referring to BAT) compared to original CAPEX. Same for OPEX.
KPI29:Expected impact on exports because of the project. Indicate the annual increase in exports (in M€)	

Acknowledgments

The project is supported by the Clean Hydrogen Partnership and its members.

Disclaimer

Co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or Clean Hydrogen JU. Neither the European Union nor the granting authority can be held responsible for them.

4. Bibliography

The employed bibliography is listed below.

[1] A robust and harmonized framework for reporting and monitoring European Partnerships in Horizon Europe, 2021, RTD, https://europa.eu/!b3TBfW.

[2] https://www.deloitte.com/an/en/our-thinking/insights/topics/business-strategy-growth/industrial-decarbonization-hard-to-abate-sectors.html

[3] https://www.climateaction100.org/about/. Accessed June 2024.

[4] https://www.undp.org/publications/peoples-climate-vote-2024. Accessed June 2024.

[5] Porter Novelli, "PN purpose tracker: COVID-19 & climate special edition," July 2020.

[6] Dana R. Fisher and Sohana Nasrin, "Climate activism and its effects," WIREs Climate Change, September 21, 2020.

[7] Herbert Smith Freehills, "Future of work: Adapting to the democratised workplace," November 25, 2019.

[8] Louise Matsakis, "Thousands of tech workers join global climate change strike," Wired, September 9, 2019.

[9] Adele Peters, "Most millennials would take a pay cut to work at an environmentally responsible company," Fast Company, February 14, 2019.

[10] Michela Coppola et al., Facing the heat: The economic implications of climate change, Deloitte Insights, February 26, 2021;

[11] Michael Wolf, Giving green a chance: Climate change mitigation will alter global trade, Deloitte Insights, April 15, 2021;

[12] Environmental Defense Fund, "China carbon pricing newsletter," August 3, 2021.

[13] World Economic Forum, Measuring stakeholder capitalism: Towards common metrics and consistent reporting of sustainable value creation, September 2020;

[14] IFRS, "IFRS Foundation trustees announce working group to accelerate convergence in global sustainability reporting standards focused on enterprise value," March 22, 2021.

5. Annex

Enclosed there are some of the technical information related to the project. employed bibliography is listed below.

5.1 Refractories

- Seven Cast 59. Andalusite based low cement castable.

Seven REFRACTORIES

Data Sheet
Seven Cast 59 ND

General information

Type of product	**Low Cement Castable**
Type of bond	**Hydraulic**
Maximum recommended temperature	**1600°C**
Main raw material	**Andalusite**
Material required (kg/m3)	**2500**
Maximum grain size (mm)	**6**
Water required for installation	**5-7%**
Installation method	**Vibrating casting**

Chemical properties according to EN ISO 1927-3, EN ISO 21068-2	Typical (%)	Limit (%)
Al2O3	**59,2**	**min 56,2**
Fe2O3	**1,1**	**max 1,4**
CaO	**2,3**	**min 1,9**
SiO2	**35,0**	**max 37**

Physical properties according to EN ISO 1927-5, 1927-6, 1927-8

	110 °C	800 °C	1200 °C	1600 °C
Bulk density (g/cm3)	2,50	2,45	2,40	
Cold Crushing strength (MPa)	75	80	60	
Apparent Porosity (%)		19	21	
Perm. Linear Change (%)	-0,15	-0,05	-0,10	
Thermal Cond. (W/mK)		1,78	1,85	
Reversible thermal expansion at 1000°C (%)		EN 993-19		0,65
Abrasion after firing at 815°C (cm3)		ISO 16282/ASTM C704		<10

Other properties

Packaging	**Paper bags or Big bags**
State of delivery	**Dry**
Shelf life (storage in dry conditions)	**6 months**
Installation guideline / Heating-up curve	**IG 02A / HC 01-02**

- Seven Cast 80. Bauxite based low cement castable.

Seven REFRACTORIES

Data Sheet
Seven Cast 80 NX

General information	
Type of product	**Low Cement Castable**
Type of bond	**Hydraulic**
Maximum recommended temperature	**1650°C**
Main raw material	**Bauxite**
Material required (kg/m3)	**2900**
Maximum grain size (mm)	**6**
Water required for installation	**4,5-5,5%**
Installation method	**Vibrating casting**

Chemical properties according to EN ISO 1927-3, EN ISO 21068-2	Typical (%)	Limit (%)
Al2O3	**80,6**	**min 78,6**
Fe2O3	**1,4**	**max 1,7**
CaO	**2,4**	**min 2**
SiO2	**11,6**	**max 13,6**

Physical properties according to EN ISO 1927-5, 1927-6, 1927-8	110 °C	800 °C	1200 °C	1600 °C
Bulk density (g/cm3)	2,90	2,83	2,81	2,75
Cold Crushing strength (MPa)	120	120	160	100
Apparent Porosity (%)		16	17	
Perm. Linear Change (%)	-0,15	-0,20	-0,20	0,40
Thermal Cond. (W/mK)		2,58	2,35	
Reversible thermal expansion at 1000°C (%)		EN 993-19		0,74
Abrasion after firing at 815°C (cm3)		ISO 16282/ASTM C704		<5

Other properties	
Packaging	**Paper bags or Big bags**
State of delivery	**Dry**
Shelf life (storage in dry conditions)	**6 months**
Installation guideline / Heating-up curve	**IG 02A / HC 01-02**

- Seven Cast A 84. Bauxite based low cement castable.

Data Sheet
Seven Cast A 84 NX

General information	
Type of product	**Low Cement Castable**
Type of bond	**Hydraulic**
Maximum recommended temperature	**1300°C**
Main raw material	**Bauxite**
Material required (kg/m3)	**2950**
Maximum grain size (mm)	**6**
Water required for installation	**4,0-4,5%**
Installation method	**Vibrating casting**

Chemical properties according to EN ISO 1927-3, EN ISO 21068-2	Typical (%)	Limit (%)
Al_2O_3	**80,1**	**min 78,1**
Fe_2O_3	**1,0**	**max 1,3**
CaO	**2,6**	**min 2,2**
SiO_2	**8,3**	**max 10,3**
BaO	**3,4**	**min 2,4**

Physical properties according to EN ISO 1927-5, 1927-6, 1927-8

	110 °C	800 °C	1200 °C	1600 °C
Bulk density (g/cm3)	2,98	2,94	2,95	
Cold Crushing strength (MPa)	145	180	180	
Apparent Porosity (%)		18	20	
Perm. Linear Change (%)	-0,05	-0,30	-0,20	
Thermal Cond. (W/mK)		2,68	2,73	
Reversible thermal expansion at 1000°C (%)		EN 993-19		0,74
Abrasion after firing at 815°C (cm3)		ISO 16282/ASTM C704		<6

Other properties	
Packaging	**Paper bags or Big bags**
State of delivery	**Dry**
Shelf life (storage in dry conditions)	**6 months**
Installation guideline / Heating-up curve	**IG 02A / HC 09-02**

- Seven Gun A 73. Bauxite gunning Material.

Seven REFRACTORIES

Data Sheet
Seven Gun A 73 RX

General information		
Type of product		**Gunning Material**
Type of bond		**Hydraulic**
Maximum recommended temperature		**1400°C**
Main raw material		**Bauxite**
Material required (kg/m3)	**Excluding rebound**	**2700**
Maximum grain size (mm)		**6**
Water required for installation		**Adjusted at the nozzle**
Installation method		**Gunning**

Chemical properties according to EN ISO 1927-3, EN ISO 21068-2	Typical (%)	Limit (%)
Al_2O_3	**70,8**	**min 68,8**
Fe_2O_3	**1,4**	**max 1,7**
CaO	**6,0**	**min 5,6**
SiO_2	**6,0**	**max 8**
BaO	**8,5**	**min 7,5**

Physical properties according to EN ISO 1927-5, 1927-6, 1927-8

	110 °C	800 °C	1200 °C	1600 °C
Bulk density (g/cm3)	2,50	2,52	2,40	
Cold Crushing strength (MPa)	60	75	60	
Apparent Porosity (%)		28	32	
Perm. Linear Change (%)	-0,05	-0,15	-0,40	
Thermal Cond. (W/mK)		1,19		
Reversible thermal expansion at 1000°C (%)		EN 993-19		0,72
Abrasion after firing at 815°C (cm3)		ISO 16282/ASTM C704		<20

Other properties	
Packaging	**Paper bags or Big bags**
State of delivery	**Dry**
Shelf life (storage in dry conditions)	**12 months**
Installation guideline / Heating-up curve	**IG 04A / HC 09-03**

5.2 Quality

5.2.1 Metal quality

The cleaning of the material is analyzed by the V-melt test. In Table 2 we have the limits to have a material under the specifications,

Table 2:V-melt test acceptation limits

Quality metal molten		
Total number of features	**Nº. feature/100 mm^2**	**< 1000**
Total Pores 15-30 µm	Nº. pores/100 mm^2	20
Total Pores 30-75 µm	Nº. pores/100 mm^2	5
Total Pores > 75 µm	Nº. pores/100 mm^2	0
Total Aluminium Oxides 15-30 µm	Nº. Al2O3/100 mm^2	10
Total Aluminium Oxides 30-75 µm	Nº. Al2O3/100 mm^2	2
Total Aluminium Oxides > 75 µm	Nº. Al2O3/100 mm^2	0
Total other Inclusions 15-30 µm	Nº. inclusions/100 mm^2	10
Total other Inclusions 30-75 µm	Nº. inclusions/100 mm^2	2
Total other Inclusions > 75 µm	Nº. inclusions/100 mm^2	0

In Table 3 and Table 4 we can observe the obtained values to determine the quality of the injected aluminium:

Table 3:Analysis of total pores, oxides, and inclusions

Total Features	2686	1898
Area Analyzed (mm²)	100	100
Total Pores	**1697**	**1075**
0.5 – 15 µm	1620	1068
15 – 30 µm	59	7
30 – 75 µm	15	0
> 75 µm	3	0
Total Aluminum Oxides	**887**	**507**
0.5 – 15 µm	820	504
15 – 30 µm	40	3
30 – 75 µm	27	0
> 75 µm	0	0
Total Other Inclusions	**102**	**316**
0.5 – 15 µm	97	300
15 – 30 µm	5	15
30 – 75 µm	0	1
> 75 µm	0	0

Table 4:V-melt test nowadays values

Vmet results – A319TO

	Ladle 3 A319TO	Ladle 3 A319TO		Ladle 4 A319TO	Ladle 4 A319TO	
	As melted	**After MTS 1500**	**% removal**	**As melted**	**After MTS 1500**	**% removal**
Sample	7	8		9	10	
Inclusion Index	559.4	55.1	90%	270.2	68.3	75%
Total Features	5265	2951	44%	4200	2309	45%
0.50 – 2.50 µm	927	796	14%	749	623	17%
2.50 – 5.00 µm	1832	1449	21%	1690	1076	36%
5.00 – 15.0 µm	1895	695	63%	1524	566	63%
15.0 – 30.0 µm	473	11	98%	188	36	81%
30.0 – 75.0 µm	137	0	100%	49	8	84%
> 75.0 µm	1	0	100%	0	0	
Pore	2513	1037	59%	1714	892	48%
Al oxides	1986	1378	31%	1772	907	49%
Cluster Count	275	223	19%	272	149	45%

5.2.2Density Index

The density index (DI) has been calculated before and after degassing. We can observe in Table 5 the obtained values:

Table 5: Density index values

	TEMP [°C]	Alloy AlSi9Cu3(Fe)	Density (air)	Density (vacuum)	DI
Holding F 3200	668	46000	2,707	2,5861	4,47
Crucible - pre deg 1	705	46000	2,6977	2,399	11,07
Crucible - post deg 2	660	46000	2,7068	2,6944	0,46
Crucible - pre deg	**704**	**46000**	**2,6959**	**2,5044**	**7,10**
Crucible - post deg	**650**	**46000**	**2,7075**	**2,6872**	**0,75**
Holding F 3200	**669**	**46000**	**2,7093**	**2,6886**	**0,76**
Crucible - pre deg	**727**	**46000**	**2,6812**	**2,474**	**7,73**
Crucible - post deg	**701**	**46000**	**2,701**	**2,6935**	**0,28**
Holding F 3200	**675**	**46000**	**2,703**	**2,6831**	**0,74**

5.2.3Mechanical properties

The alloy composition and the minimum mechanical properties are obtained from the EN 1706:2020 (E) standard.

For the EN-AC-46000 alloy, the minimum mechanical requirements are listed in Table 6:

Table 6: Mechanical properties

Property	Value	Units
Yield Strength	140	MPa
Ultimate Tensile Strength	240	MPa
Elongation	1	%

5.2.4Porosity

The porosity level inside the injected part is controlled with the Reference Radiographs for inspection of Al die casting defined in the ASTM E505 standard. We can observe Figure 15 as an example.

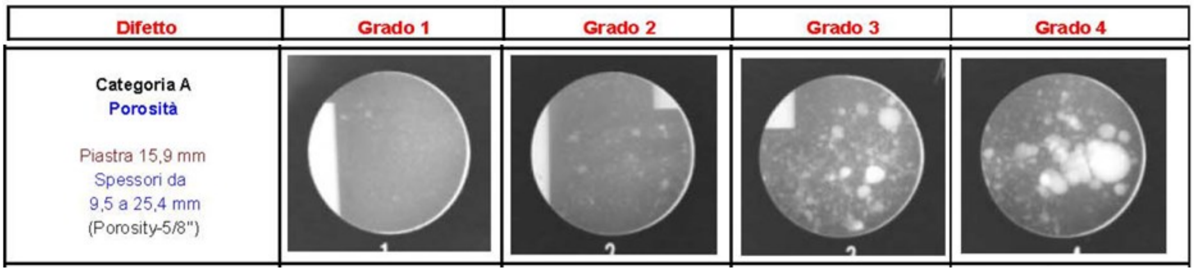

Figure 15: Porosity levels example from ASTM E505 standard.

The part presents diverse areas where the porosity must be controlled by RX and the level of 2-3 defined by the customer.