D8.4 Potential of retrofitting and developed analysis technologies for cross-sectorial usage

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HYINHEAT

Credits

Disclaimer

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Contents

Tables

Figures

List of abbreviations

Abbreviations	Explanation
CEMS	Continuous Emission Monitoring System
CO_2	Carbon dioxide
EHS	Endress+Hauser SICK
EII	Energy Intensive Industry
ER	Exploitable Result
H_2	Hydrogen
IP	Intellectual Property
KER	Key Exploitable Result
ML-MFA	Multi Level Material Flow Analysis
NG	Natural Gas
NOx	Nitrogen oxides
O_2	Oxygen
OEC	Oxygen Enriched Combustion
OEM	Original Equipment Manufacturer
OES	Optical Emission Spectroscopic
SIL	Safety Integrity Level
TRL	Technology Readiness Level

Executive Summary

This deliverable presents the work conducted in *Task 8.3: Potential of retrofitting and greenfield solutions for cross-sectorial implementation*, part of *Work Package 8 (WP8): Communication, Policy, and Exploitation* of the HyInHeat project.

The objective of Task 8.3 is to assess the potential for tentatively implementing the project's Key Exploitable Results (KERs) in sectors beyond those directly addressed by HyInHeat, focusing both on retrofitting opportunities and greenfield applications in other Energy Intensive Industries (EIIs).

Task 8.3 work builds on the results identified, which provided the basis for selecting the KERs analysed in this deliverable. The evaluation has been carried out through input from KER owners and with the support of the European Commission's Booster Service, assessing technical boundary conditions, potential end-use sectors, and early exploitation pathways.

Managing intellectual property (IP) in a Horizon project is a complex and evolving task. While IP conditions are defined early on, often before results are fully known, it is essential to continuously refine and align IP management with emerging outcomes and exploitation interests. This deliverable contributes to that process by clarifying how key results may be transferred, what actors are involved, and how collaboration among partners can maximise long-term impact through coordinated exploitation.

The work behind these findings is presented throughout this document, structured in the following sections:

Section 1 – An overview of the project is provided, and the main objectives and context of the work are introduced.

Section 2 – The methods and approaches used to conduct the analysis are described. The concept of KER is explained, along with their relevance to the project. The analytical techniques applied during the study are detailed, and the scope and limitations of the analysis are outlined.

Section 3 – The potential for applying the project's results across different sectors is examined. The process for selecting the KERs to be analysed is described. The criteria used to assess their transferability are presented, and the relevant sectors for the evaluation of the KER are mapped.

Section 4 – The exploitation pathways of each KER are explored, and their potential applications in various sectors are highlighted.

Section 5 – Strategic aspects such as intellectual property, impact, and further analysis are discussed. An overview of the IP strategy is provided. The resources and capabilities required for the exploitation of the KERs are identified, and the environmental, technological, and economic impacts of the project's results are summarized.

Section 6 – The main findings and preliminary conclusions of the work are presented. Suggestions for further analysis and recommendations for future work are offered.

1. Introduction

The HyInHeat project aims to integrate hydrogen (H_2) as a fuel in industrial high-temperature heating processes, contributing to the decarbonisation of EIIs in Europe. The project brings together a multidisciplinary consortium of over 30 partners, including industrial companies, research institutions, and technology providers, with focus on steel and aluminium sectors.

To achieve its objectives, HyInHeat is developing and testing a wide range of technologies, including burners, control systems, sensors, measurement equipment and safety tools, across eight demonstrators located in both technical centres and industrial sites. These developments span different stages of technological maturity (TRLs), with the goal of validating their feasibility, efficiency, and scalability.

A set of KERs has been identified under Task 8.3. These are defined, in line with the European Commission's guidelines, as results with strong potential for exploitation, either commercially or through policy, further research, or training. In the context of HyInHeat, a KER is considered a result that can be commercially exploited as a stand-alone product, process or service.

Building on this initial work, Task 8.3 focuses on assessing the potential for transferring these KERs to other industrial sectors, beyond the original demonstrators, and for their integration into greenfield applications, that is, new installations where H_2-based solutions could be deployed from the design stage.

This analysis is essential to guide future exploitation efforts, inform the project's IP management, and ensure that the innovations developed within HyInHeat can maximise their impact across different industrial contexts.

2. Methodology

2.1. Understanding Key Exploitable Results (KERs)

According to the Horizon Europe framework, a result is defined as *any tangible or intangible output of the action, such as data, knowledge and information whatever their form or nature, whether or not they can be protected, which are generated in the action as well as any attached rights, including intellectual property rights.*

The European IP Helpdesk, a service of the European Commission, further defines a KER as *an identified main interesting result, which has been selected and prioritised due to its high potential to be "exploited" – meaning to make use and derive benefits – downstream the value chain of a product, process or solution, or act as an important input to policy, further research or education [https://www.horizonresultsbooster.eu/ServicePacks/Details/55].*

In the context of HyInHeat, a KER is understood as a significant and self-standing output that can be commercially exploited, either as a product, service, or process, independently from the demonstrator where it was initially tested.

This definition forms the basis for the identification and evaluation of the results addressed in this deliverable. Task 8.3 began by identifying and characterising the KERs, and continued by analysing their potential for replication and greenfield application in other sectors, building a foundation for their future exploitation and transferability.

2.2. Analytical Approach

Once the concept of KERs was introduced, a questionnaire was prepared by the Task 8.3 team and shared with the WP leaders, who had detailed knowledge of the developments within their respective areas. The purpose of this document was to collect structured information on the innovations emerging from the HyInHeat project. The questionnaire included the following fields:

- Potential KER Name:
- Brief description:
- What is included in the box?
- Innovation degree (High / Medium / Low):
- Development level at the final stage:
- Self-standing exploitation? (YES / NO):
- Commercial? (YES / NO):
- Market potential (High / Medium / Low):
- Lead partner:
- Partners involved:
- Information provided by (Name + Partner):

This structured input allowed for an initial screening of exploitable results (ERs) and helped identify which outputs had the potential to be considered KERs.

In a next step, this data was complemented by individual interviews with KER owners to:

- Clarify technical parameters.
- Identify boundary conditions for use in other sectors.
- Discuss realistic pathways for sectorial replication.

Each KER was then assessed against a set of sector-specific criteria, including terms like:

- Required process temperature and pressure.
- H_2 concentration and flow requirements.
- Safety and regulatory considerations.

To facilitate comparison, a traffic light classification system (green / amber / red) was applied to each KER per sector, reflecting its estimated level of transferability.

The analysis was further supported by the European Commission's Booster Service, which provided external guidance on:

- Market positioning.
- Maturity assessment.
- Business model development.
- Stakeholder and value chain mapping.

2.3. Scope and Limitations

This analysis reflects the status of the HyInHeat project at month 33 (September 2025). As several demonstrators are still under development or in early validation stages, the findings presented here are preliminary and qualitative.

Some evaluations are based on informed assumptions and early-stage feedback. Therefore, the traffic light classification and sectoral insights should be considered indicative rather than final.

This deliverable provides a baseline analysis to guide future exploitation efforts that will be developed in other tasks of WP8.

3. Cross-sectoral Transferability Analysis

3.1. Selection of Key Exploitable Results (KERs)

The potential KERs for each WP were identified through a structured questionnaire shared with the respective WP leaders (see Figure 1). This process was coordinated by the Task 8.3 team, with the aim of collecting consistent information across all project developments. After a series of follow-up meetings to discuss and validate the relevance of the identified outputs, a total of 10 ERs were compiled.

The responses received detailing the innovation level, development stage, market potential, and commercial applicability of each result served as the basis for the initial classification. These completed questionnaires are included in Annex 1 of this deliverable.

However, not all identified ERs meet the criteria to be classified as KERs. According to the internal definition adopted by HyInHeat and aligned with Horizon Europe guidelines, a KER is understood as a stand-alone, commercially exploitable output, such as a product, service, or process with clear market potential.

The project encompasses a wide range of developments, some of which are technological (e.g. equipment, devices), while others are methodological, scientific, or procedural. While all are relevant to the project's objectives, only those with direct commercial potential qualify as KERs.

In particular, three ERs were excluded from the KER list based on the responses to the "Commercial?" field in the questionnaire and the outcome of discussions with the corresponding WP leaders:

- ER 2 – Hydrogen combustion technology for walking beam furnaces.
  This demonstrator has value as a reference but is not intended for commercial deployment.
- ER 6 – Control parameters for H_2 combustion.
  The result consists mainly of process knowledge that cannot be exploited independently.
- ER 9 – ML-MFA methodology.
  This result is primarily scientific and intended for further research, not commercialisation.

As a result, seven KERs have been retained for the analysis in this deliverable:

Table 1. List of KERs of HyInHeat project.

KER	Title	Lead Partner
1	Hydrogen combustion burner for walking beam furnaces	SARRALLE
3	Flow meter and quality analyser	EHS
4	Calorimeter by spectroscopy	EHS
5	CEMS measurement devices for NOx in H_2 combustion	EHS
7	Ultrasonic flow meter for high-temperature off-gas	EHS
8	Optical emission spectroscopy for flame analysis	LUXMET
10	Safety training material	NTNU

These KERs form the basis for the transferability and greenfield implementation analysis presented in the following sections.

3.2. Evaluation Criteria

To assess the potential for replicating the KERs in other industrial sectors and in greenfield scenarios, a set of technical and operational criteria was defined. These criteria were derived from the information provided in the KER questionnaires, follow-up interviews with the KER owners, and expert input from the European Commission's Booster Service.

The aim of this assessment is not to quantify economic or market projections, but to establish the conditions of applicability and identify barriers or enablers that affect cross-sectoral transfer.

The evaluation criteria applied include:

- Operating temperature range
  Whether the KER is suitable for processes requiring medium to very high temperatures, typical of EIIs.
- Compatibility with hydrogen and gas composition
  Whether the KER is designed to work with H_2 or H_2-rich mixtures, including blends with NG and O_2.
- Safety and regulatory considerations
  Need for certification, regulatory approval, or adaptation to sector-specific standards and safety practices.
- Technology readiness and maturity (TRL)
  The stage of development and demonstrated performance of the KER in real or representative operational environments.

To facilitate comparison, a traffic light classification system was used to rate the level of transferability of each KER to each sector:

- Green: High potential for transfer with minimal or no adaptation.
- Amber: Transfer possible with moderate adaptation (technical, regulatory or operational).
- Red: Low or no transfer potential under current conditions.

This classification is qualitative and based on available information at month 33 of the project.

3.3. Sectoral Mapping

Many industrial sectors rely on fossil fuels such as NG, fuel oil or coal to achieve the high temperatures required in their core processes. These fuels are used in furnaces, boilers, and reactors to support operations such as melting, calcination, cracking, drying, or sterilisation. However, their widespread use contributes significantly to global CO_2 emissions and other pollutants, which are increasingly subject to regulatory constraints.

As part of their decarbonisation strategies, several sectors are exploring the substitution of fossil fuels with renewable electricity and low-carbon alternatives such as green H_2. Yet this transition is particularly complex for industries with continuous, high-temperature demands, due to technical, economic and operational challenges.

In this context, the KERs developed within HyInHeat, which have been designed for high-temperature H_2 combustion and associated measurement and safety technologies, have the potential to be transferred to other sectors facing similar constraints.

The following sectoral analysis identifies industries with comparable process characteristics where such replication or greenfield deployment could be feasible:

- Glass: Requires sustained temperatures of 1400–1600 °C in melting furnaces, primarily using NG. Its shift to H_2 is already under early testing in several pilot projects.
- Cement: Involves kilns operating over 1400 °C to produce clinker. It is one of the most CO_2-intensive industries and a strong candidate for H_2 substitution.
- Ceramics: Firing stages require 1000–1400 °C depending on the product. Though more fragmented, it has growing interest in clean heat technologies.
- Minerals: Includes calcination and smelting operations often exceeding 1000 °C. Sub-sectors such as lime and magnesia production are actively exploring alternatives to fossil fuels.
- Pulp and paper: Uses high temperatures in drying and chemical pulping stages. While not as heat-intensive as others, there is growing interest in renewable energy sources, including H_2.
- Refining: Strongly reliant on high-temperature units like crackers and reformers, typically operating above 400–600 °C. H_2 is already used as a feedstock, and H_2-based combustion could decarbonise utilities.
- Water: Though generally not heat-intensive, certain processes (e.g. sludge treatment, desalination) involve thermal energy needs. Relevance is limited but non-negligible.
- Chemicals: High-temperature processes such as steam cracking or reforming are widespread. As an early H_2 adopter, the sector is well positioned for applying KERs.
- Pharmaceuticals: Involves high temperatures for sterilisation, synthesis, and drying. It has strict regulatory requirements and medium thermal demand.
- Oil and gas: Besides extraction and transport, downstream facilities like petrochemical plants share process similarities with refining. H_2 integration is already being piloted.
- Food and beverages: Many processes involve heat (e.g. baking, drying, pasteurisation), but typically at lower temperature ranges. H_2 is relevant mainly for industrial-scale operations.

Further details on each sector's processes, temperature needs, and decarbonisation context are available in Annex 2.

4. KERS exploitation pathways and sectoral application potential

Building on the methodology presented in section 3 and the sectoral insights outlined in the previous analysis, this section explores potential exploitation pathways for each of the seven KERs identified in the HyInHeat project.

For each KER, a qualitative evaluation has been conducted to assess its applicability in different industrial contexts, considering factors such as technical compatibility, integration complexity, regulatory requirements, and commercial potential. The assessment combines internal project data gathered through questionnaires and expert validation, with market intelligence regarding decarbonisation trends and technological readiness across sectors.

The purpose of this section is to offer a structured and realistic perspective on the potential transferability of each KER beyond its initial demonstration context. It outlines relevant sectors for replication or greenfield adoption, examines key enabling conditions and potential barriers, and identifies possible stakeholders and exploitation pathways to support successful deployment.

The analysis is presented individually for each KER, using a common structure to facilitate comparison.

4.1. KER1: Hydrogen Combustion Burner Technology for Walking Beam Furnaces

4.1.1 General Description and Value Proposition

This KER consists of a H_2-ready burner developed for walking beam furnaces. Its main innovation lies in the ability to operate with two different fuels, such as H_2 and NG, including blends, and two oxidisers (air and pure oxygen, including also the whole range from 21-100%) within a single installation. This dual compatibility enables a smooth, reversible transition towards decarbonisation without requiring major infrastructure changes.

The burner has been designed across a wide power range (25 to 5000 kW) and is suitable for heating applications requiring temperatures between 500 and 2000 °C. The fuel and oxidiser are mixed at the burner nozzle exit. The flame length can be adjusted to fit each application, providing flexibility across furnace designs.

The value proposition of this KER lies in offering a realistic, scalable, and low-risk path to H_2 adoption in high-temperature industrial processes. It also allows operational flexibility to adapt to energy prices and availability (e.g., switching between H_2 and NG, and between air and O_2), contributing to OPEX optimisation.

4.1.2 Development Context and Exploitation Strategy

The technology is being developed and demonstrated by Sarralle, together with Nippon Gases, within the steel sector as part of the HyInHeat project. It will be deployed in a real industrial demonstrator and will reach TRL 8, indicating high readiness for commercial application.

The primary exploitation strategy is direct commercialisation. Initial market entry is planned through selected pilot installations with current customers. These Proof-of-Concepts (PoCs) will validate technical performance and operational reliability. Based on this experience, the technology will be offered as a market-ready solution including adaptation and technical support. Several potential clients have been identified within Sarralle’s existing industrial network.

Further exploitation will follow a phased approach depending on the availability of resources, certification timelines, and collaboration opportunities. The commercial roll-out is expected to evolve based on feedback from pilot phases and partnerships with industrial adopters.

4.1.3 Sectoral Application Potential

Beyond steel, the technical characteristics of the burner make it suitable for transfer to other high-temperature, EIIs. Those with clearer compatibility include aluminium, glass, ceramics, pulp and paper, lime, and non-ferrous metals such as zinc, copper and lead. These sectors show similar thermal requirements and process conditions that could accommodate this H_2-ready technology with minimal adaptation.

Other industries, such as cement, minerals, refining, water, chemicals, and pharmaceuticals, may also be viable contexts for replication. However, these would require more detailed process-specific evaluations to assess technical compatibility, safety constraints and integration potential.

4.2. KER3: Flow Meter and Hydrogen Quality Analyser

4.2.1 General Description and Value Proposition

This KER is an advanced instrument designed to measure both the flow and the quality of fuel gases, with a specific focus on H_2-rich mixtures. Its key innovation lies in a newly developed algorithm that enables the simultaneous measurement of total gas flow and the H_2 concentration within the mixture. This dual functionality represents a novel approach in H_2 process control, especially relevant for decarbonisation initiatives in EIIs.

The device operates optimally when the H_2 content in the gas mixture exceeds 90 percent and is compatible with line sizes ranging from DN50 to DN400. Tested configurations demonstrate performance with gas flows between 5 and 27,500 m^3/h and pressures from 8 to 105 bar(g). These characteristics position the instrument as a versatile and high-precision solution for process monitoring, safety assurance and performance optimisation in H_2 applications.

Its value proposition centres on enabling real-time, accurate and integrated control over H_2 usage in industrial settings. By consolidating two key measurements into a single system, it reduces instrumentation complexity and supports safer and more efficient H_2 integration into legacy or new processes.

4.2.2 Development Context and Exploitation Strategy

The analyser is being developed and tested within the HyInHeat project by EHS, with validation activities in two demonstrators. The focus is on its application in oil and gas and refining sectors, which are the company's current primary markets. It is not yet a commercial product and is undergoing final technical validation to assess performance under varying industrial conditions.

The initial route to exploitation will prioritise internal development and validation. Further work will be conducted to test the analyser's performance and reliability in different process configurations and operational envelopes. Depending on the results of these tests, EHS may consider extending the application scope to adjacent sectors through direct sales or co-development agreements with system integrators.

Commercialisation may also benefit from future collaborations with equipment manufacturers or plant operators to refine the device's design and ensure sector-specific compliance. The exploitation strategy will be further defined as more data is collected from pilot activities and as market readiness is assessed.

4.2.3 Sectoral Application Potential

This H_2-specific flow meter shows strong potential for replication in sectors with demanding process control requirements and fuel quality monitoring needs. Sectors such as glass manufacturing, minerals processing and chemical production present promising conditions for adoption, given their use of gaseous fuels, high energy consumption and the relevance of accurate flow and composition analysis in process optimisation and safety compliance.

Additional sectors, such as ceramics, water treatment and pharmaceuticals, may also benefit from this technology, although further analysis will be required to evaluate technical feasibility, integration constraints and the need for calibration or adaptation to specific gases and pressure conditions. The device's flexibility, broad operational envelope and capability to measure high-purity H_2 flows make it a versatile solution for industries pursuing decarbonisation pathways and digital process control upgrades.

4.3. KER4: Calorimeter by spectroscopy

4.3.1 General Description and Value Proposition

This KER is a novel analyser designed to determine the calorific value or Wobbe index of fuel gases through a spectroscopic approach. Unlike traditional calorimeters, this system measures the concentrations of individual gas components and calculates the calorific value and Wobbe index accordingly. This method offers enhanced flexibility and precision, particularly relevant for process optimisation in EIIs transitioning to low-carbon fuels.

The analyser can be tailored to specific industrial applications by adapting the sample handling system or modifying the design to accommodate varying process conditions, including (1) process pressure, (2) presence of particles, dust, or aerosols in the sample gas, (3) dew point considerations (water and hydrocarbons), and (4) ambient temperature.

The prototype developed within the HyInHeat project is capable of operating in ambient temperatures ranging from 5 to 40 °C. Sample gases should be within the 0 to 40 °C range and pressurised between 2 and 3 bar(g). These specifications make the analyser suitable for a wide range of industrial environments, although further validation is ongoing.

Its value proposition lies in offering a non-combustion-based, real-time analysis of fuel quality, reducing operational complexity and enabling more accurate control of combustion processes. This is particularly beneficial for industries seeking to improve energy efficiency and reduce emissions.

4.3.2 Development Context and Exploitation Strategy

The analyser is currently in the testing phase and has not yet reached commercial readiness. It is being developed and validated within the HyInHeat project by EHS, with no equivalent product currently available in the company's portfolio. The focus is on collecting performance data under diverse operating conditions to assess its reliability and adaptability.

The initial exploitation strategy will centre on internal validation and refinement. As testing progresses, the potential for broader application will be evaluated, including possible collaborations with system integrators or equipment manufacturers to tailor the analyser for specific industrial needs.

Future commercialisation may involve co-development agreements or pilot deployments in selected sectors. The exploitation roadmap will be further defined based on the outcomes of ongoing trials and market readiness assessments.

4.3.3 Sectoral Application Potential

Although the analyser is still under development, preliminary evaluations suggest strong applicability across several industrial sectors. It demonstrates high relevance for the glass, cement, ceramics, and oil and gas industries, where accurate fuel quality monitoring is essential for process optimisation and energy efficiency. These sectors are considered primary candidates for early adoption due to their reliance on gaseous fuels and the need for precise control over combustion parameters.

Other sectors such as minerals processing, pulp and paper, refining, water treatment, chemical production, pharmaceuticals, and food and beverages show moderate potential. In these cases, further technical validation is required to assess integration feasibility, calibration needs, and compatibility with specific process conditions, such as pressure ranges and gas compositions.

Overall, the analyser's flexibility, non-combustion-based measurement approach, and adaptability to various environmental and process conditions position it as a promising solution for industries pursuing decarbonisation and digitalisation of fuel management systems.

4.4. KER5: Devices for Continuous Emission Monitoring System measurement for NO_x in H_2 combustions

4.4.1 General Description and Value Proposition

This KER focuses on the measurement of NOx emissions in H_2 combustion processes. Accurate NOx reporting is essential for regulatory compliance; however, current EU Continuous Emission Monitoring System (CEMS) regulations are not well-suited for H_2 as a fuel. Existing frameworks do not allow for fair comparison between different fuels, as they rely on dry basis reporting. To enable meaningful and equitable reporting, a shift toward calorific value-based metrics is required. Until such regulatory updates are implemented, market deployment of H_2-specific NOx measurement solutions remains constrained.

Within the HyInHeat project, four different analysers have been deployed to evaluate NOx concentrations under H_2 combustion conditions. Two of these devices (GM32 and MCS300P) are provided by EHS, while the remaining two are sourced from subcontractors. The inclusion of at least one subcontractor was planned from the outset to test solid-state electrolytic measurement technologies. The use of multiple analysers enables a comprehensive assessment of NOx behaviour, particularly under high water content conditions typical of H_2 combustion.

The critical parameters of this KER5 vary depending on the analyser type. Each device can be adapted to specific industrial applications by modifying the sample handling system or the analyser design itself, based on factors such as (1) process pressure, (2) presence of particles, dust, or aerosols, (3) dew point (water and hydrocarbons), (4) ambient temperature, (5) gas concentrations.

Boundary conditions are analyser-specific and are detailed below:

- MCS300P (extractive): operates with sample gas temperatures between 100–200 °C, sample pressures from −0.2 to +0.2 bar(g), and ambient temperatures from +5 to +50 °C.
- GM32 (in-situ, cross-duct): suitable for exhaust gas temperatures up to 650 °C, sample pressures from −0.06 to +0.2 bar(g), and ambient temperatures from −20 to +55 °C.
- Solid-state electrolytic sensors (quasi in-situ): capable of measuring NOx concentrations from 0 to 3100 ppm, with process temperatures up to 1400 °C, sample gas temperatures up to 450 °C, and ambient temperatures from 0 to +50 °C.

This flexible configuration allows the system to be tailored to a wide range of industrial environments, although regulatory limitations currently restrict its commercialisation.

4.4.2 Development Context and Exploitation Strategy

The NOx measurement system is being developed and validated within the HyInHeat project by EHS, with a focus on understanding its performance under H_2 combustion conditions. While the technology is already used in sectors such as power generation, waste incineration, cement, and chemicals, its adaptation for H_2-rich environments is still under evaluation.

Due to regulatory constraints, the immediate exploitation strategy will prioritise internal testing and collaboration with regulatory bodies to advocate for updated reporting standards. Once appropriate frameworks are in place, the technology may be commercialised through direct sales or partnerships with system integrators and equipment manufacturers.

Further development will focus on refining analyser designs, improving measurement accuracy under high humidity conditions, and ensuring compatibility with sector-specific operational requirements. The exploitation roadmap will evolve based on regulatory progress and pilot project outcomes.

4.4.3 Sectoral Application Potential

Although the current regulatory environment limits immediate market entry, the NOx measurement system shows strong potential for cross-sectoral application. It is already in use in industries such as power generation, cement, and chemical processing, where emission monitoring is critical.

In addition, the technology is considered highly applicable to sectors such as glass, ceramics, minerals, pulp and paper, refining, water treatment, pharmaceuticals, oil and gas, and food and beverages. These industries share common needs for accurate emissions monitoring and are likely to benefit from the system's adaptability and precision once regulatory barriers are addressed.

Overall, the analyser's modular design, compatibility with H_2 combustion, and potential for regulatory alignment position it as a valuable solution for industries pursuing cleaner and more transparent emissions reporting.

4.5. KER7: Ultrasonic flow measurement equipment of the off gas for higher temperatures

4.5.1 General Description and Value Proposition

This KER introduces an ultrasonic flow measurement device specifically designed to operate under elevated exhaust gas temperatures up to 350 °C. This capability marks a significant advancement over conventional ultrasonic flow meters, which are typically limited to lower temperature ranges. The device enables accurate measurement of gas flow and velocity in harsh industrial environments, supporting improved process control and energy efficiency.

Key operational parameters include a gas flow range between 65 and 7800 m^3/h and a pressure range from 0.8 to 1.1 bar(a). These specifications make the device suitable for a wide variety of applications where hot gases are generated and flow monitoring is essential.

Its value proposition lies in enabling precise and reliable flow measurement in high-temperature exhaust conditions, which is particularly relevant for industries seeking to optimise combustion processes, reduce emissions, and enhance operational safety.

4.5.2 Development Context and Exploitation Strategy

The ultrasonic flow meter has been developed within the HyInHeat project by EHS to address the challenges of measuring gas flow in H_2 combustion and other high-temperature processes. One of its key applications is in glass melting, where exhaust gas temperatures can exceed 1000 °C. In such environments, controlling the outflow is critical for optimising combustion, improving energy efficiency, and minimising pollutant emissions.

The device is currently undergoing validation and performance testing. Its exploitation strategy will focus on sectors where high-temperature gas flows are common and where existing flow measurement technologies fall short. Initial deployment may involve pilot installations in selected industries, followed by broader commercialisation through partnerships with system integrators and equipment manufacturers.

Further development will explore integration with digital control systems and adaptation to sector-specific requirements, ensuring the device meets regulatory and operational standards across diverse industrial settings.

4.5.3 Sectoral Application Potential

The ultrasonic flow meter shows strong potential for application in sectors where hot gases are produced, and flow monitoring is critical. It is particularly well-suited for industries such as glass, minerals, refining, chemicals, and oil and gas, where high-temperature exhaust flows are common and precise control is essential for process optimisation and safety.

Additional sectors such as ceramics, water treatment, and pharmaceuticals may also benefit from this technology, although further analysis is needed to assess technical feasibility and integration requirements.

Overall, the device's ability to operate under elevated temperatures and its broad flow range make it a promising solution for industries aiming to enhance combustion control, reduce emissions, and improve energy efficiency.

4.6. KER8: OES flame measurement for any flame + characterization/analysis

4.6.1 General Description and Value Proposition

This KER presents an Optical Emission Spectroscopic (OES) measurement system developed by Luxmet, specifically designed for extreme and high-temperature metallurgical processes. The system enables OES measurements in environments where such analysis was previously not feasible, offering a significant technological advancement in combustion diagnostics.

The equipment allows for the measurement and analysis of flames generated from various combustion processes, including NG, H_2, air, O_2, and NG/H_2 blends. It operates effectively at process temperatures starting from 800 °C.

Its value proposition lies in providing a single, integrated solution for flame analysis across a wide range of combustion scenarios, supporting process optimisation, emissions control, and safety improvements in high-temperature operations.

4.6.2 Development Context and Exploitation Strategy

Luxmet's primary market focus is the metal industry, where the system is already being applied. The company has identified potential for transferring this technology to seven additional sectors, although specific details remain confidential due to strategic business considerations.

At present, no formal IP protection has been pursued. However, if the results prove commercially viable, Luxmet may consider protective measures to secure its innovation. The experience and outcomes from this development will also be leveraged in future research and development activities, both within and beyond the scope of HyInHeat.

4.6.3 Sectoral Application Potential

While the system is currently targeted at the metal industry, Luxmet has identified broader potential for cross-sectoral application. The equipment's ability to operate under extreme temperature conditions and analyse diverse combustion processes makes it a promising solution for other industries.

Overall, the system's robustness, adaptability, and precision position it as a valuable tool for industries seeking advanced combustion monitoring and control in extreme operating environments.

4.7. KER10: Safety training material

4.7.1 General Description and Value Proposition

This KER focuses on H_2 hazard awareness through a comprehensive and modular training programme. The training covers a wide range of topics including safety engineering, risk assessment, ignition and combustion phenomena, explosion protection, and human and organisational factors. It also integrates societal and environmental considerations, offering a holistic approach to H_2 safety that goes beyond conventional technical training.

Designed for high-temperature industrial environments, the training is adaptable to other sectors beginning to adopt H_2 technologies. Its modular structure allows for customisation based on plant-specific needs, workforce size, and existing safety competence levels. The programme is scalable, ranging from small teams of five individuals to large facilities with over 200 personnel, and is suitable for plants with medium to high levels of process automation.

The training is particularly relevant for installations where H_2 consumption exceeds 10 m^3/h, marking the threshold for meaningful safety planning. It also addresses the challenge of limited H_2-specific risk data, helping organisations build internal knowledge and improve safety protocols through structured learning.

A dedicated startup will support the customisation and future deployment of the training programme, ensuring its relevance and accessibility across diverse industrial contexts.

4.7.2 Development Context and Exploitation Strategy

The training programme has been developed within the HyInHeat project by NTNU to address the growing need for H_2 safety awareness in industrial settings. It is designed to be flexible and responsive to the evolving demands of H_2 integration, particularly in sectors transitioning to low-carbon energy sources.

The exploitation strategy includes offering tailored training packages based on plant size, H_2 usage, and automation level. The degree of customisation required ranges from 30% to 80%, reflecting the diversity of industrial processes and risk profiles. The programme also accounts for varying levels of on-site H_2 expertise, from no prior knowledge to moderate competence, ensuring accessibility for all organisations regardless of their starting point.

Future deployment will be supported by a dedicated startup, which will manage content adaptation, delivery, and sector-specific integration. The training will also contribute to the development of H_2 risk databases, enhancing industry-wide safety planning and regulatory compliance.

4.7.3 Sectoral Application Potential

The H_2 safety training programme demonstrates strong applicability across multiple industrial sectors. It is particularly relevant for glass, cement, ceramics, minerals, refining, chemicals, and oil and gas, where high-temperature operations and H_2 usage present significant safety challenges. These sectors benefit from targeted training that addresses both technical and organisational aspects of H_2 risk.

Other sectors such as pulp and paper, water treatment, and pharmaceuticals show moderate potential. Their relevance depends on the extent of H_2 adoption and the complexity of their operational environments. For example, pharmaceuticals may benefit in R&D or clean H_2 applications, while water treatment and food and beverages currently show limited transferability due to low H_2 use and lower process temperatures.

Overall, the training programme's adaptability, modularity, and comprehensive scope position it as a valuable resource for industries pursuing safe and effective H_2 integration.

4.8. Sectoral Replication Overview

This section provides a consolidated overview of the sectoral replication potential identified across all KERs. While each KER has its own specific technical features and context of application, a cross-cutting analysis reveals a group of high-temperature, EIIs that consistently emerge as viable targets for transfer or greenfield deployment.

The sectors have been assessed based on technical compatibility (e.g., temperature range, integration constraints, fuel types), potential regulatory drivers, and alignment with decarbonisation objectives. Although the depth of analysis may vary depending on the maturity of each KER, this overview aims to:

- Highlight sectors with high potential for replication.
- Identify those requiring further evaluation due to integration or safety constraints.
- Support the design of future validation activities and exploitation planning.

The classification is based on the technical screening performed in Task 8.3, complemented by market insights and expert input from consortium partners. The results are synthesised in Table 2 using a colour-coded assessment (green = high compatibility; amber = moderate compatibility with adaptation needs; red = low compatibility or limited relevance). This overview serves as a visual complement to the individual sectoral discussions included in each KER section.

Table 2. Potential for cross-sectorial implementation.

	KER1 Burner	KER3 Input flow	KER4 CV	KER5 NOx	KER7 Outflow flow	KER10 Safety
Glass	Green	Green	Green	Green	Green	Green
Cement	Amber		Green	Green		Green
Ceramics	Green	Amber	Green	Green	Amber	Green
Minerals	Amber	Green	Amber	Green	Green	Green
Pulp and paper	Green		Amber	Green		Amber
Refining	Amber	Green	Amber	Green	Green	Green
Water	Amber	Amber	Amber	Green	Amber	Red
Chemicals	Amber	Green	Amber	Green	Green	Green
Pharmaceutical	Amber	Amber	Amber	Green	Amber	Amber
Oil and gas		Green	Green	Green	Green	Green
Food and beverages			Amber	Green		Red

Table 2 does not include a column for KER8 because the company owner of this KER wants to keep it confidential due to strategic business considerations.

5. Cross-Cutting Strategic Dimensions: IP, Impact and Further Analysis

5.1 Intellectual Property Strategy

The protection and management of IP generated in the HyInHeat project is a key factor for enabling effective exploitation of its KERs. As is common in collaborative Horizon Europe projects, IP considerations are complex, given the number of contributing partners and the evolving nature of the innovations during the project lifecycle.

At this stage, the following strategic pillars have been identified for the IP management of the KERs:

Ownership and Access Rights

Ownership of each KER is assigned to the partner(s) who generated it, in accordance with the Grant Agreement and the Consortium Agreement (CA). In cases of joint development, co-ownership arrangements are governed by clauses in the CA that define use, protection, and revenue-sharing mechanisms.

To ensure fair and effective exploitation, access rights for background and foreground IP are granted among partners when necessary to implement the project or exploit specific results, following the principles defined in the Horizon Europe Model Grant Agreement.

Protection Measures

For each KER, protection strategies are being assessed depending on the nature of the result and its exploitation path:

- Patentability is being considered for results with high novelty and commercial potential, particularly hardware-based technologies or innovative measurement systems.
- Confidentiality is being maintained where patenting is not viable or strategic. In these cases, the know-how is preserved internally and safeguarded through Non-Disclosure Agreements (NDAs) with third parties.
- Copyright and database rights may be applied to software-related or data-driven components.

Each exploitation route (direct sale, licensing, internal use) will require tailored protection, and these strategies are under discussion with legal and commercial advisors within the consortium.

Partner Collaboration and Risk Mitigation

Given the collaborative nature of HyInHeat, ensuring alignment between partners on IP-related decisions is critical. Regular checkpoints have been established through WP8 to:

- Facilitate early identification of results with potential IP relevance.
- Encourage partner dialogue on ownership, protection strategy, and future use.
- Avoid future conflicts or delays in the exploitation phase.

Any transfer of IP or external licensing will require the prior agreement of the owning partner(s) and may be subject to internal review to ensure compatibility with the project's goals and commitments.

5.2 Resources and Capabilities Required for Exploitation

The successful exploitation of the KERs identified in the HyInHeat project will require a coordinated mobilisation of resources across multiple domains. While each KER may present specific technical requirements or market pathways, there are shared capabilities and support mechanisms that are critical across the portfolio. These are outlined below.

Technical Capabilities

All KERs under consideration involve technologies with advanced thermal, combustion, or measurement components. Therefore, the following technical resources will be essential:

- Engineering expertise in H_2 combustion, fuel gas handling, and high-temperature systems.
- Facilities and equipment for testing, prototyping, and adapting technologies to different industrial settings.
- Capabilities for integrating hardware into complex process environments and ensuring compatibility with sector-specific safety and operational standards.

Commercial Capabilities

Exploitation routes may include direct commercialisation, OEM partnerships, or licensing models. In all cases, the following commercial capacities will be important:

- Identification and engagement of early adopters in target sectors.
- Development of commercial partnerships with furnace manufacturers, industrial system integrators, or measurement technology providers.
- Market intelligence to support go-to-market strategy, pricing, and channel selection.

Financial Requirements

Bridging the gap between demonstration and market adoption will require targeted financial support. Common needs across KERs include:

- Funding for industrial-scale validation and pilot installations.
- Resources to cover certification, compliance testing, and potential redesigns.
- Investment in initial production, marketing materials, and sales efforts.

These needs may be addressed through a combination of public grants, strategic partnerships, and private investment, depending on the exploitation model selected for each KER.

Legal and IP Support

Effective exploitation also depends on strong legal foundations, particularly regarding IP and collaboration:

- Support in drafting licensing agreements, NDAs, and joint development contracts.
- Legal guidance for protecting proprietary elements through patents or confidentiality agreements.
- Coordination among project partners to align ownership, access rights, and exploitation interests.

This analysis provides a preliminary overview of the shared capacities and support structures needed for exploitation.

5.3 Environmental, Technological and Economic Impact

The HyInHeat project aims to accelerate the decarbonisation of EIIs by enabling the integration of H_2 combustion technologies. The seven KERs identified within the project represent a diverse set of developments, from hardware innovations and analytical devices to digital tools and advanced control systems, all designed to facilitate the transition towards cleaner industrial heating processes.

Despite their technical differences, the KERs share a common objective: to support industrial stakeholders in reducing greenhouse gas emissions, improving energy efficiency, and maintaining competitiveness in a low-carbon economy. The expected impacts of these results can be grouped into three main dimensions:

Environmental impact

The shift to H_2-based heating technologies enables a significant reduction in CO_2 emissions, especially in hard-to-electrify sectors. The KERs offer alternatives to fossil fuel dependency in high-temperature processes, contributing directly to EU climate goals and decarbonisation strategies. Additional benefits include lower emissions of pollutants such as NOx, depending on the combustion configurations.

Technological impact

The developments under HyInHeat validate key technical building blocks for industrial H_2 adoption. These include combustion systems, control and measurement instruments, and safety monitoring technologies; all essential to enabling safe, efficient, and scalable implementation. Many of the KERs also serve as enablers of retrofitting existing infrastructures, making the transition more accessible to SMEs.

Economic and industrial impact

Beyond environmental gains, the commercial exploitation of these KERs can reinforce the competitiveness of European industry. They open new business opportunities, especially for equipment manufacturers and service providers working in H_2 technologies. Furthermore, they strengthen Europe's industrial autonomy in a critical area of the energy transition.

6. Key Findings and Preliminary Conclusions

The cross-sectoral analysis of HyInHeat's KERs highlights the importance of combining a solid technical foundation with early strategic thinking regarding exploitation and replication. While the technological developments offer promising opportunities for decarbonisation across EIIs, their real-world impact depends on factors that extend beyond performance metrics or TRL levels.

A key takeaway is the relevance of adopting a shared and anticipatory exploitation strategy, developed progressively as the project unfolds. In large consortia such as HyInHeat, the alignment of partner expectations, the definition of ownership structures, and the early identification of exploitation routes are critical to ensuring that innovations do not remain confined to the pilot or research stage.

The use of external support mechanisms, such as the Horizon Results Booster service, has proven valuable in guiding partners through a structured evaluation process. These services help refine exploitation pathways, clarify value propositions, and assess sectoral transferability with external expertise and benchmarking.

Another relevant insight is the need for strong coordination among partners involved in the development, integration and potential commercialisation of each KER. The collaborative nature of Horizon Europe projects can amplify exploitation potential, but it also demands clear governance, proactive IP management and a transparent roadmap for joint action.

Finally, this exercise reinforces the idea that impact is not a by-product of technical success. It requires deliberate planning, targeted validation in relevant use cases, and the ability to adapt strategies as markets, policies, and technologies evolve. This deliverable offers an initial framework to support that transition.

6.1 Further Analysis and Recommendations

While the current deliverable presents a comprehensive mapping and preliminary exploitation strategy for the most promising results, several key areas remain open and will require further development:

- Completion of ongoing technical validations and pilot installations.
- Refinement of exploitation roadmaps based on feedback from industrial demonstrators.
- Formalisation of commercial agreements and governance frameworks among partners.
- Alignment of IP management with emerging market opportunities.
- Sector-specific market studies to fine-tune replication strategies.

Ensuring coordination, transparency and mutual alignment among partners will be essential to achieving coherent and impactful exploitation of HyInHeat outcomes.

Annex 1

This annex 1 presents the questionnaire (Figure 1) shared with the WP leaders to collect the information related to the developments within their respective areas, together with their answers.

This information was used for the selection of KERs, already explained in section 3.1.

	Potential KER 1	Potential KER2
Potential KER Name		
Brief Description		
What is included in the *box* ?		
Innovation degree (*High / Medium / Low*)		
Development level at the final stage		
Self-standing exploitation? (*YES / NO*)		
If NOT What else is needed?		
Commercial? (*YES / NO*)		
If NOT Commercial Explain		
Market potential (*High / Medium / Low*)		
Lead partner		
Partners involved		
Information provided by (*Name + Partner*)		

Figure 1. Screenshot of the questionnaire shared to collect information on the potential KERs.

ER 1

Potential KER Name: Hydrogen combustion burner for walking beam furnaces.

Brief description: Burner technology capable of operating with NG and H_2 in the whole range, including blends (0 to 100%), and air and oxycombustion technology.

What is included in the box? Hardware: burner capable of operating with NG/H_2 and Air/O_2.

Innovation degree: High/Medium

Development level at the final stage: TRL 7-8 Burners demonstrated in industrial environment.

Self-standing exploitation? -

Commercial? -

Market potential: High

Lead partner: SARRALLE

Partners involved: NIPPON GASES, ARCELORMITTAL OLABERRIA

ER 2

Potential KER Name: Hydrogen combustion technology for a walking beam furnace.

Brief description: A retrofitting solution for walking beam furnaces to use H_2/air, H_2/O_2 enriched combustion (H_2/OEC), and H_2/O_2 technologies. This solution enables the reduction of CO_2 emissions and improves furnace efficiency, while ensuring steel quality during reheating.

What is included in the box? Flow train for H_2 combustion, H_2 infrastructure, programming of level 1 and level 2 control systems, safety assessment, application to authorities, upgrade of air, instrument air, oil, valves, Safety Integrity Level (SIL) classifications and new installations, installation of measurement equipment, upgrades to operators' panels, thermocouples, image system for quality assessment of descaling, etc.

Innovation degree: High/Medium

Development level at the final stage: TRL 7-8 (Prototype demonstrated in an operational environment).

Self-standing exploitation? Yes

Commercial? No, because the pilot furnace is not used for production purposes, only as demonstrator of what can be expected during industrial installation and use.

Market potential: Low as it is not intended as production equipment but more as a demonstrator to guide future commercial installations. But this solution in itself won't be commercialized since it is not production scale.

Lead partner: SWERIM

Partners involved: SSAB, LINDE, EHS, OULU

ER 3

Potential KER Name: Flow meter and quality analyser.

Brief description: Instrument to measure simultaneously the flow and the quality of a fuel gas.

What is included in the box? The instrument, comprising the sensor and the electronics.

Innovation degree: Medium

Development level at the final stage: TRL 5-field. It is being tested.

Self-standing exploitation? Yes

Commercial? Yes, but still to be validated.

Market potential: Medium

Lead partner: EHS

Partners involved: -

ER 4

Potential KER Name: Calorimeter by spectroscopy.

Brief description: Instrument to measure the calorific value (or Wobbe index) of fuels.

What is included in the box? The instrument, comprising the sensor and the electronics.

Innovation degree: Medium

Development level at the final stage: TRL 5-field. It is being tested.

Self-standing exploitation? Yes

Commercial? Yes, but still to be validated.

Market potential: Medium

Lead partner: EHS

Partners involved: -

ER 5

Potential KER Name: Devices for Continuous Emission Monitoring System (CEMS) measurement for NO_x in H_2 combustions.

Brief description: Proof of technological feasibility for this measurement. Today all certified devices are not able of handling such high water contents.

What is included in the box? Gas analyser equipment: electronics, software.

Innovation degree: High

Development level at the final stage: Non-commercial product available by the end of the project (Dec 2026). Pre-series devices available (tested on field).

Self-standing exploitation? Yes.

Commercial? Yes.

Market potential: High

Lead partner: EHS.

Partners involved: C-TEC, SWERIM

ER 6

Potential KER Name: Control parameter of H_2 combustion process.

Brief description: Since there is a lack of experience from industrial-sized H_2 combustion processes, the best measurement parameter to control the process is not known yet. The test measurements conducted during the HYINHEAT project will be used to identify the parameters to control the combustion best.

What is included in the box? -

Innovation degree: Medium.

Development level at the final stage: Process principle shall be ready to use.

Self-standing exploitation? Yes.

Commercial? No, because the knowledge of the best control parameter itself is not commercially used. However, there is indirect commercial usage from selling the respective measurement products.

Market potential: Low.

Lead partner: EHS.

Partners involved: C-TEC, SWERIM.

ER 7

Potential KER Name: Ultrasonic flow measurement equipment of the off gas for higher temperatures.

Brief description: Increasing the temperature stability of critical components up to 350 °C.

What is included in the box? Mechanics, electronics, software.

Innovation degree: Medium / Low.

Development level at the final stage: Pre-series devices available (tested on field).

Self-standing exploitation? Yes.

Commercial? Yes.

Market potential: High.

Lead partner: EHS

Partners involved: SWERIM

ER 8

Potential KER Name: Optical emission spectroscopic flame measurement for any flame + characterization/analysis.

Brief description: Equipment for measuring the optical emissions from burners (NG/H_2; air/O_2; different mixes of H_2 and NG till 100% of H_2) in high-temperature furnaces. Analysis algorithms for OES analysis from burners in high-temperature furnaces.

What is included in the box? Measurement equipment, software, and UI required for the analysis. Analysis algorithms for flame characterization.

Innovation degree: -

Development level at the final stage: More R&D will most probably be required (tested at lab-scale; demonstrators Swerim, C-TEC). Most probably it will be finished/completed. More testing will be required.

Self-standing exploitation? Yes.

Commercial? Yes

Market potential: Medium / High

Lead partner: LUXMET

Partners involved: OULU

ER 9

Potential KER Name: Plant-level ML-MFA methodology

Brief description: Mass balance consistent physical accounting of material flows, energy and emissions to identify emission mitigation strategies within the plants.

What is included in the box? MFA methodology, consultation with industrial partner, accounting model of the flows (e.g., in Excel) that can also be reused with other/new data by the company, evaluation and interpretation.

Innovation degree: Medium.

Development level at the final stage: -

Self-standing exploitation? No.

Commercial? No, because its main use is for scientific purpose and further projects.

Market potential: Low.

Lead partner: NTNU.

Partners involved: -

ER 10

Potential KER Name: Safety training material.

Brief description: Adaptable training equips operators in high-temperature process industries with essential H_2 safety skills. Its modular format addresses specific technical needs, enabling efficient resource use. The material supports economic goals by mitigating safety risks, enhancing cost-effectiveness, and fostering market readiness for H_2 integration in industrial settings.

What is included in the box? Training modules in the form of presentation slides, designed to cover key H_2 safety topics relevant to high-temperature industries.

Innovation degree: Medium. Training tailored for H_2 safety in high-temperature industries is innovative for the sector. However, the innovation is incremental rather than groundbreaking.

Development level at the final stage: -

Self-standing exploitation? Yes.

Commercial? Yes.

Market potential: Medium.

Lead partner: NTNU.

Partners involved: -

Annex 2

For the transferability assessment of the KERS, industries with comparable process characteristics were identified and explained in section 3.3. Further details on each sector's processes, temperature needs, and decarbonisation context are available in this Annex 2.

Many industries depend heavily on fossil fuel, such as NG, fuel oil, coal, and petroleum by-products to generate the high temperatures required for their production processes. These fossil fuels are commonly used in furnaces, boilers, reactors, and combined heat and power (CHP) systems to supply the thermal energy necessary for operations like chemical reactions, drying, sterilisation, and the transformation of raw materials.

However, this reliance on fossil fuels comes at a significant environmental cost. Their combustion is a major source of global carbon dioxide (CO_2) emissions and contributes to climate change. In addition to CO_2, the burning of these fuels releases other harmful pollutants, including nitrogen oxides (NOx), sulphur oxides (SOx), particulate matter, and volatile organic compounds (VOCs), which negatively impact air quality and public health.

As awareness of these environmental impacts grows, and as regulatory pressures intensify, industries are increasingly being called upon to reduce their carbon footprint and adopt more sustainable practices. This shift is driving a wave of innovation and investment in cleaner technologies and alternative energy sources.

In response, many sectors are implementing a range of decarbonisation strategies. These include improving energy efficiency, electrifying heat-intensive processes using renewable electricity, adopting low-carbon fuels such as green H_2 or biomass, and increasing the use of recycled materials to reduce energy demand.

Despite this progress, the transition away from fossil fuels remains a complex and demanding challenge, particularly for industries that rely on continuous and high-temperature processes. Achieving a fully decarbonised production system will require sustained innovation, significant capital investment, and robust policy support to enable the widespread adoption of low-carbon solutions

Below is a description of each of the sectors analysed in this document.

Glass industry

The glass industry is a key sector in the global economy, with applications ranging from the manufacture of packaging and building materials to automotive and technology components. Its production process is based on the melting of raw materials such as silica sand, sodium carbonate and limestone, which are combined at extremely high temperatures to form a homogeneous glassy mass. This molten glass is moulded and cooled to produce glass products with different properties and uses. To reach the temperatures required in melting furnaces, which typically range from 1400 to 1600 °C, the industry relies heavily on fossil fuels. NG is the most commonly used fuel, although fuel oil and, to a lesser extent, coal are also used,

Cement industry

The cement industry is one of the most important in the world, as it provides the basic material for the construction of infrastructure, housing, and civil works. Its production process is based on the calcination of limestone (calcium carbonate) along with other materials such as clay, sand, and iron ore. These components are ground and fed into a rotary kiln, where they are subjected to extremely high temperatures, often exceeding 1400 °C, to form what is known as clinker, the main component of cement.

Ceramics industry

The ceramics industry is a diverse and essential sector that produces a wide range of products, from household items like tiles, dishes, and sanitary ware to advanced technical ceramics used in electronics, aerospace, and medicine. The manufacturing process typically involves shaping raw materials such as clay, kaolin, feldspar, and quartz, followed by drying and firing at high temperatures to achieve the desired hardness, durability, and aesthetic qualities. A critical stage in ceramic production is the firing process, which requires sustained high temperatures, often between 1000 and 1400 °C, depending on the type of ceramic being produced.

Minerals industry

The minerals industry encompasses a broad range of activities related to the extraction, processing, and transformation of mineral resources into usable materials for construction, manufacturing, technology, and energy production. This includes the production of metals like iron, aluminium, copper, and zinc, as well as non-metallic minerals such as lime, magnesia, and various industrial minerals. These processes are essential to modern infrastructure and industrial development but are also highly energy intensive. A central aspect of mineral processing is the need for high-temperature heat, often exceeding 1000 °C, particularly in operations such as smelting, calcination, and sintering.

Pulp and paper industry

The pulp and paper industry is a vital part of the global economy, producing a wide range of products such as paper, cardboard, tissue, and packaging materials. The manufacturing process begins with the extraction of cellulose fibres from wood or recycled paper, which are then processed into pulp. This pulp undergoes various treatments, including bleaching, drying, and pressing, to produce the final paper products. A key stage in this process involves the use of high temperatures, particularly during the drying and chemical pulping phases.

Refining industry

The refining industry plays a crucial role in transforming crude oil into usable products such as gasoline, diesel, jet fuel, heating oil, and petrochemical feedstocks. Refineries are complex industrial facilities that use a combination of physical and chemical processes to separate, convert, and purify the various components of crude oil. These processes include distillation, cracking, reforming, and treating, each requiring precise control and significant energy input. A central aspect of refining operations is the need for high-temperature heat, particularly in units such as distillation columns, catalytic crackers, and reformers.

Water industry

The water industry, encompassing the supply, treatment, and distribution of water, is essential for public health, agriculture, industry, and environmental sustainability. It involves a range of processes, including the abstraction of raw water from natural sources, purification to meet drinking water standards, and the treatment of wastewater before it is returned to the environment. These operations are supported by extensive infrastructure such as pumping stations, treatment plants, and distribution networks. Although the water sector is not typically associated with high-temperature processes, there are specific areas, particularly in thermal treatment of sludge, desalination, and advanced water recycling, where high levels of heat are required.

Chemicals industry

The chemical industry is a cornerstone of modern economies, producing a vast array of products that underpin sectors such as agriculture, healthcare, construction, and manufacturing. It involves the transformation of raw materials, such as oil, NG, minerals, and air, into chemicals, polymers, and other materials through complex physical and chemical processes. These processes are carried out in large-scale facilities that require precise control of temperature, pressure, and reaction conditions. A significant portion of chemical manufacturing depends on high-temperature processes, often exceeding 800 °C, particularly in operations such as steam cracking, reforming, and synthesis reactions.

Pharmaceutical industry

The pharmaceutical industry is a highly specialised and regulated sector dedicated to the research, development, manufacturing, and distribution of medicinal products. It plays a vital role in public health by providing treatments and vaccines that improve quality of life and combat disease. The production of pharmaceuticals involves a wide range of chemical and biological processes, many of which require precise control of temperature, pressure, and reaction conditions to ensure product safety and efficacy. Although not as energy intensive as heavy industries, pharmaceutical manufacturing does involve high-temperature processes, particularly in the synthesis of active pharmaceutical ingredients (APIs), sterilisation, and drying operations.

Oil and gas industry

The oil and gas industry is one of the most significant and EII globally, responsible for the extraction, processing, and distribution of petroleum and NG products. These resources are essential for fuelling transport, generating electricity, producing heat, and serving as feedstocks for countless industrial and consumer goods. The industry operates through a complex network of upstream (exploration and production), midstream (transportation and storage), and downstream (refining and distribution) activities. A critical aspect of oil and gas operations involves high-temperature processes, particularly in refining and petrochemical production. Units such as distillation columns, catalytic crackers, and reformers require sustained heat at temperatures often exceeding 400 °C.

Food and beverages industry

The food and beverage industry is a vast and essential sector that encompasses the processing, packaging, and distribution of products consumed daily across the globe. It includes everything from large-scale industrial food production to beverage bottling and dairy processing. These operations require strict hygiene standards, precise temperature control, and reliable energy supplies to ensure food safety, product quality, and regulatory compliance. A significant part of food and beverage manufacturing involves high-temperature processes, such as pasteurisation, sterilisation, drying, baking, roasting, and evaporation.

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