

ESTEP 2025 Annual Event

28-30 October 2025
Udine (ITALY)

How decarbonisation, digitisation
and circular solutions forge the
sustainable European steel future?

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High-temperature electrolysis for decarbonisation of the steel sector: the SYRIUS project, a real-scale demonstration



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The project is supported by the Clean Hydrogen Partnership and its members under Grant Agreement 101192534.

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 the Clean Hydrogen Partnership. Neither the European Union nor the granting authority can be held responsible for them.



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High-temperature electrolysis for decarbonisation of the steel sector: the SYRIUS project, a real-scale demonstration

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Current challenges

- Steel industry is one of the largest energy consumers with an average of ~5.2 MWh of primary energy per tonne of steel produced, resulting in **9% of all anthropogenic CO₂ emissions worldwide**¹. Of the total current steel production:
 - 78% is attributed to the “primary route”;
 - the remaining 22% (41.5% in the EU, with peaks of 81% in Italy and 61% in Spain) is attributed to the “secondary route”, based on electric arc furnace (EAF) that has lower energy demand and carbon footprint;
- **In all cases, significant CO₂ emissions are related also to the hot rolling mill processes downstream the cast steel production**
- Demand reduction, Energy efficiency, **Fuel switching**, electrification, and grid decarbonization, Technology shift to low-carbon steelmaking, and Carbon capture, utilization, and storage (CCUS) are the five pillars to reduce CO₂ emissions from the iron&steel making industry, needed to meet the Net zero emission target

¹ <https://doi.org/10.1016/j.jclepro.2022.134182>

² https://eta-publications.lbl.gov/sites/default/files/china_steel_roadmap-2mar2023.pdf



SYRIUS project

The EU-funded project SYRIUS will address these challenges by integrating a 4.2 MWel Solid Oxide Electrolyser (SOEC) into the process line of an EAF steel plant, enabling on-site hydrogen production with waste heat recovery and circular integration of process by-products



Title: SOEC HYDROGEN INTEGRATION AND CIRCULAR USE IN STEELMAKING PROCESS

Acronym: SYRIUS

Starting date: 1st January 2025

End date: 30th June 2029 (duration: 52 months)

Coordinator: EUCORE

Consortium: 10 Beneficiaries and 3 affiliated entities from 6 EU Member States: 3 SMEs, 6 large company, 2 universities and 1 research center

Topic: HORIZON-JTI-CLEANH2-2024-01-05 - Hydrogen production and integration in energy-intensive or specialty chemical industries in a circular approach to maximise total process efficiency and substance utilization

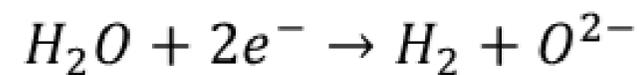
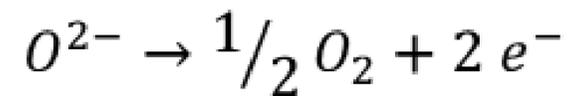
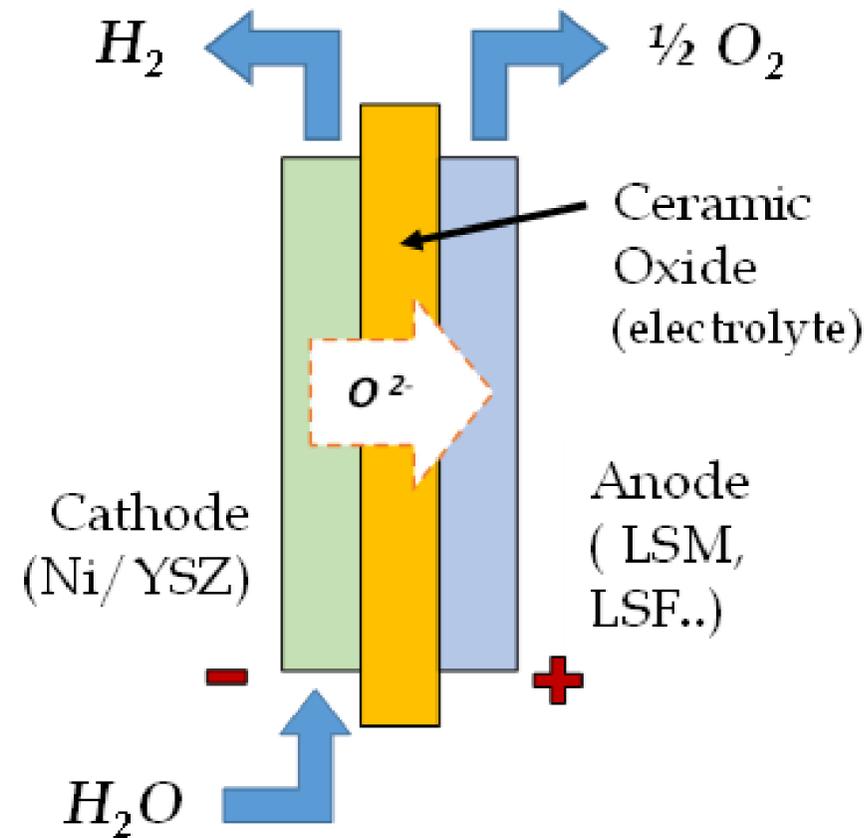
Total costs estimated: € 29,051,310.49 (IA)

EU contribution: € 9,999,165.49.



Principles of a SOEC (Solid Oxide Electrolyzer)

- A high-temperature electrochemical device that uses a solid ceramic electrolyte (typically based on ZrO_2) to split water (steam) into hydrogen and oxygen.
- It converts electrical energy into chemical energy, usually operating between **600°C - 800°C**
- The SOEC's high operating temperature allows higher efficiency (e.g. >80-85%) than low temperature electrolyzers (e.g. alkaline, PEM)
- Maximum efficiency is achieved using waste heat sources to provide steam



Solid oxide cell stack.
Credits: Elcogen

$$\eta_{el} = \frac{\dot{m}_{H_2} \times LHV_{H_2}}{P_{el}}$$

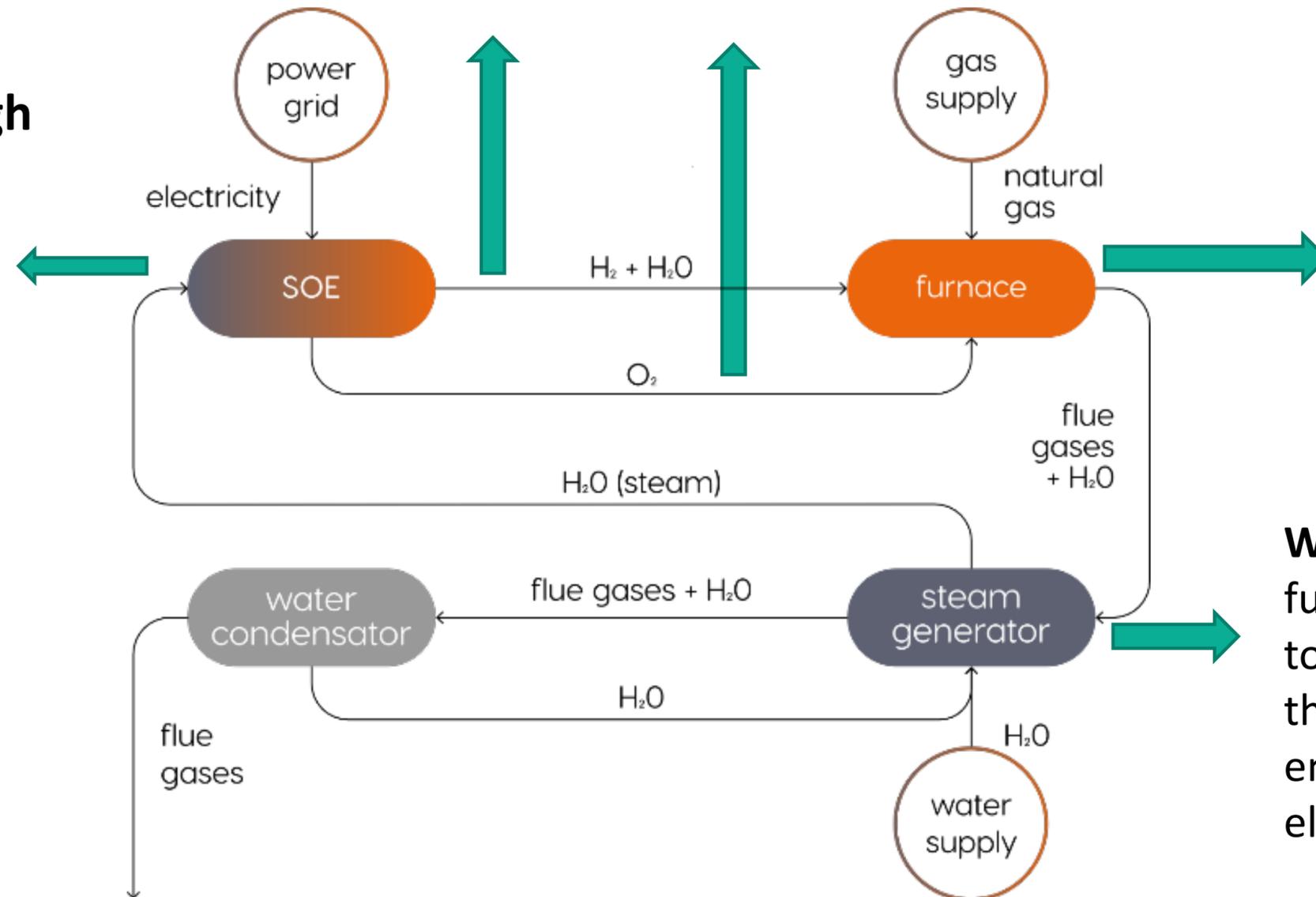
SYRIUS concept

Hydrogen produced on-site will be directly fed into a high-efficiency, fuel-flexible slab reheating furnace.

The **oxygen** by-product from the electrolysis process is captured and reintegrated into the furnace operations, improving combustion efficiency and further reducing fuel usage.

The 84 MW_{th} slab reheating furnace can operate with **variable H₂-natural gas mixtures**, reducing CO₂ emissions by 5,600 tonnes per year during the project and up to 35,700 tonnes per year with future expansion

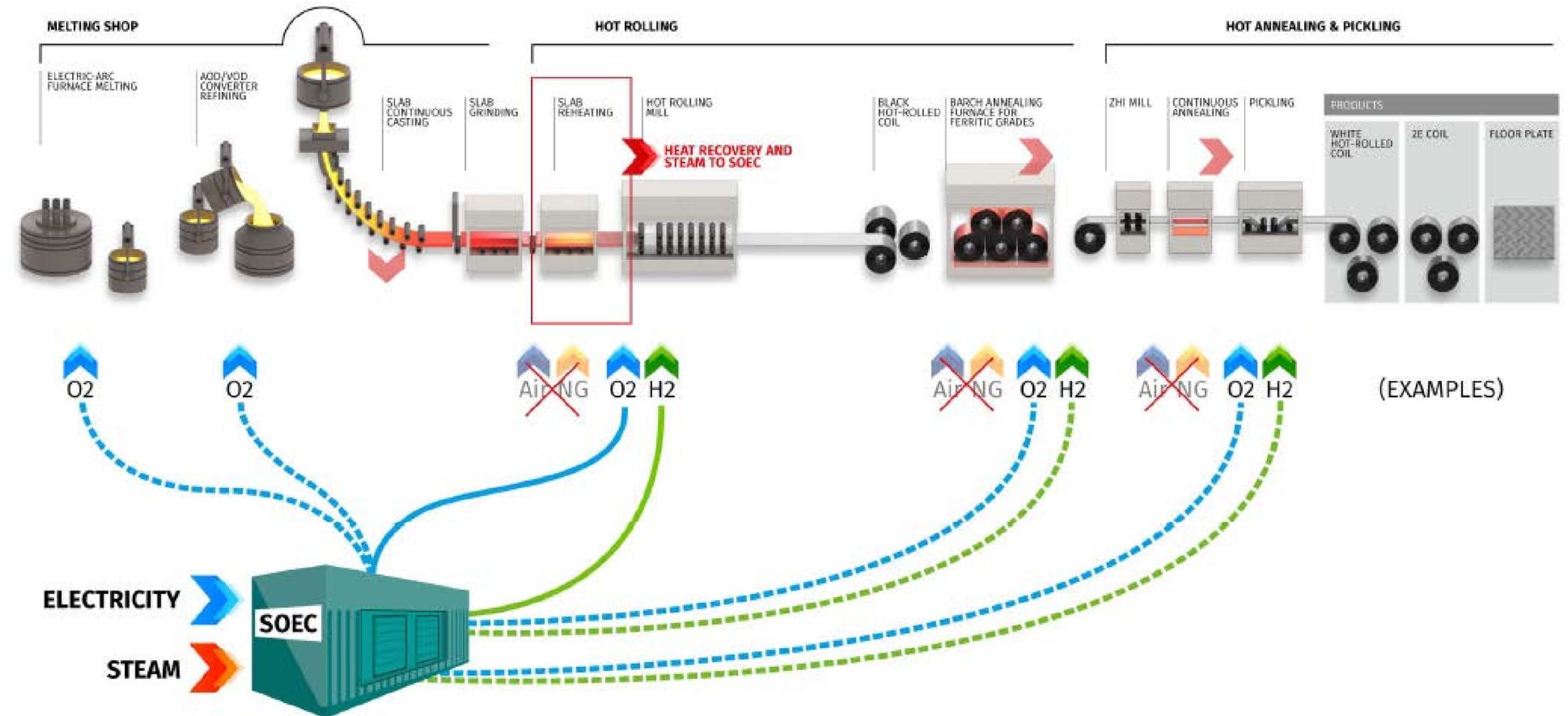
The SOEC operates at **high temperature**, with high electrical efficiency (specific consumption target < 39 kWh_{el}/kg_{H2}), utilizes steam (at low pressure, T≅200°C) recovered from the steel reheating process.



Waste heat from the reheating furnace is recovered and used to generate steam, which feeds the SOEC system to enhance energy efficiency and lower electricity consumption.

SYRIUS – Exploitation potential and targets

- Several potential integration pathways for a SOEC in a EAF steelwork (dashed lines)
- The actual configuration developed within the SYRIUS project (solid lines) for deployment at the Acciai Speciali Terni (AST) plant in Italy



SYRIUS - concept

The proposed system is constituted by individual units at different maturity level (TRLs):

- i. A high-temperature SOEC;
- ii. Flexible hydrogen and oxygen-enriched air burner in a new reheating furnace;
- iii. A heat recovery integration with SOEC;
- iv. A process integration including Energy Management System (EMS).

The system will reach TRL7 for the core part (the electrolysis plant) and TRL8-9 for the other plant and project components.

The study also includes safety, techno-economic assessments, as well as life cycle and sustainability analyses to quantify environmental benefits.



SYRIUS - Ambition

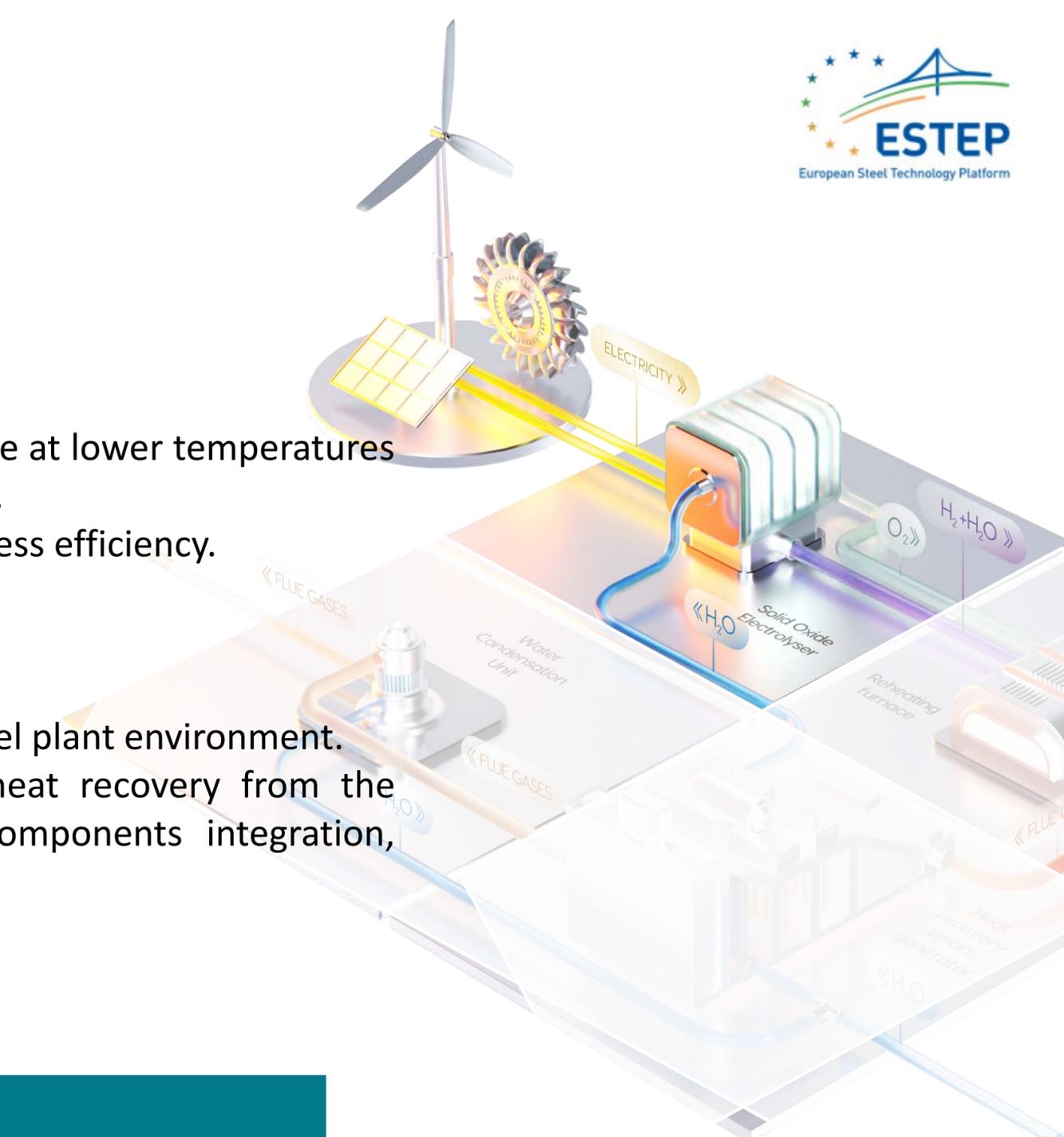
i. A high-temperature SOEC;

State of the art:

- conventional electrolysis systems (such as alkaline or PEM electrolysis) operate at lower temperatures and require higher electricity consumption, typically around 50-60 kWh/kg H₂.
- Limited integration with industrial heat recovery systems reduces overall process efficiency.
- Challenges in scalability and durability for industrial use.

Progress Beyond state of the art within SYRIUS:

- Deployment of a 4.2 MW high-temperature SOEC system integrated into a steel plant environment.
- SOEC consumption <39 kWh/kg_{H2} thanks to the optimization of waste heat recovery from the reheating furnace, improvements in large-scale balance of plant and components integration, significantly reducing electricity and additional heat demand.
- Production capacity of 100 kg/h of green hydrogen.
- Full circular integration through steam recovery from the furnace off-gases.



Technical performance KPIs	Project targets
Specific consumption	< 39 kWh _{el} /kgH ₂ 8-9 kWh _{th} /kgH ₂
Hydrogen production rate	100 kg/h
Current density	0.5-0.75 A/cm ²

SYRIUS - Ambition

- i. A high-temperature SOEC;
- ii. Flexible hydrogen and oxygen-enriched air burner in a new reheating furnace;

State of the art:

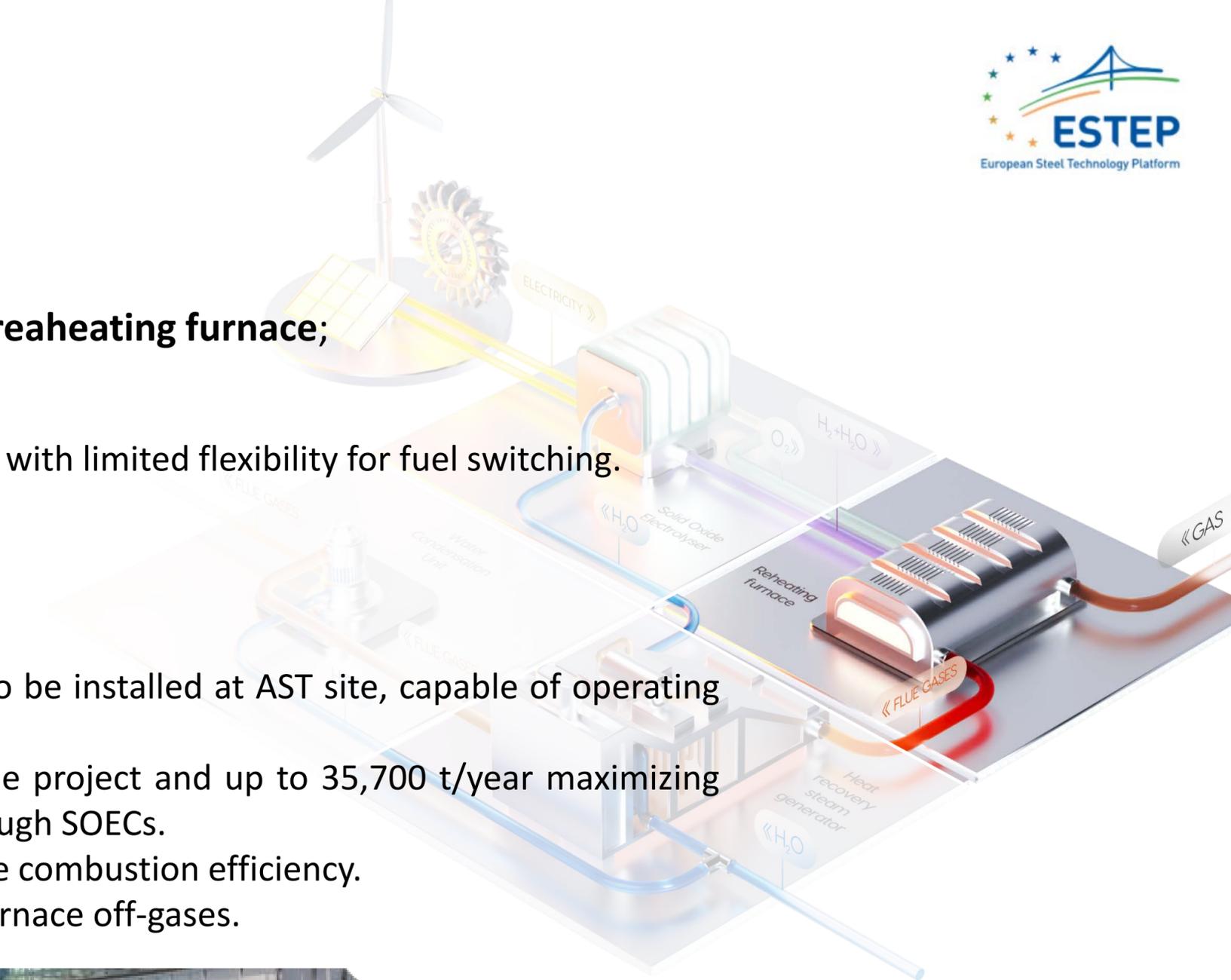
- Conventional slab reheating furnaces primarily rely on natural gas, with limited flexibility for fuel switching.
- High CO₂ emissions associated with fossil fuel combustion.
- Energy efficiency constraints due to limited waste heat recovery

Progress Beyond state of the art within SYRIUS:

- Connection to a new fuel-flexible Walking Beam Furnace (WBF) to be installed at AST site, capable of operating on various hydrogen-natural gas mixtures.
- Expected CO₂ emission reduction of up to 5,600 t/year during the project and up to 35,700 t/year maximizing heat recovery for steam production and hydrogen production through SOECs.
- Integration of recovered oxygen from the SOEC process to optimize combustion efficiency.
- Enhanced energy efficiency through the recovery of steam from furnace off-gases.



Walking Beam Furnace (WBF). Credits: Tenova

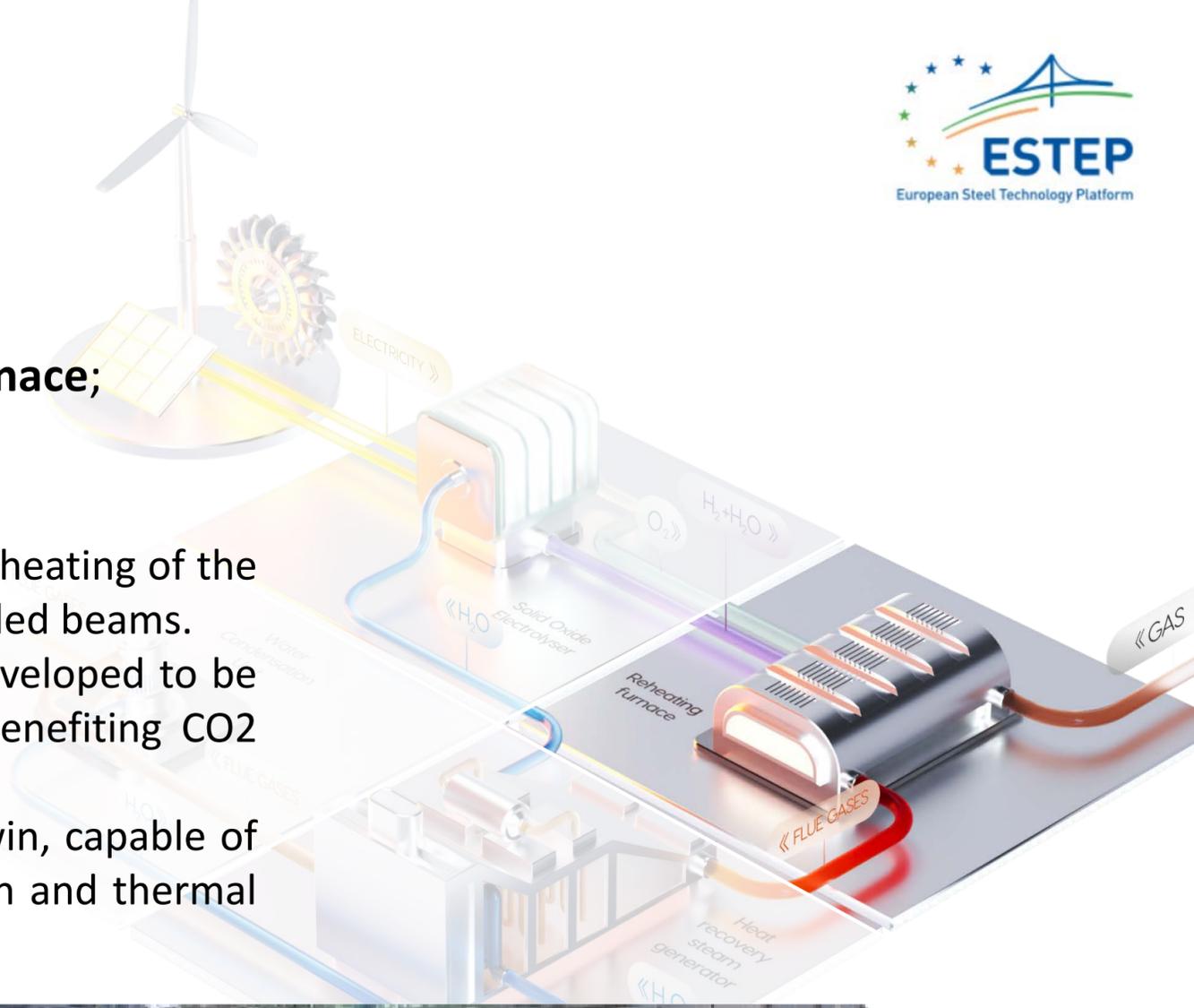


SYRIUS - Ambition

- i. A high-temperature SOEC;
- ii. Flexible hydrogen and oxygen-enriched air burner in a new reheating furnace;

Main features of the WBF:

- high thermal and combustion efficiency, thanks to some measures such as deep preheating of the combustion air and advanced refractory-insulating linings for both the walls and cooled beams.
- Ultra Low NOx type burners: in addition to being hydrogen-ready, they are also developed to be fed with pure oxygen (lancing), further increasing the furnace's efficiency and benefiting CO2 emissions.
- The automation is supported by mathematical models, integrated with a Digital Twin, capable of managing the main functions of the furnace in the presence of variable production and thermal cycles scenario, transients and stops of the Hot Strip Mill.



H₂-Ready TSX burners. Credits: Tenova



Walking Beam Furnace (WBF). Credits: Tenova

SYRIUS - Ambition

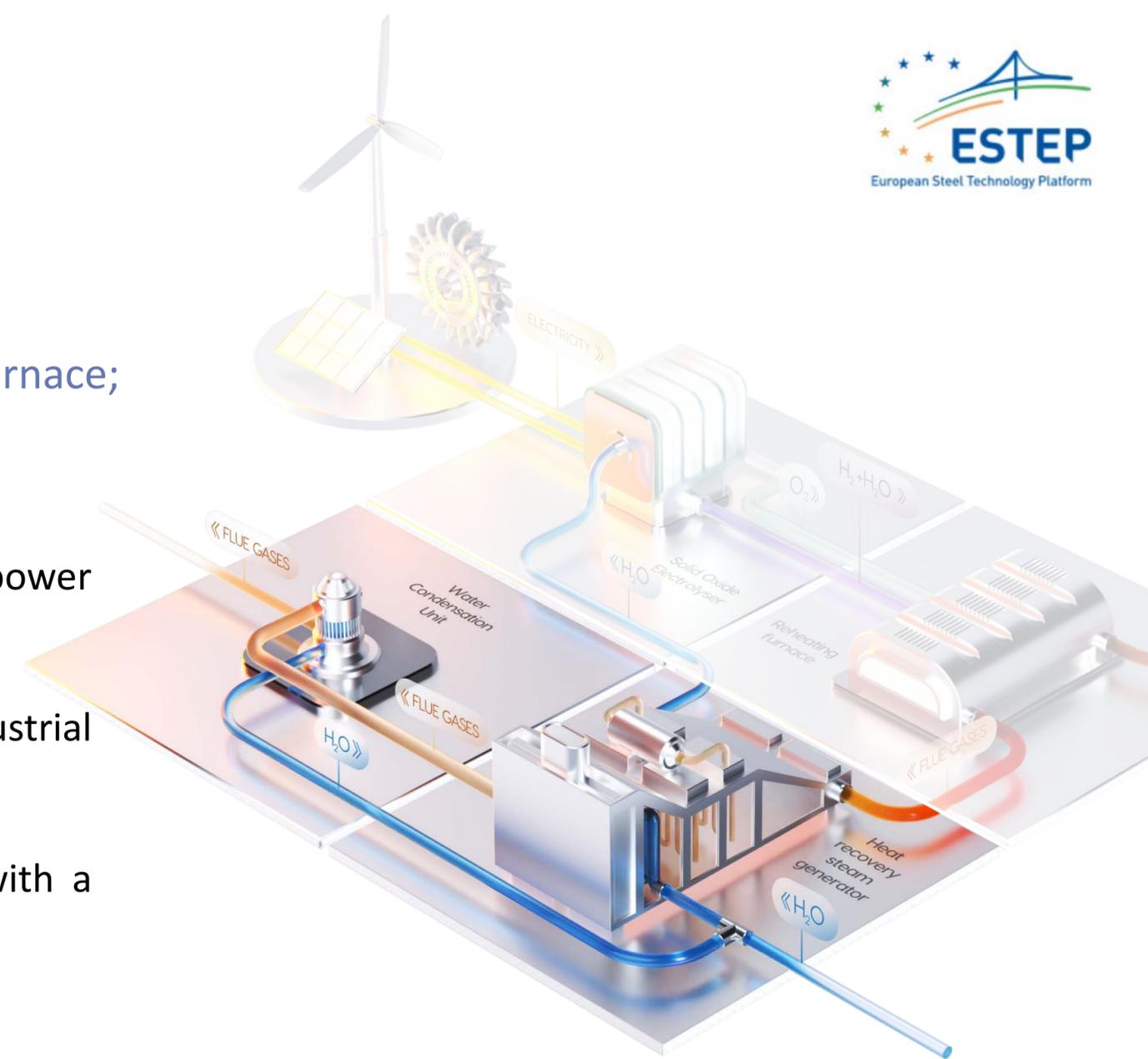
- i. A high-temperature SOEC;
- ii. Flexible hydrogen and oxygen-enriched air burner in a new reheating furnace;
- iii. **A heat recovery integration with SOEC;**

State of the art:

- Fully commercial and well-known technology for installation both in the power generation field and in industrial applications for heat recovery;
- At the AST site, a complex steam circuit is in operation;
- TEN has developed the iRecovery® system for recovering waste heat from industrial furnaces

Progress Beyond state of the art within SYRIUS:

- First-of-a-kind integration of a steam loop with a high-temperature SOEC (with a commercial downstream industrial process);
- Design and management of a dual heat exchange circuit;
- Exploration of lower-temperature heat recovery options.



Technical performance KPIs	Target
Heat recovery efficiency	> 85% in dual-loop configuration
Flue gas cooling and water recovery	> 90% water recovery and reuse
Steam purity	High-purity steam suitable for SOEC (> 99.9% H ₂ O)

SYRIUS – Ambition - EMS

Process integration includes also the **use of an advanced EMS based on model predictive control**, capable of dynamically optimizing SOEC operation when integrated with PV plants and batteries to form a Virtual Power Plant.

State of the art:

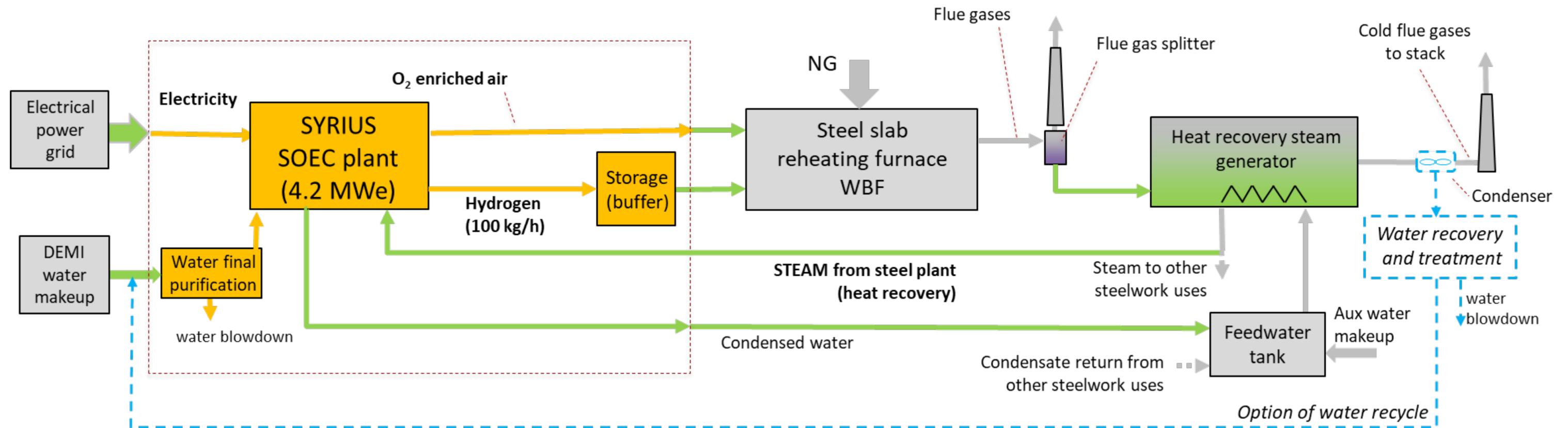
- Lack of dynamic energy management for industrial hydrogen systems.
- Inability to optimize energy flows considering fluctuating renewable energy sources or variable industrial loads.
- Limited integration with hydrogen storage and production systems

Progress Beyond state of the art within SYRIUS:

- Development of an advanced EMS to coordinate:
 - hydrogen production from SOEC
 - on-site hydrogen storage management
 - flexible operation of steel plant loads and integration with external energy sources
- Improved operational flexibility and cost-efficiency through intelligent management of industrial loads.
- Enhanced energy optimization by integrating data from virtual PV plants

Technical performance KPIs	Current state	Target
Load flexibility management	No existing systems for SOEC + renewables + industrial load	Real-time optimization achieved
Operational costs reduction	Limited integration and cost/efficiency recovery	>15% compared to conventional strategies

SYRIUS – preliminary layout



- Optimization of waste heat recovery from the reheating furnace, improvements in balance of plant and components integration, significantly reducing electricity and additional heat demand
- Production capacity of 100 kg/h of green hydrogen
- Full circular integration through steam recovery from the furnace off-gases

SYRIUS phases and timeline

1. Analysis

technical and regulatory groundwork, including engineering studies, infrastructure mapping, permitting and safety assessment, to prepare the AST site for the SOEC integration.

3. Integration

the technological components developed in the previous phase will be physically integrated at the AST site. System commissioning and interface validation will ensure readiness for demonstration.

5. Impact evaluation

assessment of SYRIUS circularity, sustainability, and scalability through Material and Energy Flow Analysis, LCA, Social-LCA, TEA, and CBA, supporting the development of a business plan for post-project uptake and replication.

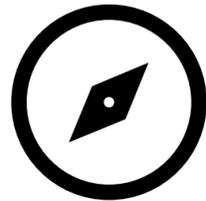
2025

2026

2027

2028

2029



2. Development

customisation of the SOEC stack, burner, EMS, and heat recovery units, and supporting systems for compatibility with the AST plant.

Delivery of SOEC system and installation at AST

4. Demonstration

testing of the full integrated system over 5,000 cumulative operating hours, validating technical, operational, and safety performance under real conditions

- (i) Definition of the system architecture
- (ii) Performing of a preliminary simulation-based design
- (iii) Comparison of multiple configuration options

SYRIUS – Summary of exploitation potential and targets



Environmental KPIs within project timeline – Decarbonization impact and energy savings

KPI	Target	Expected benefit
CO ₂ emissions reduction during project	5,600 t/y	Immediate environmental benefit
O ₂ recovery	800 kg/h of O ₂ through oxygen enriched air produced by the SOEC and recovered effectively in the plant	Improved efficiency
Fossil fuel consumption reduction	1-2% during the project	Cost savings and emission cuts
Water recovery potential	Up to 1,000 kg/h in the project plant	Promote circular water use
Heat recovery capacity	700 kW of heat recovered for 1 t/h steam production	Boosts overall energy efficiency

Strategic Impact – High-level outcomes and EU policy alignment

KPI / Goal	Target	EU policies alignment
Annual CO ₂ saving (with full decarbonization potential)	> 35,700 t/y in a future expansion at larger scale (25 MW SOEC with heat integration with the furnace) > 10.9 Mt/year with large scale deployment in the steel industry*	Supports EU's 2050 climate neutrality goal
Heat recovery potential	>2.8 TWh/year with large scale deployment in the steel industry*	Boosts overall energy efficiency
Production of renewable hydrogen	Pre-certification of renewable hydrogen based on the requirements of RED II for RFNBOs	Renewable Energy Directive
Industrial hydrogen cost (LCoH)	< €2.2/kg with technology scale up	Makes green hydrogen competitive with fossil fuels
Market replication potential	Scalable solution for steel and other hard-to-abate sectors	Accelerate industrial decarbonisation - REPowerEU

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Thank you for your attention !

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