PROCEEDINGS OF ECOS 2026 - THE 39TH INTERNATIONAL CONFERENCE ON
EFFICIENCY, COST, OPTIMIZATION, SIMULATION AND ENVIRONMENTAL IMPACT OF ENERGY SYSTEMS
28 JUNE – 03 JULY, 2026, CONSTANTA, ROMANIA

Leveraging ORC technology to enhance renewable hydrogen production efficiency and industrial decarbonization

Georgios Mitkidis[a], *Stella Giannisi[b],* Lisa Borchert-Wright[c], Richard Aumann[d],
Nikolaos Skordoulias[e], Sotirios Karellas[f]

[a] *Motor Oil (Hellas) Corinth Refineries S.A. (MOH), Marousi-Athens, Greece, gmitkidis@moh.gr, CA*

[b] *Motor Oil (Hellas) Corinth Refineries S.A. (MOH), Marousi-Athens, Greece, sgiannisi@moh.gr*

[c] *ORCAN Energy AG – The Efficiency Company (ORCAN), Munich, Germany, lisa.borchert-wright@orcan-energy.com*

[d] *ORCAN Energy AG – The Efficiency Company (ORCAN), Munich, Germany, Richard.Aumann@orcan-energy.com*

[e] *Laboratory of Thermal Processes, Thermal Engineering Section, School of Mechanical Engineering, National Technical University of Athens (NTUA), Athens, Greece, nskordoulias@mail.ntua.gr*

[f] *Laboratory of Thermal Processes, Thermal Engineering Section, School of Mechanical Engineering, National Technical University of Athens (NTUA), Athens, Greece, sotokar@mail.ntua.gr*

Abstract:

Renewable hydrogen produced via electrolysis powered by renewable energy sources such as wind and solar is a critical enabler of industrial decarbonisation. Despite its environmental benefits, its large-scale deployment is hindered by high production costs, primarily driven by electricity prices. Improving system efficiency and reducing energy consumption are therefore essential to enhance its economic viability. This study investigates the integration of waste heat recovery through Organic Rankine Cycle (ORC) technology in an industrial alkaline electrolysis (AEL) system within a refinery environment. The work is conducted under the EU-funded EPHYRA project, which aims to demonstrate large-scale renewable hydrogen production and industrial symbiosis. Two configurations are evaluated: (i) direct coupling of the ORC with the electrolyser to recover heat from the electrolyte loop and (ii) indirect coupling, where the ORC exploits medium-temperature waste heat from refinery processes, such as Hydrodesulfurisation (HDS) unit rundown streams, to generate zero carbon electricity that can be supplied virtually to the electrolyser. The results show that direct coupling can recover up to 90–100% of the electrolyser waste heat, producing up to 527 kWe for a 50 MW electrolyser system, while reducing cooling water consumption. However, operational constraints and cooling risks limit its practical implementation. In contrast, the indirect configuration demonstrates higher ORC efficiency (up to 8%) due to higher temperature heat sources and improved operational stability. The selected optimal scenario achieves net power outputs of up to 228 kWe, annual CO_2 emissions reductions of approximately 1,100 tonnes, and a levelised cost of energy as low as 20 €/MWh under subsidised conditions. Overall, the integration of ORC systems with electrolysis and refinery waste heat streams enhances energy efficiency, reduces operational costs, and supports circular economy principles. The findings provide a scalable and replicable pathway for improving the competitiveness of renewable hydrogen and accelerating industrial decarbonisation.

Keywords:

Alkaline electrolysis; Hydrogen; Industrial symbiosis; ORC; Waste heat; efficiency.

1. Introduction

Renewable hydrogen has emerged as a key solution for industrial decarbonisation, fuelled by the pressing need to combat climate change and shift towards a sustainable, low-carbon economy. Renewable hydrogen is produced through electrolysis powered by renewable energy sources, such as wind and solar, and is a crucial vector in reducing the carbon footprint of energy-intensive sectors. Electrolysis processes, the most matured being the alkaline electrolysis (AEL), has emerged as a promising technology to scale up the production of renewable hydrogen and contribute to meeting these ambitious climate targets [1].

Despite its significant environmental advantages, the cost of renewable hydrogen remains considerably higher compared to fossil-based hydrogen and low-carbon hydrogen alternatives, posing economic challenges for large-scale adoption. The primary cost driver for renewable hydrogen production remains the price of electricity, which is often volatile and can significantly impact the overall feasibility of projects. As a result, ensuring that the power used in electrolysis is both affordable and certified as renewable is fundamental to achieving widespread adoption and realising genuine emissions reductions [2], [3].

To address the dual challenge of high-power costs and the need for verifiable renewable energy, the integration of waste heat recovery systems presents a promising solution increasing the industrial energy efficiency [4]. Specifically, by harnessing waste heat from electrolysis process, the overall system efficiency is increased. Literature indicates that increased electrolyser system efficiency by up to 15% via waste heat utilisation is achievable, making this approach highly attractive [5]. Another study [6], showed via process simulations in Aspen Plus that utilising PEM electrolyser’s waste heat through an ORC system can increase first law efficiency from 78% to 98% (considering thermal and electrical conversion efficiencies). This enhanced efficiency translates into lower electricity demand from external sources, reduced carbon footprint, and improved competitiveness for renewable hydrogen in the market. However, the technoeconomic feasibility of such integration has not been yet investigated in an industrial relevant environment.

Waste heat recovery can be achieved with Organic Rankine Cycle (ORC) technology. ORC systems recover low-grade waste heat to generate power without emissions [6] using an organic working fluid instead of water. **Figure 1** shows the ORC concept and the principle of operations. ORC systems suit applications like industrial processes, geothermal, or biomass where temperatures are below 300–400°C. Therefore, such systems constitute a potential solution to valorise waste heat from electrolysers, where the heat source temperature is typically between 70-90^{o}C increasing the overall system energy efficiency. The ability of ORC technology to convert otherwise unused thermal energy into valuable power provides a direct means to reduce the net energy cost for hydrogen production, while also save in cooling water consumption. Consequently, coupling renewable hydrogen production with ORC systems provides a strategic pathway to maximise decarbonisation benefits, enhance industrial competitiveness, and accelerate the transition to a sustainable energy future.

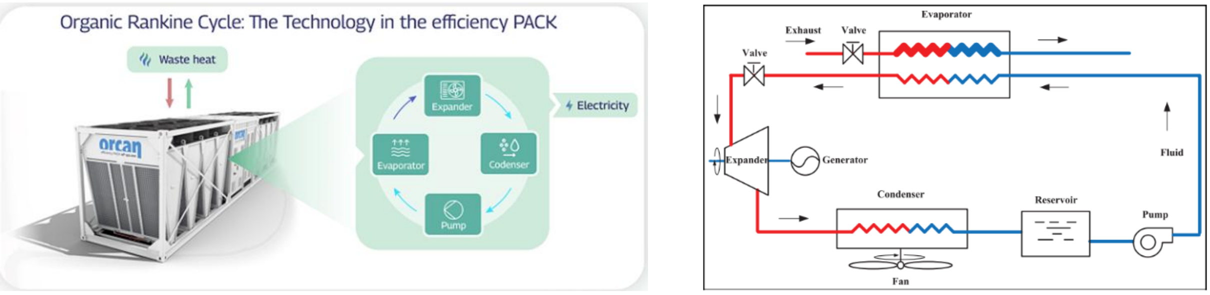

Figure 1*. Organic Rankine Cycle concept and principle of operation by ORCAN Energy AG*

Furthermore, in industrial settings, such as refineries, significant quantities of waste heat are routinely generated from various processes [7], [8]. Harnessing this waste heat through an ORC system not only improves the overall energy balance of the facility but also aligns with circular economy principles by maximising resource utilisation and minimising environmental impact. When this generated electricity supplies virtually the electrolysis system there is an indirect coupling of the ORC with renewable hydrogen production with cost and environmental benefits.

In this paper, a comprehensive study has been performed to explore the benefits of integrating an ORC system with waste heat streams in an electrolysis system and other industrial processes specifically from refinery sources, i.e. high flow-rate rundown heat streams currently cooled against air and/or cooling water. More specifically, the study investigates direct coupling of the ORC system with the electrolyser stack to recover heat from the lye solution, and utilisation of waste heat from other refinery operations, such as rundown diesel streams from HDS units. These approaches are evaluated in terms of technical feasibility, energy recovery potential, and cost-effectiveness, providing valuable insights for future industrial decarbonisation initiatives.

The work has been conducted in the framework of the EPHYRA project (101112220 – HORIZON-JTI-CLEANH2-2022-2), an EU-funded project by Clean Hydrogen Joint Undertaking (CHJU). The main scope of EPHYRA is to demonstrate the integration of a first of-its-kind renewable hydrogen production facility at industrial scale in South-East Europe by constructing and operating a renewable hydrogen electrolysis plant within MOH's Corinth refinery, originally designed at 30 MW and now being implemented at 50 MW capacity. EPHYRA also introduces the concept of industrial symbiosis through a series of innovative solutions and synergies. Industrial symbiosis aims to make renewable hydrogen competitive to fossil hydrogen by utilizing optimal energy management strategies, oxygen by-product utilization, utilization of non-fresh water sources and waste heat recovery. The integration of waste heat recovery system in the industrial electrolysis plant and other refinery sources and the demonstration of its benefits is the scope of this paper.

2. Methodology

As part of the EPHYRA project, the industrial coordinator (MOH) with the support of the technology supplier (ORCAN) conducted a study to explore the feasibility of integrating an Organic Rankine Cycle (ORC) system to a 30 MW alkaline electrolyser (AEL) and its upscale to 50 MW and/or other units within the industrial environment (refinery) to valorize their waste heat, utilize generated zero carbon electricity to virtually supply the electrolyser and boost the overall efficiency.

The AEL system is co-located in MOH industrial complex (refinery) enabling synergies and industrial symbiosis. The ORC is conceptualized and modelled in proprietary simulations tools to harness waste heat from both the proposed AEL module as well as existing refinery operations [9, 10].

The industrial AEL system has an optimal operational temperature within a range of 80–90 °C. Since, electrolysis is an exothermic reaction, the lye solution is continuously recycled, separated from the gases and cooled externally at 70-72 °C before going back to the electrolyser cells. At base case, its thermal management is achieved through a dedicated cooling water circuit, wherein water enters the system at 32 °C and exits at 42 °C which is subsequently cooled in a cooling water tower. In this scenario the ORC is directly coupled with the electrolyzer stack via a closed loop system to recover heat from the electrolyte solution instead of this being cooled with open loop cooling water. Effective thermal recovery is feasible through integration of the ORC evaporator with the lye solution. This way the ORC system utilizes the waste heat from the AEL module and at the same time replaces cooling water that would be used to cool down the AEL stacks.

In addition, the integration of other waste heat sources from the industrial asset was studied either complementary to the electrolyser or on a stand-alone basis with respect to its performance and cost efficiency. Their waste heat recovery potential was evaluated based on both temperature and mass flow rate. Among the identified streams, two rundown diesel streams from an HDS unit were selected as the optimal heat source due to their relatively high mass flow rate, which translates into greater recoverable thermal energy. These streams exhibit temperatures between 100 °C and 130 °C.

The two scenarios assessed are depicted in **Figure 2** and are described below:

- Scenario-A: Electrolyser cooled by an ORC with air-cooled condenser (**Figure 2-A**). The ORC is directly coupled with the electrolyser stack via a closed loop water system to recover heat from the lye solution. The ORC system utilizes the waste heat from the AEL module replacing the cooling water.
- Scenario-B: Electrolyser cooled by cooling water and ORC using another source of waste heat available in the refinery to provide electricity to electrolyser (**Figure 2-B**). Two rundown diesel streams from a HDS unit were selected as the optimal heat source for this solution due to their relatively high thermal flow rate (100 °C and 130 °C). The zero-carbon electricity produced by the ORC is virtually allocated to the Electrolyser via an advanced energy management system.

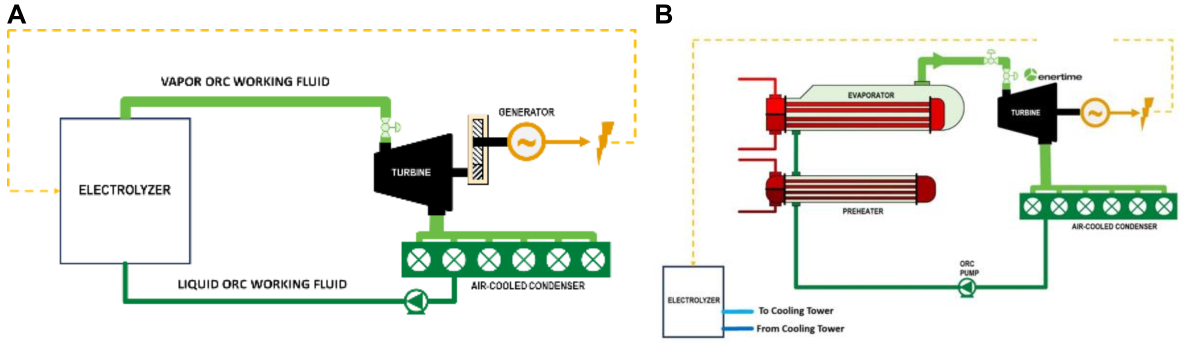

***Figure 2**. Proposed Waste Heat Valorization concepts via ORC integrated with electrolysis system.*

3. Results and Discussion

The ORC system vendor (ORCAN) offers a compact, plug and play solution with containerized modules (ISO 669 40'HC container). The system has an intermediate closed water loop as the heat transfer medium and the condenser is air-cooled offering a fully standardized solution that minimizes safety risks. This standardized system is called "The Efficiency Pack" and is shown in Figure 3.

Figure 3. *A schematic of "The Efficiency Pack" (left) and a photograph from a reference site (right).*

Based on the modelling performed by the vendor, the integration of an ORC system with the Electrolyser (Scenario-A) can effectively utilize the majority of the Electrolyzer waste heat (90-100%). The ORC system in Scenario-A is able to generate 406-580 kWe gross power from 10 efficiency packs (58 kWe gross power output per unit), utilizing 90-94% of a 30 MW electrolyser's waste heat at Beginning of Life (BOL) and End of Life (EOL) conditions accordingly. Accounting the power consumption of the ORC system, e.g. pumps, the net power output is 217 – 310 kWe (31 kWe net power output per unit) for the 30 MW electrolyser. Similarly, for a 50MW electrolyser system the gross generated power is 754-986 kWe and the net generated power is 403 – 527 kW$_e$ from 17 efficiency packs utilizing 96%-100% of its waste heat at BOL and EOL conditions. In both cases the ORC net efficiency is ~3%, driven by the low inlet temperature.

Scenario-A would benefit from reducing the cooling water consumption in the electrolyser, while also supply carbon-free energy. On the other hand, this configuration may present a major risk with regards to the effective ability to cool the electrolyser during summer operation. Mitigating this risk requires a major overdesign of the heat exchanger dedicated to cooling the electrolyser, with an impact on the investment cost for this component. Also varying AEL conditions between BOL and EOL may lead to underutilized ORC asset.

Scenario-B considers decoupling the electrolyser from the ORC: the electrolyser will be cooled with a cooling water loop (or air cooling) while the ORC will be installed in other unit within the refinery to exploit medium-grade waste heat (100-130°C) and increase its efficiency. In this case the ORC will be integrated to the electrolyser in-directly by supplying its produced energy through the energy management system. It also allows the ORC to work with heat sources that are normally stable throughout the year, unlike the waste heat from the electrolyser which is more variable throughout the year as it depends directly on the load of the electrolyser. This solution is preferred from the standpoint of ORC operation, performance efficiency and demonstrating such a system in an industrial environment for further deployment.

In Scenario-B utilizing the waste heat from the refinery HDS unit rundown diesel streams, the ORC can produce 228 kWe net output from 2 efficiency packs by using the medium temperature hot diesel stream (127°C), and/or 209 kWe net output from 3 efficiency packs by using the low temperature (110^{o}C) hot diesel stream. Both streams could also be combined in a cascade configuration of 5 efficiency packs to increase the net power output to 437 kWe. This solution would however lead to reduced ORC efficiency, increased plot plan and capital intensity that would exceed the plot limitations in the non-ATEX area of the HDS unit and the EPHYRA budget limitations, respectively. Therefore, this solution is not further considered in current analysis.

The integrated system for renewable hydrogen production within the EPHYRA project is depicted in Figure 4. Figure 4 introduces also the concept of the digital twin (open loop) that is being developed within the EPHYRA to optimize the electrolyser operations formulating also the thermal energy integration strategy and the electrical energy management strategy.

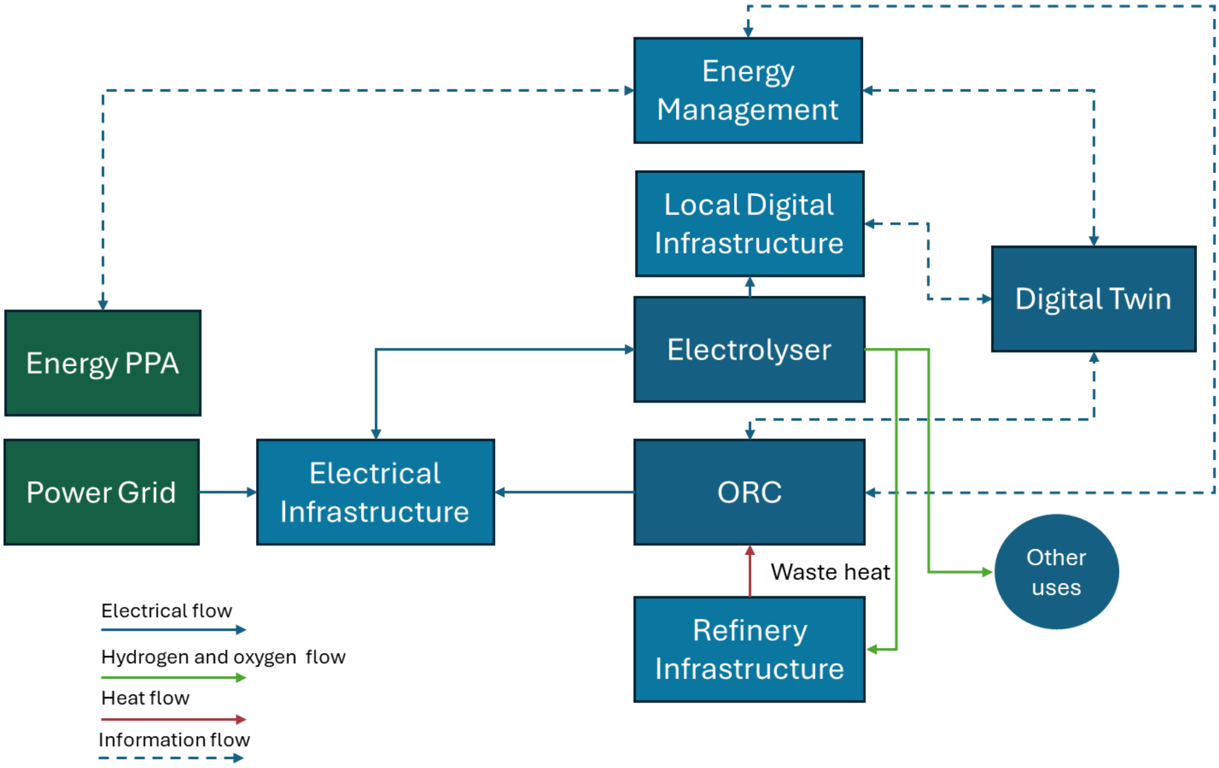

***Figure 4**. Schematic representation of the integrated hydrogen production system.*

The scenario assessment results are shown in **Table 1**. The results indicate that Scenario B1 is the most cost-effective solution with the highest achieved ORC efficiency (**Figure 5**). Therefore, this solution was selected for implementation within the framework of the EPHYRA project. With this scenario 967 tonnes of CO_2 are saved annually from the energy production, assuming an emission factor of around 500 gCO_2 per kWh of existing power plant (gas turbine) in the refinery. Additional CO_2 savings of 127 tpa are achieved from the by-pass of the air coolers of the rundown stream. The Levelized Cost of Electricity (LCOE) from the proposed system is estimated at 126 EUR/MWh unsubsidized* and 20 EUR/MWh subsidized with EPHYRA grant.

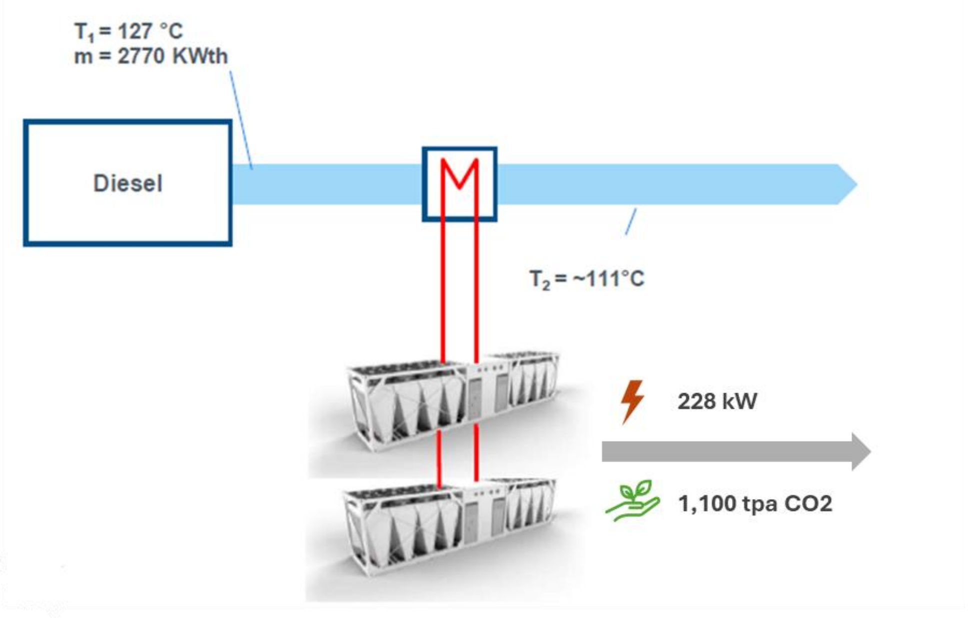

***Figure 5**. Proposed solution to be implemented within the EPHYRA project.*

---

[*] With CAPEX on installed basis.

***Table 1**. Comparison of the ORC integration scenarios.*

	Scenario A1 **30 MW**	**Scenario A2** **50 MW**	**Scenario B1**	**Scenario B2**
Temperature In/Out	85/70 ^{o}C	85/70 ^{o}C	127/110 ^{o}C	110/80 ^{o}C
Overall Heat Removal	7651 kW_{th} (BOL) 10930 kW_{th} (EOL)	14209 kW_{th} (BOL) 18581 kW_{th} (EOL)	2770 kW_{th}	4947 kW_{th}
Electricity gross generation	406 kW_e (BOL) 580 kW_e (EOL)	754 kW_e (BOL) 986 kW_e (EOL)		
Electricity net generation	217 kW_e (BOL) 310 kW_e (EOL)	403 kW_e (BOL) 527 kW_e (EOL)	228 kW_e	209 kW_e
# Efficiency Packs	7 – 10	13 – 17	2	3
ORC Efficiency	3%	3%	8%	4%
Capital Cost per net Power Output [1]	12900 €/kW_e	12900 €/kW_e	3500 €/kW_e	5700 €/kW_e
Capital Cost per Heat Abated [1]	366 €/kW_{th}	366 €/kW_{th}	289 €/kW_{th}	243 €/kW_{th}
Payback Time (unsubsidised/subsidised)[2]	7 yrs / 4 yrs	9 yrs / 6 yrs	6 yrs / 1 yrs	9 yrs / 4 yrs

[1] *Capital Costs indicated on Equipment E&P basis (uninstalled)*

[2] *The payback time is estimated with CAPEX assumption on installed basis. Subsidised payback time considers the EPHYRA subsidy*

The payback time is calculated considering the total capital costs on installed basis with and without the EPHYRA subsidy. The revenue stream consists of the revenues from the produced power plus the CO_2 emission savings compared to its counterpart, i.e. the refinery's power plant, and the savings due to the reduced need for cooling water for the electrolyser.

4. Conclusions

A comprehensive techno-economic analysis was conducted within the EPHYRA project to evaluate the potential of utilizing waste heat from Electrolyser and other medium-temperature heat streams within the Refinery via an Organic Rankine Cycle (ORC) system to generate carbon free power and increase industrial efficiency.

A key finding is the ORC unit's capacity to recover the majority of waste heat produced by the electrolysis unit- up to 90-100%. This significantly reduces the cooling water demand. The investment cost is around 370 EUR/kWth and the co-generated power output is 0.03 kWe/kWth (3% efficiency).

However, the analysis has identified as the optimal configuration to be implemented within the project the ORC system, utilising a medium-temperature (127°C) diesel rundown stream. This solution is the most viable and cost-effective for integration within the available EPHYRA budget, fitting also the available plot plan.

The proposed ORC system offers a compact solution, making it suitable for sites with limited available space. It produces carbon-free energy, saving approximately 1,100 tonnes of CO_2 per annum in respect to its counterpart, i.e. the refinery power plant, with a LCOE of 126 EUR/MWh, which is considerably reduced to 20 EUR/MWh when the EPHYRA subsidy is accounted. Its higher efficiency (~8%), attributed to the higher inlet temperatures, sets a benchmark for future ORC integrations in similar industrial environments. By virtually integrating the power generated by the ORC system with the electrolysis system through advanced energy management, the project underscores the potential for seamless symbiosis between these technologies, paving the way for enhanced operational flexibility and energy optimisation.

Looking forward, the successful demonstration of ORC-electrolyser integration within the EPHYRA project provides a replicable framework for other industrial settings. Future research and development should focus on further optimising system efficiency, exploring additional waste heat sources, and enhancing the scalability of the technology. The insights gained here are expected to inform policy, investment, and technological strategies for the widespread adoption of integrated waste heat recovery solutions in renewable hydrogen production.

Acknowledgment

This research was funded by the Clean Hydrogen Partnership and its members Hydrogen Europe and Hydrogen Europe Research through project EPHYRA with Grant Agreement No. 101112220.

References

[1] S. O. Jeje, T. Marazani, J. O. Obiko and M. B. Shongwe, "Advancing the hydrogen production economy: A comprehensive review of technologies, sustainability, and future prospects," *International Journal of Hydrogen Energy,* vol. 78, pp. 642-661, 2024.

[2] G. Georgopoulos, P. Papadopoulos, G. Mitkidis and S. Giannissi, "Active trading and regulatory incentives lower the levelized cost of green hydrogen in Greece," *Communications Earth & Environment,* vol. 6, no. 370, p. 1–14, 2025.

[3] N. Skordoulias, S. Karellas, D. Lyridis, S. Giannisi and G. Mitkidis, "RES-Electrolyser Coupling within TRIERES Hydrogen Valley – A Flexible Technoeconomic Assessment Tool," *Energy Conversion and Management,* vol. 327, p. 119562, 2025..

[4] L. Pastore, A. Sgaramella, G. Bruno, G. Basso and L. d. Santoli, "Coupling high-temperature electrolysis and industrial waste heat for on-site green hydrogen production: energy, economic and environmental analysis," *International Journal of Hydrogen Energy,* vol. 126, pp. 87-98, 2025.

[5] E. van der Roest, R. Bol, T. Fens and A. v. Wijk, "Utilisation of waste heat from PEM electrolysers – Unlocking local optimization," *International Journal of Hydrogen Energy,* vol. 48, no. 72, pp. 27872-27891, 2023.

[6] A. M. V. Vives, R. Wang, S. Roy and A. Smallbone, "Techno-economic analysis of large-scale green hydrogen production and storage," *Applied Energy,* vol. 346, p. 121333, 2023.

[7] KCORC, "Thermal Energy Harvesting: The Path to Tapping into a Large CO2 free European Power Source," Knowledge Center on Organic Rankine Cycle technology (KCORC), Tech. Rep., Version 2, Delft, The Netherlands, 2025.

[8] A. Auld, A. Berson and S. Hogg, "Organic Rankine cycles in waste heat recovery: a comparative study," *International Journal of Low-Carbon Technologies,* vol. 8, no. suppl_1, p. i9–i19, 2013.

[9] F. Vélez, J. Segovia, M. C. Martín, G. Antolín, F. Chejne and A. Quijano, "A technical, economical and market review of organic Rankine cycles for the conversion of low-grade heat for power generation," *Renewable and Sustainable Energy Reviews,* vol. 16, no. 6, pp. 4175-4189, 2012.

[10] J. B. M. Kamal, L. Kyriakidis and B. D. a. H. A.-G. Saskia Bublitz, "Optimal Operation of an Alkaline Electrolyzer in an Industrial Setting Using Effective Linearization Techniques," in *ESCAPE36 conference*, Sheffield, UK, 21-24 June 2026.

[11] L. Kyriakidis, J. B. M. Kamal, S. Bublitz, B. Dorneanu and H. Arellano-Garcia, "Energy Management of a Renewable-Powered Alkaline Electrolyzer System: A Comparative Study of Nonlinear Optimization Methods," in *ESCAPE36 conference*, Sheffield, UK, 21-24 June 2026.