Hydrogen Utilization in Industry. A Cost Comparison between On-Site Production and External Supply

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ABSTRACT

Hydrogen has gained prominence as a versatile and sustainable energy carrier with significant potential for decarbonizing various industrial processes. This paper explores the utilization of hydrogen in an industrial context, focusing on its applications, benefits, challenges, and future prospects. Key industrial sectors, such as refining, chemicals, and steel production, are discussed, highlighting the role of hydrogen in reducing greenhouse gas emissions and enhancing energy efficiency.

Additionally, the paper addresses the technical and economic challenges associated with hydrogen adoption and outlines the research and development efforts required to unlock its full industrial potential. Furthermore, the economic convenience of on-site hydrogen production is compared against the supply from an external source, proposing a formula for a quick assessment of the most profitable alternative.

INDEX TERMS

cost, decarbonization, green hydrogen, industry

I. INTRODUCTION

The energy transition, *i.e.* the current shift from a system mainly based on fossil fuels to the deep penetration of renew- able energy sources, is of prominent importance to combat the current climate change that is causing desertification, melting of glaciers, and increased extreme phenomena such as floods and hurricanes.

The industrial sector is a major contributor to global carbon emissions, making it imperative to explore clean energy alter- natives, although this is a challenging task. Hydrogen, with its unique properties and versatile applications, has emerged as a promising solution in the last few years. In detail, hydrogen can replace traditional fuels in the steel and chemical industrial sectors, where it is necessary to reach high temperatures that cannot be achieved through electrification, or in the heavy transport sector, where the on-board electricity generation via fuel cells allows longer travel range and shorter refueling time with respect to battery electric vehicles [1]. Moreover, hydro- gen can be used as a reacting chemical element in industrial processes such as the production of pig iron, replacing coke in iron oxide reduction reactions.

The strengths of hydrogen are [2]:

- High specific energy (heating value per unit mass);
- Great availability (hydrogen is the most abundant element in the universe);
- Its combustion produces only water vapor without emit- ting CO_2.

With specific reference to the hydrogen as an energy vector, further major benefits of hydrogen are [2]:

- Decarbonization: Hydrogen's combustion and use in industrial processes generate only water as a byproduct, reducing carbon emissions. This aligns with global efforts to mitigate climate change and achieve net-zero emissions;
- Energy Efficiency: Hydrogen can enhance energy efficiency in various applications. For instance, in steel pro- duction, it allows for the elimination of energy-intensive coke ovens and blast furnaces, resulting in significant energy savings;

- Energy Storage: Hydrogen can store excess renewable energy, ensuring a stable energy supply for industries. This is particularly valuable in regions with intermittent renewable energy sources, as hydrogen can serve as a reliable energy buffer.

This paper examines the integration of hydrogen in industrial processes and its potential to revolutionize various sectors. Section II provides a recap of some relevant issues related to the widespread transition to a hydrogen-based energy system. Section III illustrates the proposal of synthetic formulas for the assessment of the economic and environmental profitability of green hydrogen production systems, whose results are shown in Section IV. Section V discusses the results and shows the main conclusions.

II. HYDROGEN-RELATED ISSUES

A. Hydrogen Production

Although hydrogen is known to be the most abundant element in the universe, it is not a primary energy source because it is naturally available bound to other elements and it must be produced by consuming energy. This is why hydrogen is considered an energy vector rather than a proper energy source.

Hydrogen can be produced through various methods, including Steam Methane Reforming (SMR), electrolysis, and gasification, with each method having its advantages and challenges. Nevertheless, although SMR is the method with the highest carbon emissions, it is still the main technology used now in the world, due to its advantages such as high efficiency and low operational and production costs [3].

With the current technological level, the unique truly sustainable hydrogen production process, with almost no impact on the environment, is green hydrogen production, which is based on renewable electricity used to power electrolyzers that break down the water molecule into hydrogen and oxygen. Recent advancements in electrolysis have made green hydrogen production increasingly attractive for industrial use. Electrolysis, powered by renewable energy sources, generates ”green hydrogen,” which is free from carbon emissions during production. The main drawback of this process is the high cost, which is the main reason why in 2021, only 35 kton of hydrogen were produced via water electrolysis out of 94 Mton of the world production [4].

B. Hydrogen Industrial Applications

1) Refining: Hydrogen is a crucial feedstock in refining processes, enabling the removal of impurities and enhancing the production of cleaner fuels. Its integration can reduce the carbon footprint of the industry significantly. Hydrocracking and hydrotreating, two hydrogen-dependent processes, are vital for improving fuel quality and reducing sulfur content. The use of hydrogen in the refining industry has led to the development of hydrogen hubs, where hydrogen is produced, stored, and distributed to nearby refineries.

2) Chemicals: The chemical industry relies heavily on hydrogen for ammonia, methanol, and other key compounds. Transitioning to green hydrogen can reduce emissions and contribute to sustainable chemical production. Hydrogenation reactions in the chemical industry are vital for synthesizing a wide range of products, from pharmaceuticals to plastics. Additionally, the use of hydrogen in the chemical sector aligns with the principles of the circular economy, allowing for the recycling of hydrogen in various processes.

3) Steel Production: Hydrogen can replace coal in steelmaking, resulting in ”green steel.” This innovation not only reduces emissions but also improves the quality of the final product. Direct reduction processes using hydrogen can eliminate carbon dioxide emissions and offer a cleaner alternative to traditional blast furnace methods. Some steel manufacturers are already piloting projects to produce steel using hydrogen, paving the way for a more sustainable steel industry.

C. Current Challenges

1) High cost: Hydrogen production and transportation costs are critical factors influencing its adoption in industrial applications. While hydrogen offers numerous environmental benefits, the cost of producing, storing, and transporting it remains a significant challenge. Green hydrogen, produced through electrolysis powered by renewable energy, is considered the most sustainable option but is often more expensive than gray or blue hydrogen, which is derived from fossil fuels with carbon capture and storage (CCS) [3].

The cost of green hydrogen largely depends on the price of renewable electricity, the efficiency of the electrolysis process, and economies of scale. Lowering the cost of green hydrogen is essential to its competitiveness. Ongoing research and development efforts aim to enhance electrolyzer efficiency, reduce material costs, and optimize system design. Additionally, governments and industry stakeholders can play a crucial role in cost reduction through incentives, subsidies, and investment in infrastructure.

2) Storage and transportation: The massive adoption of hydrogen also presents economic and technical challenges from the storage and transportation points of view. Hydrogen has a lower energy density by volume, compared to traditional fuels, besides its reactivity with the oxygen in the air, requiring specialized storage and transportation solutions. Compression and liquefaction are common methods to transport hydrogen efficiently, but they come with energy and infrastructure costs. Innovations in high-pressure tanks and pipelines are under- way to improve hydrogen transport cost-effectiveness. In the meantime, solid-state chemical storage technologies are being developed, reducing safety-related issues but increasing costs. Collaborative efforts between industry and policymakers are necessary to develop cost-efficient transportation infrastructure, including pipelines and distribution networks, to enable the widespread use of hydrogen in industrial settings [3].

3) Safety: Handling and storing hydrogen safely is critical due to its flammability. Stringent safety protocols and training are essential to minimize risks associated with hydrogen use. Additionally, the development of safe hydrogen storage technologies is a priority.

4) Infrastructure: Expanding hydrogen infrastructure is necessary for its widespread adoption. This includes building hydrogen refueling stations, pipelines for hydrogen transport,

and retrofitting existing industrial facilities to accommodate hydrogen use.

D. The Sicilian case

The Hydrogen Valley in Sicily represents a pioneering initiative in the use of hydrogen as a clean energy carrier in a regional context. It is a collaboration between industrial partners, energy companies, and research institutions combining their expertise to create sustainable energy ecosystems based on hydrogen produced from renewable energies in which Sicily is rich, particularly solar and wind power. The Hydrogen Valley project harnesses this resource potential by using excess electricity generated from renewable sources to produce green hydrogen through electrolysis. This hydrogen can then be used in various sectors, including industry, transportation, and energy storage, promoting regional sustainability and economic development. The Hydrogen Valley not only contributes to reducing greenhouse gas emissions but also improves energy resilience and security by providing a model for integrating hydrogen technologies into regional energy systems, in line with broader global efforts to transition to a more sustainable, low-carbon future. For these reasons, on , the Sicilian Region's Department of Energy published a call for proposals aimed at selecting project proposals for the construction of renewable hydrogen production plants on brownfield sites [5]. The call was financed with resources from the National Recovery and Resilience Plan (Piano Nazionale di Ripresa e Resilienza, *in Italian*) for ”Green Revolution and Ecological Transition,” totaling 40 million euros, which will be divided among the four projects that passed the selection process, namely those of the companies Etna Hitech S.c.p.a., Societa` Agricola Agrobiofer, Duferco Energia and Res Integra [6]. Also noteworthy is the Hybla Project presented to regional institutions by Sasol Italy and Sonatrach Raffineria Italiana, an ambitious initiative to build an innovative plant capable of producing 7800 tons/year of hydrogen and 25,000 tons/year of ”low carbon” syngas, with the capture and reuse of CO_2 and a reduction in greenhouse gas emissions of 120 thousand tons/year. The hydrogen and ”low carbon” syngas, produced with energy from renewable sources, will be used to decarbonize processes at the two production sites and can also be used to meet potential additional needs in the area [7].

Sonatrach itself also signed a Memorandum of Understanding with Eni aimed at accelerating the development of gas fields in Algeria and especially decarbonization through green hydrogen. The Memorandum also provides for the technical and economic evaluation of a green hydrogen pilot project at Bir Rebaa North (BRN), in the Algerian desert, with the aim of contributing to the decarbonization of the BRN gas plant operated by the joint venture SONATRACH-Eni GSE [8]. The agreement represents a further step in strengthening energy cooperation between Italy and Algeria, and this is where Sicily can play a key role; thanks to its strategic location, Sicily can act as a link between the Italian peninsula and the countries of North Africa, where green hydrogen can be produced at a lower cost by exploiting local renewable energy resources, and transported to Sicily through pipelines.

III. PROPOSAL OF A FORMULA FOR THE HYDROGEN PROFITABILITY EVALUATION

As already stated in previous sections, due to the current high costs related to green hydrogen production (mainly related to the electrolyzers), this technology is still hardly adopted, particularly in the industrial sector. Nevertheless, the current price levels are becoming more attractive and the availability of a formula for the quick assessment of the economic profitability might enhance the penetration of green hydrogen.

Adopting the point of view of a factory with a high hydrogen demand who wants to shift to green hydrogen, the following two options are available:

- green hydrogen purchase from an external producer, assessing the cost due to the production, the transport to the factory and the producer profit;
- green hydrogen production with an on-site plant, assessing the costs for the installation and the operation of the necessary equipment.

In order to develop an easy-to-use formula but provide reliable information, the following assumptions were made:

1) the comparison was performed on an annual basis;
2) investment and operating costs related to the on-site hydrogen production were assumed as proportional to the hydrogen demand.

The assumption n. 1) is included to suppose that the external producer can offer a constant supply price independent of the season. Due to this assumption, the investment costs should be allocated on an annual basis. This operation was performed by multiplying the investment costs by the Uniform Series Capital Recovery Factor (UCRF) [9] of each component was evaluated according to (1).

$$UCRF = \frac{d\,(1+d)^N}{(1+d)^N - 1} \tag{1}$$

where d is the real discount rate and N is the useful life of each component. Using this technique, the replacement of a single component is also taken into account intrinsically. Investment costs are evaluated using an average unit cost for each component.

Adopting an approach alike the Levelized Cost Of Hydrogen (LCOH) calculation, the costs related to the two scenarios were equated in order to identify the breakeven operating cost offered by the external producer that makes the two alternatives economically equivalent, as in (2).

$$C_{H2,break} H_{2,dem} = \sum_i S_i\, C_{CAPEX,i}\, UCRF_i + \sum_j C_{OPEX,j} \tag{2}$$

where $C_{H2,break}$ is the breakeven operating cost to be evaluated, $H_{2,dem}$ is the annual hydrogen demand, i is the *i-th* component to be purchased (*e.g.* renewable energy system, electrolyzer, hydrogen storage), S

is its rated size, C_{CAPEX} is its unit investment cost, and $C_{OPEX,j}$ is the *j-th* operating cost or revenue related to the green hydrogen production (*e.g.* equipment running costs or tax incentives for emissions reduction).

Using (2) and the assumptions listed above, it is possible to write (3).

$$C_{H2,break} = \sum_i K_i \, C_{CAPEX,i} \, UCRF_i \; + \sum_j A_j \qquad (3)$$

where K_i and A_j are the proportionality factors between the annual hydrogen demand and the rated size of the *i-th* component or the *j-th* operating cost, respectively.

This formula for the breakeven cost can be interpreted as a simplified version of the LCOH, defined as the ratio between the discounted cash flow over the lifetime of the investment and the discounted hydrogen production over the lifetime of the investment, as in (4).

$$LCOH = \frac{\sum_{i=1}^{N} \frac{I_i + M_i + O_i - R_i}{(1+d)^i}}{\sum_{i=1}^{N} \frac{H_{2,i}}{(1+d)^i}} \qquad (4)$$

In (4), I_i is the investment cost in *i-th* year, M_i is the maintenance and service cost in *i-th* year, O_i is the operational cost in *i-th* year, R_i is the revenue income in *i-th* year, and $H_{2,i}$ is the hydrogen production in *i-th* year.

The approach used so far can be easily applied to extend (3) to the case of a final user with additional demands such as electricity or heating. In the case of electricity, the same equipment purchased for green hydrogen production might be used to fulfill both final requirements only with a higher value of the renewable energy system rated size. If e is the ratio between the annual electricity demand cost and the annual hydrogen demand cost, (3) can be extended to (5):

$$C_{H2,break} = \sum_i \frac{K_i \, C_{CAPEX,i} \, UCRF_i}{(1+e)} + \sum_j \frac{A_j}{(1+e)} \qquad (5)$$

Lastly, since the transition to a hydrogen-based energy system would also cause secure carbon emissions reduction, the considerations illustrated hereto might be also applied to environmental aspects. Taking into account the Global Warming Potential (GWP), *i.e.* the most commonly used indicator in Environmental Life Cycle Assessment studies to evaluate the equivalent carbon emissions, investment costs and operating costs in Eqn. (3) and (5) can be replaced with embodied GWP and operating GWP, respectively, as in (6)

$$GWP_{H2,break} = \sum_i \frac{K_i \, GWP_{embodied,i}}{N_i \, (1+e)} + \sum_k \frac{B_k}{(1+e)} \qquad (6)$$

where $GWP_{H2,break}$ are the life cycle operating emissions related to the green hydrogen production in an external facility and transport to the final user, N_i is the useful life of the *i-th* component while B_k are the proportionality factors between the annual hydrogen demand and the *k-th* operating GWP.

IV. CASE STUDY

In order to provide an order of magnitude of the breakeven costs and emissions from the formulas shown in the previous section, the steel industry in the Italian economic context was selected. In the case study, the equipment for the on-site pro- duction of green hydrogen is made up of a photovoltaic system powering an alkaline electrolyzer. The hydrogen production is stored in a pressurized tank before being sent to the industrial facility.

The breakeven cost was evaluated considering capital and operating costs for the equipment to be installed. In detail, the operating costs were evaluated for the water consumption of the electrolyzer while maintenance costs or environmental subsidies were neglected.

A unique value of real interest rate to evaluate the UCRF of all the technologies, set equal to the Weighted Average Cost of Capital (WACC) of the electricity distribution sector in Italy [10].

The embodied GWP for the alkaline electrolyzer and for the storage tank were evaluated from data reported in [11] and [12], respectively.

The proportionality factors were gathered from the results of an optimization study performed by some of the authors [13].

The main parameters used for this study are recapped in Table I, where *OH* is the number of annual operating hours of the facility.

TABLE I
PARAMETERS USED FOR THE CASE STUDY

Parameter	Value
Annual steel production	1,018,211 tons [14]
Hydrogen demand per 1 ton steel	51 kg [15]
Electricity demand per 1 ton steel	3.48 MWh [15]
Alkaline electrolyzer efficiency $\eta_{EL,e}$	54 kWh/kg$_{H2}$ (50 - 60) [16], [17]
Alkaline electrolyzer water demand $\eta_{EL,w}$	10 kg/kg$_{H2}$
Useful life for photovoltaic system	25 years [18]
Useful life for alkaline electrolyzer	20 years [16]
Useful life for hydrogen tank	50 years [12]
Investment cost for photovoltaic system	786.59 C/kW [19]
Investment cost for alkaline electrolyzer	875 C/kW (450 - 1300) [3]
Investment cost for hydrogen tank	623.95 C/kg [20]
Real interest rate (WACC)	5.2% [10]
Photovoltaic system investment factor	3,450*$\eta_{EL,e}$/*OH* [13]
Alkaline electrolyzer investment factor	3,000*$\eta_{EL,e}$/*OH* [13]
Hydrogen tank investment factor	12,000/*OH* [13]
OPEX factor	C_w $\eta_{EL,w}$ [13]
Electricity supply price	392.5 C/MWh [21]
Water supply price C_w	4.16 C/ton
Photovoltaic system embodied GWP	357.732 kg $CO_{2,eq}$/kW [18]
Alkaline electrolyzer embodied GWP	28 kg $CO_{2,eq}$/kW [11]
Hydrogen tank embodied GWP	1.699 kg $CO_{2,eq}$/ton [12]
Operating GWP factor	0 kg CO_2/year
Electricity supply GWP	0.7089 kg $CO_{2,eq}$/kWh [22]

V. RESULTS

The parameters shown in Table I were used in the equations shown in the previous section to identify the average breakeven hydrogen cost and breakeven hydrogen carbon emission in different cases.

These values should be considered as the maximum value of supply price or carbon emission which should be given by a hydrogen external producer to be more convenient than the on-site hydrogen production alternative.

The results of the case studies are shown in the following Table II, III, IV, and V, where a sensitivity on the main parameters related to the alkaline electrolyzer (investment cost and efficiency) is also provided, using the extreme values shown between parenthesis in Table I.

It is worth mentioning that, in order to completely satisfy the high hydrogen and electricity demands of the final user, the resulting rated sizes of both photovoltaic and electrolyzer have the order of magnitude of 1 GW or more. Although it is technically feasible, there are only a few solar farms in the world with this value of rated size up to date, mainly due to space constraints. However, the investment cost of these plants would be consistent with the average turnover of a steel plant.

A. *Electricity demand = 0*

The first set of results refers to the installation of equipment for the production of green hydrogen to meet the plant's final demand without taking into account the electricity demand (e = 0). For this case study, the photovoltaic system rated size was identified as the value allowing to cover the annual electrolyzer electricity demand, assuming the annual equivalent peak hours equal to h_{eq} = 1000 h/year. Thus, the investment factor for photovoltaic becomes $3{,}000^{*}\eta_{EL,e}/h_{eq}$. The rated sizes of the equipment are about 1.2 GW for the electrolyzer, about 8.5 GW for the photovoltaic, and about 87 tons for the storage tank.

Analyzing the results shown in Table II, the outcome is that, with current conditions, the breakeven cost for an external supplier might still overcome on-site production cost, since the LCOH for hydrogen produced through SMR ranges between 0.8 and 2.7 €/kg [2]. However, governments might introduce some incentives to push investors into this technology.

The results in Table II are in line with the figures provided by IEA for the LCOH for green hydrogen (3.2 - 7.7 USD/kg) [23] and to the value provided by RSE for green hydrogen produced with photovoltaic technology (LCOH = 6.8 USD/kg) [3].

Regarding the life cycle carbon emissions shown in Table III, where the sensitivity analysis was performed only on the electrolyzer performance, the results show that it is highly profitable to invest in an on-site green hydrogen production plant from an environmental point of view and that it would be hard for an external supplier to become more convenient than these values.

For this reason, this technological option might be a great contribution to the decarbonization of the steel sector. As a comparison term, GWP values for steam methane reforming of natural gas vary from 8.9 to 12.9 $kg_{CO2\ eq}/kg_{H2}$.

It is important to highlight that the right-hand side of (5) and (6) are not dependent on the hydrogen demand in the case of e = 0, thus making these results generic.

TABLE II

HYDROGEN BREAKEVEN COST FOR A FINAL USER WITH HYDROGEN DEMAND

$C_{H2,break}$ [€/kg$_{H2}$]		***Electrolyzer efficiency***		
		50 kWh/kg	54 kWh/kg	60 kWh/kg
Electrolyzer investment cost	450 €/kW	9.41	10.15	11.27
	875 €/kW	10.13	10.93	12.13
	1300 €/kW	10.85	11.71	13.00

TABLE III

HYDROGEN BREAKEVEN GWP FOR A FINAL USER WITH HYDROGEN DEMAND

	Electrolyzer efficiency		
	50 kWh/kg	54 kWh/kg	60 kWh/kg

$GWP_{H2,break}$ [$kg_{CO2,eq}/kg_{H2}$]	2.18	2.35	2.61

B. *Electricity demand ≠ 0*

The second set of results refers to the installation of equip- ment to cover both the electricity and green hydrogen final demands of the plant. This scenario requires an oversizing of the photovoltaic system from about 8.5 GW to about 12 GW, in order to completely cover the annual electricity demand of the steel production plant (3.5 TWh/year), in addition to the electrolyzer demand. The other two components have the same rated size.

In this case, since the breakeven hydrogen cost appears at both the right-hand side and left-hand side of (5) (it is at the denominator of e), is necessary to perform an iterative calculation.

It is easy to verify that, for this case study, the annualized investment cost for the photovoltaic would be lower than the annual electricity bill, thus making the investment highly attractive. For this reason, all the results shown in Table IV have negative values, meaning that an external supplier of hydrogen and electricity should offer a negative price in order to be economically competitive! Similar outcomes can be drawn for the equivalent carbon emissions shown in Table V. Nevertheless, as already stated, the economic or environmental profitability in this case are not the true barrier to the diffusion of this technology, since the space required to install a 12 GW photovoltaic plant would be huge and hard to find.

TABLE IV

HYDROGEN BREAKEVEN COST FOR A FINAL USER WITH ELECTRICITY AND HYDROGEN DEMANDS

$C_{H2,break}$ [€/kg_{H2}]		***Electrolyzer efficiency***		
		50 kWh/kg	54 kWh/kg	60 kWh/kg
Electrolyzer investment cost	450 €/kW	-13.49	-12.75	-11.63
	875 €/kW	-12.77	-11.97	-10.76
	1300 €/kW	-12.05	-11.19	-9.90

TABLE V - Hydrogen Breakeven GWP For A Final User With Hydrogen Demand

	Electrolyzer efficiency		
	50 kWh/kg	54 kWh/kg	60 kWh/kg
$GWP_{H2,break}$ [$kg_{CO2,eq}/kg_{H2}$]	-45.22	-45.05	-44.78

C. *Electricity demand ratio e = 1.5*

The last set of results refers to the installation of equipment to completely cover both the green hydrogen final demand and part of the electricity demand of the plant. Keeping constant the value of *e*, another set of iterative simulations was performed, changing the breakeven hydrogen cost, the share of electricity, and the photovoltaic rated size accordingly. Results are shown in TABLES VI and VII, showing that the hydrogen breakeven cost ranges between 4.9 €/kg and 6.2 €/kg while the electricity share ranges between 27.4% and 34.8%.

TABLE VI - Hydrogen Breakeven Cost For A Final User With Electricity And Hydrogen Demands With $e = 1.5$

$C_{H2,break}$ [€/kg_{H2}]		*Electrolyzer efficiency*		
		50 kWh/kg	54 kWh/kg	60 kWh/kg
Electrolyzer investment cost	450 €/kW	4.89	5.16	5.58
	875 €/kW	5.16	5.45	.89
	1300 €/kW	5.42	5.74	6.21

TABLE VII - Electricity Share For A Final User With Electricity And Hydrogen Demands With $e = 1.5$

E_{share} [%]		*Electrolyzer efficiency*		
		50 kWh/kg	54 kWh/kg	60 kWh/kg
Electrolyzer investment cost	450 €/kW	27.39	28.92	31.23
	875 €/kW	28.88	30.53	33.01
	1300 €/kW	30.37	32.14	34.80

VI. CONCLUSIONS

Hydrogen holds tremendous promise in decarbonizing industrial processes. Its applications in refining, chemicals, and steel production are just the beginning. Addressing challenges and fostering collaboration between industry, government, and academia is essential to unlock hydrogen's full potential in industrial contexts. As efforts to combat climate change intensify, hydrogen is poised to play a pivotal role in the transition to a sustainable and low-carbon industrial sector. The present paper illustrated the derivation and application of synthetic formulas for the evaluation of the breakeven cost between the on-site production and the purchase of green hydrogen. The case studies demonstrated the economic and environmental feasibility conditions of shifting to on-site green hydrogen production in industrial sectors, proving that this technology is still not economically mature enough to rival fossil fuel-based technologies. On the other hand, exploiting the renewable energy system to satisfy both hydrogen and electricity demands is a very profitable investment option.

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