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VIABILITY OF THE HYDROGEN ENERGY

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Annotation. This article review examines the potential of hydrogen as a key solution to decarbonize energy systems and reduce global greenhouse gas emissions. In the research has been analysed various production methods, focusing on electrolysis powered by renewable energy sources, evaluating the environmental and technical challenges associated with scaling up renewable hydrogen production. Using a combination of studies, the article evaluates the efficiency and sustainability of current hydrogen related technologies. The research reveals that while big progress has been made in improving electrolyser efficiency and reducing costs, challenges remain in achieving large-scale deployment due to infrastructure limitations and energy storage issues. The study concludes that green hydrogen has substantial potential to contribute to the global energy transition, but its widespread adoption will require continued investment in research, policy support and infrastructure development. These results suggest that hydrogen, if integrated with existing renewable energy systems, could play a critical role in achieving net-zero emissions targets by nearly future.

Keywords: green hydrogen; renewable energy; energy transition; decarbonization

INTRODUCTION

Raw materials are getting scarce due to the constant development of new technologies and the needs of people. The mitigation of climate change depends on the use of different kinds of energy sources away from fossil fuels.

Despite the fact that numerous renewable energies have been developed during the last years, none of them have had the impact to substitute the polluting energies. This is the main reason for the several side effects in the daily life of the people. It is important to consider all the benefits given by different sorts of possibilities, analysing and applying them.

Green hydrogen has the potential to solve those problems in a wide range of aspects, such as industry, transport and residential applications. Especially in terms of decreasing the contamination of the planet which is provoking heavy changes on it. Unless drastic measures are taken to reduce the carbon dioxide released, the outcome will be catastrophic.

The objective of this article is demonstrating the potential of the hydrogen as a sustainable energy source. For that, the main tasks to take in account are:

1. To analyse the production of hydrogen and its use in the industrial area.
2. To compare the hydrogen storage and transportation methods.
3.To determine the current hydrogen use given to hydrogen.

THE RESEARCH METHODS

This research has used a quantitative research method focused at analysing the data from diverse studies. The principal keywords used are all related with hydrogen, from the production to the usage of hydrogen in different scenarios. The research has analysed the advantages and disadvantages of the implementation of hydrogen as an alternative energy source. The principal databases used are *Science Direct* and *IEEE*, with articles from 2018 to present.

The main keywords used in the research are the ones shown in the following table. All of them are related to green hydrogen and its use. Example of that is the transport and production of this new renewable source.

Additionally, the research incorporates statistical tools to evaluate trends and patterns in the adoption of green hydrogen technologies across various sectors. Data from the selected studies were systematically categorized and analysed to identify key challenges and opportunities associated with scaling up hydrogen production and its integration into existing energy systems. The findings from this analysis provide valuable insights into the current state of green hydrogen development and the potential pathways for its widespread implementation.

Table 1

Keywords research

Key words	*Science Direct*	*IEEE*	Total
Hydrogen	871 047	9089	880 136
Green hydrogen	382 404	1149	383 553
Hydro production	52 475	2050	54 525

Hydro electrolysis	5129	61	5190
Hydro transport	33 660	312	33 972
Hydro energy	63 473	9426	72 899

The diversity of keywords used further ensures a well-rounded investigation into different aspects of hydrogen's role in energy systems.

HYDROGEN PRODUCTION IN THE INDUSTRIAL AREA

Based on the technique used to produce hydrogen, the energy source used and its effects on the environment, hydrogen is categorised into various colour shades, including blue, grey, brown, black and green (Squadrito, Maggio, Nicita, 2023). Using the steam-reforming/auto-thermal reforming method, grey hydrogen is extracted from natural gas, but CO_2 is emitted into the atmosphere as a by-product. When the steam-reforming method converts natural gas into hydrogen and the CO_2 emissions from the process are captured, this is known as blue hydrogen (Nicita et al., 2020). The most prevalent type of hydrogen used today is brown hydrogen, mainly produced via the gasification of hydrocarbon-rich fuel, in which CO_2 is released into the atmosphere as a by-product.

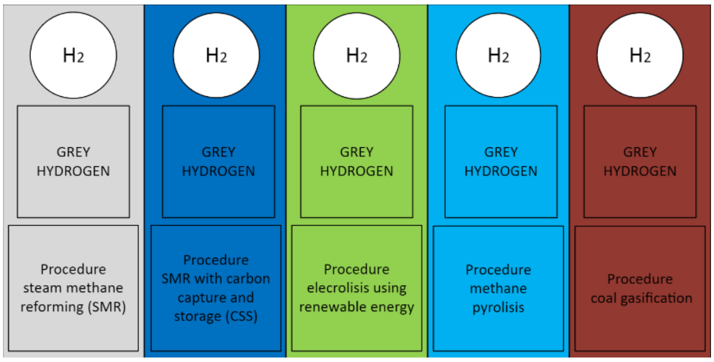

Figure 1. **Different hydrogen types**

Green hydrogen refers to hydrogen produced using renewable energy sources, typically through a process called electrolysis (Squadrito, Maggio, Nicita, 2023). This method uses electricity from renewable sources such as wind, solar, or hydropower to split water (H_2O) into its constituent parts hydrogen (H_2) and oxygen (O_2). When powered by renewable energy, the process results in zero carbon emissions, making it a key component of the energy transition towards sustainability. Also, this technology has been known for a long time, and is applied on the industrial scale (Chatenet et al., 2022) usually for production processes requiring high purity hydrogen.

$$2H_2O(l) \rightarrow 2H_2(g) + O_2(g) \quad (1)$$
$$H_2O + \text{energy} \rightarrow H_2 + \tfrac{1}{2} O_2 \quad (2)$$

For every kilogram of hydrogen produced by electrolysis, approximately 8 kilograms of oxygen is produced using about 9 kilograms of pure water and consuming about 50–55 kWh of electricity (depending on the electrolysis technology). But, usually, only hydrogen is cost-assessed without considering oxygen; only in recent few years the valorisation of oxygen was considered (Maggio, Nicita, Squadrito, 2019).

It is important to mention that another method, the so-called photoelectrochemical (PEC) hydrogen production technique, depends on the use of solar radiation to drive the water-splitting process directly; PEC cells transform solar energy into hydrogen (Song et al., 2022). Although this technology is still in its infancy, it indicates promise for producing hydrogen sustainably and effectively (Cao et al., 2020).

Due to the increasing large diffusion of PV and wind technologies converting sun and wind power into electric power, and a vision for the transition to 100% electric energy from RES, water electrolysis is considered the most suitable way for hydrogen production.

Although green hydrogen holds great promise in the transition to a cleaner energy future, challenges like high production costs and energy demands remain. Emerging technologies, such as photoelectrochemical hydrogen production, offer exciting possibilities for improving efficiency. As renewable energy technologies advance, green hydrogen could become a crucial part of our energy system, but continued innovation and investment will be key to unlocking its full potential.

COMPARISON OF THE HYDROGEN STORAGE AND TRANSPORTATION

The hydrogen can be stored in the form of liquid, gaseous fuel or solid state and the storage method is based on the use given to the hydrogen or the exportation method (Maka, Mehmood, 2024). Using high pressure tanks is one of the most effective ways of storing hydrogen but the most cost-effective, compressed hydrogen can be stored in gas form (Sarpong-Mensah, 2023). To get the hydrogen in liquid form, Joule-Thompson expansion cycle is the most used and simplest liquefaction technique, the problem is that storing the hydrogen in liquid form makes necessary high energy usage (Ahmad, Oko, Ibhadon, 2024). Hydrogen in solid form is obtained by chemical bonding to the form of metal hydrides, it is needed a delay between initial heating and the release of the hydrogen gas, and insufficient heat to generate hydrogen from the hydride (Sarpong-Mensah, 2023).

The selection of the storage form of the hydrogen strongly depends on the use or on the energy conversion it will be applied. On the one hand the costs of the gas form are lower, on the other hand in liquid form the volumetric energy density is high; also stored in solid form is considered safer and more efficient (Sarpong-Mensah, 2023).

The main ways to transport the hydrogen are by ship and by pipeline (Schmitz et al., 2024). The hydrogen in liquid form can be transported via ship and also, in some cases via trucks or other vehicles; by pipelines the hydrogen is transported commonly in gas form (Andeobu, Wibowo, Grandhi,2024). In the case of the ships, which are commonly used, the hydrogen has to be in liquid form. To get the hydrogen in liquid form has to be under -253ºC and the flashpoint is at -231ºC at 1 atm pressure (Cordazo et al., 2024). To get the liquid state, the pressure of the hydrogen is decreased, to the point that it can be dangerous on numerous occasions due to their high volatility (Zhu et al., 2024).

Currently pipelines are getting more and more common in the hydro transport sector. Proof of it is that Portugal and Spain reaffirmed they are willing to bolster the construction of a submarine green hydrogen pipeline, whose execution should begin in 2027, given the commitment to renewable energies. However, it has some drawbacks too. In these pipelines gas can be transported in gas or liquid form, but liquid hydrogen has some unique properties that give advantages over gas hydrogen, including higher energy density, ability to be transported over long distances and lower investment cost (Cordazo et al., 2024). The fluid mechanics of hydrogen transport present unique challenges due to hydrogen's low viscosity and high diffusivity, which influence turbulence and flow regimes within pipelines (Raj, et al, 2024). Due to the constant contact between the hydrogen and the pipeline, the pipeline easily gets embrittled by hydrogen, that is why it is important to elect proper materials such as high-strength steel pipelines (Sarpong-Mensah, 2023). Pressure drop in hydrogen pipelines is also a significant concern, affecting both the efficiency and safety of the transport system (Raj et al., 2024).

Choosing the right way to store hydrogen whether as a gas, liquid, or solid depends on the specific needs of the application and involves balancing factors like cost, energy density, safety, and efficiency. Liquid hydrogen, for example, can store more energy in a smaller space, but it requires a lot of energy to keep it cold and comes with risks, like being more volatile. As for transporting hydrogen, the infrastructure, including pipelines and ships, is improving, but there are still challenges to address, such as finding the right materials, controlling pressure, and ensuring smooth flow.

CURRENT HYDROGEN USAGE IN ENERGY SYSTEMS

Hydrogen is one of the least complex and plenteous elements on the planet, endowed with some special characteristics from being harmless, flexible, transportable and storable (Lui, Chen, Tsang, 2020). There are many different uses for hydrogen, such as energy storage, power generation, industrial production and fuel for fuel cell vehicles (Communication from the commission to the European parliament, the European Council, the Council, 2022).

The main usage of hydrogen currently is to decarbonize the polluted areas in crowded places and industrial areas, example of that is the efficiency that green hydro has in mining labours. In addition to the chemical and oil and gas sectors, it can also be utilised in transportation applications such as Internal Combustion Engines (ICEs) and fuel cells. A fuel cell vehicle powered by pure hydrogen is considered an emission-free vehicle because the only byproduct is water. While maintaining comparable characteristics in terms of peak speed, range, and acceleration, fuel cell vehicles are considered way more efficient than conventional vehicles (Staffell et al., 2019). Hydrogen can be converted into energy and methane, powering homes, industries, refineries and used as fuels for vehicles, trucks, ships and airplanes (Andeobu, Wibowo, Grandhi, 2024). In this way hydrogen provides high utilisation efficiency when converted into different forms of energy and also being one of the safest fuels in relation to the toxicity and fire hazards (Zayed, Sopian, Al-Hinai, 2020). That's why they are implementing hydro daily on heating private affairs such as buildings or public areas.

Hydrogen has a lot of promise as a clean and efficient energy source, offering real solutions for reducing emissions across industries and transportation. Its versatility makes it a key player in the shift toward more sustainable energy systems, especially when paired with other low-carbon technologies. As it will continue to explore and implement hydrogen in more areas, it could play a crucial role in creating a cleaner, more efficient energy future for everyone.

CONCLUSIONS

1. Hydrogen production is categorized into different colors based on the method of extraction, energy sources and environmental impact. Grey hydrogen, produced from natural gas with high CO2 emissions and blue hydrogen, where

CO_2 is captured, represent conventional methods that still contribute to greenhouse gas emissions. On the other hand, brown hydrogen, produced via the gasification of hydrocarbon-rich fuels, also results in significant CO_2 emissions. Green hydrogen, produced through electrolysis powered by renewable energy sources such as wind, solar or hydropower, emerges as the most environmentally friendly option, offering a pathway to zero carbon emissions. Though electrolysis has been established as a reliable industrial process for high-purity hydrogen production, emerging technologies like photoelectrochemical cells, which directly utilize solar energy, hold potential for further improving sustainability in hydrogen production. As renewable energy technologies continue to proliferate, electrolysis powered by renewable sources is posed to be a central method for producing hydrogen for a sustainable, low-carbon future.

2. Hydrogen storage and transport methods are chosen based on factors like application, cost, energy density and safety. Hydrogen can be stored in gaseous, liquid or solid form, each with its advantages and limitations. Gaseous hydrogen is cost-effective but has a lower energy density, while liquid hydrogen offers higher volumetric energy density but requires significant energy for its liquefaction, making it less efficient. Solid-state storage, typically through metal hydrides, is considered safer and more efficient, though it requires additional heat for hydrogen release. Hydrogen transport is primarily done through ships or pipelines, with liquid hydrogen being preferred for maritime transport due to its higher energy density. However, transporting liquid hydrogen presents challenges, including its extremely low temperature requirements and volatility. Pipelines, increasingly used for hydrogen transport, also face challenges such as the risk of hydrogen embrittlement and pressure drops, which can affect efficiency and safety. Advances in materials, such as high-strength steel and the development of new infrastructure, such as the planned submarine hydrogen pipeline between Portugal and Spain, are expected to help overcome these hurdles and support the growing hydrogen economy.

3. Hydrogen is a versatile and abundant element with a wide range of applications across industries, from energy storage and power generation to fuel for vehicles and heating. Its primary use today is in decarbonizing industrial and densely populated areas, such as in mining operations and the chemical, oil and gas sectors. In transportation, hydrogen fuel cell vehicles offer a promising solution for reducing emissions, as they produce only water as a byproduct and provide higher efficiency compared to conventional internal combustion engine vehicles. Additionally, hydrogen can complement other low-carbon technologies, serving as an alternative to natural gas for heating and being used in various sectors, including homes, industries, profile, and hydrogen, plays a key role in the transition to a more sustainable and cleaner energy system.

REFERENCES

Ahmad, A., Oko, E., Ibhadon, A. (2024). Comparative energy and exergy analysis of ortho-para hydrogen andnon-ortho-para hydrogen conversion in hydrogen liquefaction. International Journal of Hydrogen Energy. 78, 991-1003. DOI https://doi.org/10.1016/j.ijhydene.2024.06.368

Andeobu, L., Wibowo, S., Grandhi, S., (2024). Renewable hydrogen for the energy transition in Australia - Current trends., challenges and future directions. International Journal of Hydrogen Energy. 87, 1207-1223. DOI https://doi.org/10.1016/j.ijhydene.2024.08.499

Cardozo, P., Bo, C., Hyung, K., Choi, B., (2024). Risk assessment of hydrogen leakage and explosion in a liquid hydrogen facility using computational analysis. International Journal of Hydrogen Energy. 91, 950-964. DOI https://doi.org/10.1016/j.ijhydene.2024.10.129

Chatenet, M., Pollet, B., Dekel, D., Dionigi, F., Deseure, J., Millet, P., Braatz, R., Eikerling, M., Staffell, I., Balcombe, P., Shao-Horn, Y., Schäfer, H., (2022). Chem. Soc. Rev.. Water electrolysis: from textbook knowledge to the latest scientific strategies and industrial developments. 186, 109547. DOI https://doi.org/10.1039/D3CS00883E

Communication from the commission to the European parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions REPowerEU (2022), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A230%3AFIN

Lui, J., Chen, W., Tsang, D., You, S., (2020). A critical review on principles, applications, and challenges of waste-to-hydrogen technologies. Renew. Sustain. Energy Rev.. 134, 110365. DOI https://doi.org/10.1016/j.rser.2020.110365

Maggio, G., Squadrito, G., Nicita, A., (2022). Hydrogen and medical oxygen by renewable energy based electrolysis: a green and economically viable route. Appl. Energy. 306, 117993. DOI https://doi.org/10.1016/j.apenergy.2021.117993

Maka, A., Mehmood, M., (2024). Green hydrogen energy production: current status and potential. Clean Energy. 8(2), 1-7. DOI https://doi.org/10.1093/ce/zkae012

Raj, A., Larsson, S., Ljung, A., Forslund, T., Andersson, R., Sundstrom, J., Lundstrom, T., (2024). Evaluating hydrogen gas transport in pipelines: Current state of numerical and experimental methodologies. International Journal of Hydrogen Energy. 67, 136–149. DOI https://doi.org/10.1016/j.ijhydene.2024.04.140

Sarpong-Mensah, J., Wadhawan, J., (2023). Green Hydrogen work from University of Hull. Retrieved from: https://www.researchgate.net/publication/369794068_GREEN_HYDROGEN

Schmitz, R., Brandes, J., Nolte, H., Kost, C., Lux, B., Haendel, M., Held, A., (2024). Implications of hydrogen import prices for the German energy system in a model-comparison experiment. International Journal of Hydrogen Energy. 63, 566-579. DOI https://doi.org/10.1016/j.ijhydene.2024.03.210

Squadrito, G., Maggio, G., Andaloro, A., Nicita, A., (2020). Distributed hydrogen generation & energy communities for a zero-emission energy economy, in: E-Book of Abstracts of Hydrogen Power Theoretical and Engineering Solutions. International Symposium -HYPOTHESIS XV, On-Line Conference/, 18-19.

Squadrito, G., Maggio, G., Nicita, A., (2023). The green hydrogen revolution. Renewable Energy. 216, 119041. DOI https://doi.org/10.1016/j.renene.2023.119041

Staffell, I., Scamman, D., Abad, A., Balcombe, P., Dodds P., Ekins, P., Shah, N., Ward, K., (2019). The role of hydrogen and fuel cells in the global energy system. Energy & Environmental Science. 12 (2), 463-491. DOI https://doi.org/10.1039/C8EE01157E

Zayed, A., Sopian, K, Al-Hinai, A., (2020). Review of energy storage services, applications, limitations, and benefits. Energy Reports. 6, 288-306. DOI https://doi.org/10.1016/j.egyr.2020.07.028

Zhu, S., Fang, S., Bao, S., Zhi, X., Wang, K., Qiu, L., (2024). Efficient cooling strategies for liquid hydrogen pipelines: A comparative analysis. Renewable Energy. 236, 121488. DOI https://doi.org/10.1016/j.renene.2024.121488