IOP Conference Series:
Earth and
Environmental Science

PAPER • OPEN ACCESS

A review on blue and green hydrogen production process and their life cycle assessments

To cite this article: Ali Mahmoud Hamed *et al* 2023 *IOP Conf. Ser.: Earth Environ. Sci.* **1281** 012034

A review on blue and green hydrogen production process and their life cycle assessments

Ali Mahmoud Hamed[1], Tengku Nordayana Akma Tuan Kamaruddin[*,1], Nabilah Ramli[1] and Mohd Firdaus Abdul Wahab[2]

[1] Department of Mechanical & Aerospace Engineering,
[2] Department of Chemical Engineering & Sustainability,
Kulliyah of Engineering, International Islamic University Malaysia
E-mail: tengku_dayana@iium.edu.my

Abstract. Green and blue hydrogen are two types of hydrogen generated from renewable energy sources and fossil fuels, respectively. Green hydrogen is created by splitting water molecules into oxygen and hydrogen using renewable energy sources such as wind, solar or nuclear power in a process known as electrolysis. Blue hydrogen, on the other hand, is produced by reforming natural gas and capturing and storing the resulting carbon emissions. The production of both green and blue hydrogen has implications for the environment, and a life cycle assessment (LCA) can be used to evaluate the environmental impacts of hydrogen production and use. An LCA considers the entire life cycle of a product, from raw material extraction to end-of-life disposal and assesses the potential environmental impacts at each stage. The LCA of green hydrogen production generally shows a lower environmental impact compared to blue hydrogen production. This is because green hydrogen production does not emit any carbon emissions during the process, whereas blue hydrogen production still results in the emission of carbon dioxide. However, the environmental impact of green hydrogen production can vary depending on the source of the renewable energy used for electrolysis.

1. Introduction

Hydrogen has the ability to provide answers to problems associated with rising global energy demand, such as global warming, that are economically practical, financially rewarding, socially favourable, and energetically efficient [1,2]. Although hydrogen is odorless and invisible to our sight, it is frequently described in terms of a variety of colors such as green, blue, and grey hydrogen. The color designations are determined by the source of the hydrogen and the production process [3]. Both green and blue hydrogen have the potential to be used as a clean energy source in a variety of applications, such as fuel for transportation, heating, and electricity generation. However, the environmental impact and cost of producing each type of hydrogen vary significantly. Green hydrogen is currently more costly to produce than blue hydrogen, but this is likely to drop as the technology spreads and economies of scale are realised [4-5].

Hydrogen production life cycle assessment (LCA) is crucial Because it offers an in-depth assessment of the environmental consequences related to the whole life cycle of hydrogen generation. By conducting an LCA, stakeholders can better examine the environmental impact of hydrogen

IOP Conf. Series: Earth and Environmental Science 1281 (2023) 012034 doi:10.1088/1755-1315/1281/1/012034

production and clarify opportunities to reduce the environmental impact of hydrogen production throughout its life cycle. An LCA can also help assess the environmental impact of different hydrogen production methods, such as green and blue hydrogen production. In addition, LCA can help inform policy decisions related to hydrogen production and use [6-7].

2. Green hydrogen production process

Green hydrogen is the only type that is created in a climate neutral manner, indicating that it might be crucial in attempts to achieve net zero emissions. By electrolyzing water with clean electricity produced in excess by renewable energy sources like solar or wind power, green hydrogen is produced. Electrolysers employ an electrochemical process to split water into its constituents, hydrogen and oxygen with no carbon dioxide generated [4]. Green hydrogen has numerous potential applications across various sectors. It may be used to store excess renewable energy and provide scalable energy storage solutions. In transportation, it can power heavy-duty vehicles, shipping, and aviation, offering long driving ranges and shorter refuelling times. Industrial processes can benefit from green hydrogen as a replacement for fossil-fuel-derived hydrogen, reducing carbon emissions. It can be used in power generation, providing flexibility and reliability, especially in areas with intermittent renewable energy sources. Additionally, green hydrogen can be employed for heating and residential use, exported as an energy source, and contribute to global decarbonization efforts. Despite challenges, research, technology advancements, and supportive policies are propelling the development and deployment of green hydrogen applications. Figure 1 shows the water electrolysis process flow diagram [8-9].

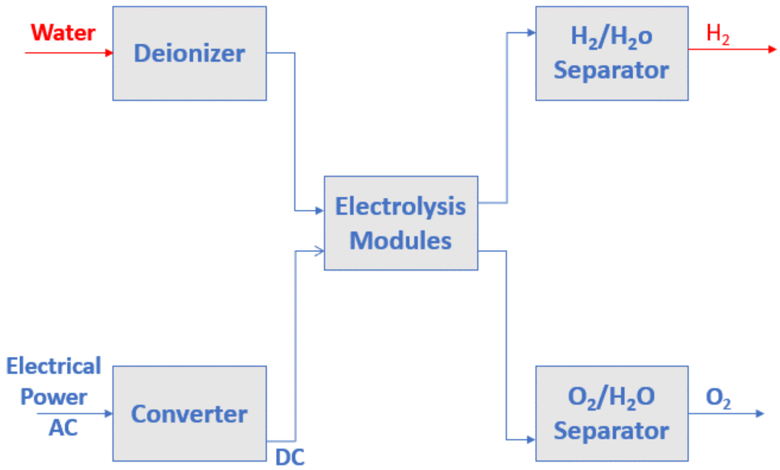

Figure 1. Water electrolysis process flow diagram [5].

The widespread adoption of green hydrogen faces challenges such as high production costs compared to fossil-fuel-derived hydrogen, limited infrastructure for production and distribution, scaling up renewable energy sources to meet demand, technological advancements to improve efficiency and durability, ensuring safety throughout the value chain, and the need for supportive policies and regulations. For 1 kg of green hydrogen produced, electrolyzers use more than 55 kWh of power. Overcoming these challenges requires collaboration, innovation, and investment to drive down costs, expand infrastructure, advance technology, ensure safety, and establish favourable policy frameworks, paving the way for the broader implementation of green hydrogen as a key element in the process of shifting to a carbon-neutral economy [10].

3. Blue hydrogen production process

Blue hydrogen is primarily produced by combining steam with natural gas using a process known as steam methane reforming (SMR). However, hydrogen is created, the emission of carbon dioxide remains a by-product. In order to absorb and store this carbon, carbon capture and storage (CCS) is necessary [11-12]. Figure 2 shows the steam methane reforming process with CCS [12].

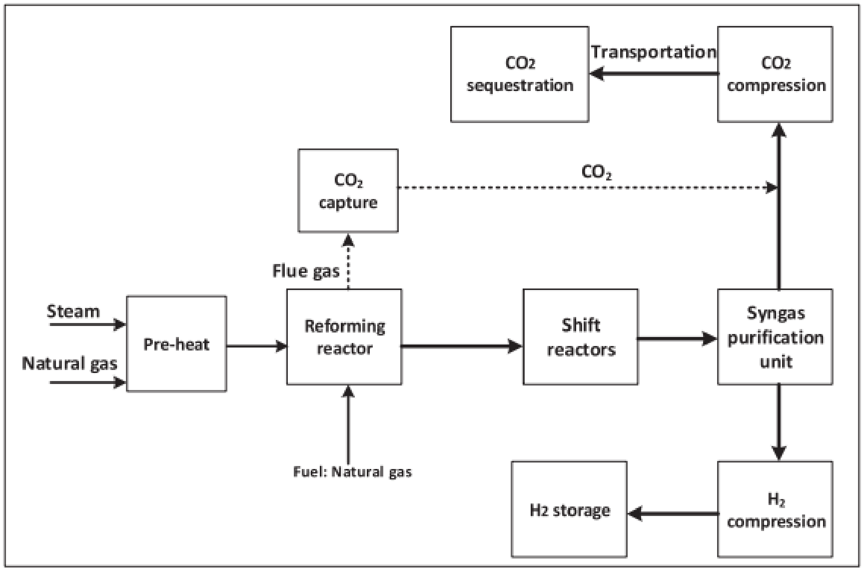

Figure 2. Process flow diagram of blue hydrogen production [12].

Blue hydrogen that produced from natural gas and integrated with carbon capture technologies, has potential applications in industrial processes, power generation, hydrogen blending, transportation, and energy storage. It can replace fossil-fuel-derived hydrogen, reducing emissions in industries like refining and steel production. It offers a low-carbon alternative for power generation and can be blended with natural gas in existing infrastructure. Blue hydrogen can be used as a fuel for transportation where electrification is challenging and can store excess renewable energy. However, concerns remain regarding the carbon footprint of natural gas extraction and the scalability of carbon capture technologies. The ultimate goal is transitioning to renewable and carbon-free sources of hydrogen, such as green hydrogen [12-13].

The adoption of blue hydrogen faces challenges including carbon emissions during production, reliance on natural gas, cost and infrastructure requirements, public perception and transition concerns, methane leakage, and the scalability of carbon capture technologies. Each 1 kg of blue hydrogen produced emits about 12 kg of CO_2. Cost and infrastructure present significant challenges for blue hydrogen adoption. Implementing carbon capture technologies and building the necessary infrastructure for blue hydrogen production and distribution can be expensive, requiring substantial investments. Developing and scaling up CCS infrastructure remains a challenge, impacting the overall cost-effectiveness of blue hydrogen. Overcoming these challenges requires research, technological advancements, supportive policies, and investments in both blue hydrogen and carbon capture, utilization, and storage (CCS) technologies. Transitioning to renewable and carbon-free hydrogen sources like green hydrogen is crucial for long-term sustainability [10-11].

4. Hydrogen life cycle assessment

A life cycle assessment is an approach for evaluating the consequences of a product's life cycle on the environment and the resources it uses [6]. LCA creates the context for the assessment to be performed and identifies the environmental effect [14,15]. Compared to natural gas reforming, certain results

IOP Conf. Series: Earth and Environmental Science 1281 (2023) 012034 doi:10.1088/1755-1315/1281/1/012034

demonstrated that the environmental impact of wind, hydropower, and solar thermal energy was lower [16]. Tabe 1 review the most common green hydrogen production methods and their environmental impact. Table 2 is a summarized review of the environmental impact of blue hydrogen production.

Table 1. Green hydrogen production methods and their environmental impact.

Hydrogen production technology	Power source	Function al unit	Environmental Impact (Greenhouse gas emissions)	Reference
High temperature water vapor electrolysis	Nuclear reactors	kg H_2	The global warming potential (GWP) is 2000 g CO_2-eq /kg H_2. (Including the nuclear power plant emissions)	(Utgikar & Thiesen, 2006)
Alkaline electrolyzer	Solar PV	Kg dry hydrogen	2.3 – 4.3 kg CO_2-eq / kg H_2	(Palmer et al., 2021)
Wind fuel cell integrated system	Wind	kWh	40.6 g CO_2-eq / kWh	(Khan et al., 2005)
Thermochemical water splitting	Solar energy	Kg H_2	1.02 kg CO_2-eq	(Zhang et al., 2022)
Water electrolysis	Wind	Kg H_2	41.80 g CO_2/kg H_2 during the electrolysis process	(Cetinkaya et al., 2012)
Thermochemical water splitting	Nuclear	Kg H_2	2027 g CO_2/kg H_2 During the operation of nuclear plant	
Waer electrolysis	Solar PV	Kg H_2	2-7 kg CO2-eq / kg H_2	(Parkinson et al., 2019)
Solid oxide fuel cell	Solar panels	kWh	GWP is 6.07^{E-02} CO_2 equivalent / kW h	(Mehmeti et al., 2016)
Solid oxide fuel cell	Wind-offshore	kWh	GWP is 8.06^{E-02} CO_2 equivalent / kW h	

Table 2. The environmental implications of producing blue hydrogen [10-13].

Environmental Impact	Summary
Greenhouse Gas Emissions (12 Kg CO_2-eq /kg H_2)	Blue hydrogen aims to capture and store CO_2 emissions from the SMR process. However, the effectiveness of carbon capture and storage technologies can vary
Methane Leakage	Methane, a potent greenhouse gas, can be released during production and transportation of natural gas.
Energy Intensity	Blue hydrogen production is energy-intensive, and the source of energy used affects its overall environmental benefits. Renewables are preferable to fossil fuels for minimizing emissions.
Water Consumption	Steam methane reforming requires significant amounts of water, potentially straining water resources in regions with water scarcity.
Environmental Impacts of CCS	Carbon capture and storage processes have their own environmental considerations, such as leakage and long-term stability of stored CO_2. Monitoring and addressing these concerns are crucial.

5. Conclusion

Green and blue hydrogen are two types of hydrogen created from renewable energy and fossil fuel, respectively. Green hydrogen is created by electrolyzing water to separate its molecules into hydrogen and oxygen using sustainable energy sources. On the other hand, blue hydrogen is produced by reforming natural gas while capturing and storing the carbon emissions that arise. Green hydrogen is currently more expensive to produce than blue hydrogen, but the cost is expected to decrease as the technology becomes more widespread and economies of scale are achieved, however blue hydrogen process emits more emissions to the environments. Life Cycle Assessment is important to clarify opportunities to reduce the environmental impact of the product to the system.

6. References

[1] Dutta, S. 2014 A review on production, storage of hydrogen and its utilization as an energy resource *Journal of Industrial and Engineering Chemistry* **20** (4) 1148-1156.

[2] Dincer, I., & Acar, C. 2016 A review on potential use of hydrogen in aviation applications *International Journal of Sustainable Aviation* **2** (1) 74-100.

[3] Kollmuss, A., Zink, H., & Polycarp, C. 2008 Making sense of the voluntary carbon market: A comparison of carbon offset standards *WWF Germany*, 1-23.

[4] Newborough, M., & Cooley, G. 2020 Developments in the global hydrogen market: The spectrum of hydrogen colours. *Fuel Cells Bulletin* **2020** (11) 16-22.

[5] Nikolaidis, P., & Poullikkas, A. 2017 A comparative overview of hydrogen production processes *Renewable and sustainable energy reviews* **67** 597-611.

[6] Finkbeiner, M., & Bach, V. 2021 Life cycle assessment of decarbonization options—towards scientifically robust carbon neutrality *The International Journal of Life Cycle Assessment* **26** 635-639.

[7] Soltani, R., Rosen, M. A., & Dincer, I. 2014 Assessment of CO2 capture options from various points in steam methane reforming for hydrogen production *International journal of hydrogen energy* **39** (35) 20266-20275.

[8] Kumar, S. S., & Himabindu, V. 2019 Hydrogen production by PEM water electrolysis–A review *Materials Science for Energy Technologies* **2** (3) 442-454.

[9] Noussan, M., Raimondi, P. P., Scita, R., & Hafner, M. 2020 The role of green and blue hydrogen in the energy transition—A technological and geopolitical perspective *Sustainability* **13** (1) 298.

[10] Tao, M., Azzolini, J. A., Stechel, E. B., Ayers, K. E., & Valdez, T. I. 2022 Engineering Challenges in Green Hydrogen Production Systems *Journal of The Electrochemical Society* **169** (5) 054503.

[11] ISO, I. 2006 ISO 14040 international standard *Environmental Management-Life Cycle Assessment-Principles and Framework. International Organisation for Standardization*.

[12] Oni, A. O., Anaya, K., Giwa, T., Di Lullo, G., & Kumar, A. 2022 Comparative assessment of blue hydrogen from steam methane reforming, autothermal reforming, and natural gas decomposition technologies for natural gas-producing regions *Energy Conversion and Management* **254** 115245.

[13] Massarweh, O., Al-khuzaei, M., Al-Shafi, M., Bicer, Y., & Abushaikha, A. S. 2023 Blue hydrogen production from natural gas reservoirs: A review of application and feasibility *Journal of CO2 Utilization* **70** 102438.

[14] Dufour, J., Serrano, D. P., Gálvez, J. L., Moreno, J., & Garcia, C. 2009 Life cycle assessment of processes for hydrogen production. Environmental feasibility and reduction of greenhouse gases emissions *International journal of hydrogen energy* **34** (3) 1370-1376.

[15] Martínez, E., Sanz, F., Pellegrini, S., Jiménez, E., & Blanco, J. 2009 Life-cycle assessment of a 2-MW rated power wind turbine: CML method *The International Journal of Life Cycle Assessment* **14** 52-63.

[16] Cetinkaya, E., Dincer, I., & Naterer, G. F. 2012 Life cycle assessment of various hydrogen production methods *International journal of hydrogen energy* **37** (3) 2071-2080.