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Simulation-Based Performance Evaluation of an AEM Green Hydrogen Production Unit in DWSIM

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ABSTRACT

Green hydrogen is becoming increasingly vital as a clean energy source for reducing pollution and addressing climate change. The Anion Exchange Membrane (AEM) technology is used to produce green hydrogen, combining the benefits of two established methods—Alkaline water electrolysis and Proton Exchange Membrane—while addressing their limitations to create a more efficient and cost-effective process. This study employs DWSIM software to simulate a green hydrogen production facility using AEM technology, which was not previously considered in prior research, particularly for large-scale production. The study also includes a sensitivity analysis for the DWSIM electrolyzer. The simulated facility follows a four-step process: purifying seawater, conducting electrolysis to split water molecules, separating the hydrogen produced, and compressing and storing it. The electrolysis equipment requires 1.5 volts per cell, with a reversible voltage of 1.23 volts. Producing one ton of hydrogen per hour requires 40 MW of renewable energy and five tons per hour of water. Additionally, a WAVE simulation calculates the required seawater, factoring in advanced filtration and ion exchange, estimating a need for 5.5314 tons of seawater. The sensitivity analysis reveals how the voltage applied to the electrolyzer impacts the number of cells, showing that increasing the voltage decreases the current in the electrolysis stack, and examines the relationship between the energy supplied to the electrolyzer and hydrogen production.

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1. Introduction

Electrochemical water splitting, commonly known as electrolysis, is a green process that separates water into hydrogen and oxygen. In the past few decades, several water electrolysis technologies have been established, with Alkaline Water Electrolysis (AWE) emerging as the most established and mature. This technology is especially well adapted to low-temperature operations. Another important method is Proton Exchange Membrane (PEM) electrolysis, which operates at temperatures ranging from 50 to 80°C and pressures of up to 200 bars. PEM can produce hydrogen gas with higher purity than AWE while maintaining higher current densities. PEM electrolysis has a considerable advantage over AWE due to its flexibility and faster response time. However, the use of expensive catalyst materials such as platinum remains a significant barrier.

The Anion Exchange Membrane (AEM) technology, which utilizes anion exchange membranes in devices like electrolyzers and fuel cells, represents a significant advancement in this field. These polymer-based membranes can conduct negative ions such as hydroxide (OH^-) while preventing other species from passing through, thus enhancing the efficiency of electrochemical devices. AEM technology not only improves performance and durability but also supports the use of cost-effective, non-precious metal catalysts, driving forward the development of sustainable energy systems [1].

In recent studies, researchers have been exploring various methods to produce green hydrogen efficiently and economically. In a study by A. Manabe and colleagues in 2012 [2], significant foundational research on AWE was conducted through a series of evaluative tests. The research used a zero-gap cell system, where the electrodes directly contact the separators, reducing cell voltage and operational issues while enhancing performance with lower overvoltage. This research contributes to the ongoing efforts to optimize AWE technology for improved efficiency and reliability. Aspen Plus was used by Monica Sanchez et al. (2019) [3] to simulate and evaluate the operation of an alkaline electrolysis facility. They employed a range of instruments, such as the Aspen Custom Modeler, to ascertain variables such as gas purity and voltage cell with current. The study discovered that while pressure changes had a larger effect on impurity production than hydrogen synthesis, temperature fluctuations also had an impact on voltage and the amount of stack power needed. The researchers found that within the studied ranges, temperature has a greater impact. Furthermore, Dohyung Jang's team (2021) [4] conducted numerical modeling to assess the impact of pressure on alkaline water electrolysis, aiming to pinpoint the optimal pressure for maximum efficiency. Their findings indicated that while increased pressure enhances the overall system efficiency (OSE) at lower pressures, it eventually leads to a decline in OSE at higher pressures due to rising cell voltage and decreasing Balance of Plant (BOP) power consumption.

Also, Dohyung Jang and colleagues (2022) [5] evaluated multiple technologies, including Alkaline Water Electrolysis (AWE), Proton Exchange Membrane Electrolysis Cell (PEMEC), and Solid Oxide Electrolysis Cell (SOEC), with SOEC utilizing waste heat identified as the most cost-effective. Concurrently, Eid Gul's (2023) [6] research focused on optimizing hybrid renewable energy systems for green hydrogen production using Anion Exchange Membrane (AEM) technology, with simulations in Aspen Plus software affirming the economic viability of the system. Table 1 represents an overview of the listed previous articles along with their simulation conditions. As shown and concluded above and in Table 1, no simulation study has been undertaken for AEM technology. In this study, a simulation study for AEM was carried out using DWSIM, followed by a parametric investigation and interpretation of the findings.

Table 1. Summary of previous simulation articles

Year	Author	Technology	Operating condition	Electrolyzer specification	References
2012	A. Manabe et al.	AWE	T= 80 - 90°C	0.2 dm ² and 1 dm ² cells <i>i</i> = 40 A/cm ²	[2]
2019	Monica Sanchez et al.	AWE	T= 75°C P= 7 bar	<i>i</i> =0.4 mA/cm ² SE=58%	[3]
2021	Dohyung Jang et al.	AWE	T= 70°C P= 10, 20, 50, 100 bar	<i>N</i> =1090 <i>i</i> = 0.6 A/cm ²	[4]
2022	Dohyung Jang et al.	AWE	-	<i>i</i> = 0.4 A/cm ² <i>V</i> _{cell} =1.88 V Supplied power= 1 MW _{el}	[5]
	Electron Transfer	PEMEC	-	<i>i</i> = 1.2 A/cm ² <i>V</i> _{cell} =1.5 V Supplied power= 1 MW _{el}	
	Calculated Efficiency	SOEC (W.H)	T= 750°C	<i>i</i> = 0.67 A/cm ² <i>V</i> _{cell} =1.26 V Supplied power= 1 MW _{el}	
2023	Eid Gul et al.	AEM	T= 60°C P= 20 bar	<i>V</i> _{cell} =2.023 V	[6]

Despite the progress, there has been a gap in applying this technology to green hydrogen production using DWSIM. This study addresses that gap by conducting case studies to determine optimal input values for the electrolyzer, as previous research did not provide these details. Additionally, it pioneers the integration of electrolysis simulation with large-scale hydrogen and oxygen separation and employs WAVE simulations to assess the seawater needed for producing the targeted green hydrogen volume. This comprehensive approach marks a leap forward in the practical application of AEM technology in clean energy production.

The study's purpose was attained by first studying the most recent research findings and then simulating the green hydrogen unit in DWSIM software. The procedure began by identifying the operational conditions unique to AEM technology. A parametric analysis was then performed to identify the ideal input parameters for the DWSIM electrolyzer to reach the study's defined capacity. The optimal system configuration for AEM technology, compatible with the most recent version of DWSIM v8.7.1, was then chosen. Finally, parametric research was performed to determine the interdependence of each parameter with the others.

2. Process simulation

2.1. Process steps

The steps for the green hydrogen production unit are presented in Fig. 1 Water treatment facilities receive water laden with various particulates and contaminants that pose a risk of obstructing critical infrastructure, including pumps, taps, and pipes. Seasonal changes influence the nature of these suspended particulates, with autumnal leaf fall, for instance, being a contributing factor. The treatment of water encompasses multiple stages: initial trash filtering, settling and clumping in ponds, sand-based filtration, further filtration, and conditioning with softening agents. These processes were replicated in a model using the WAVE system to achieve the desired seawater purification standards. After the electrolysis phase, the separated hydrogen and oxygen must undergo purification to eliminate residual water contaminants. This step is vital to avert potential contamination and deterioration of subsequent infrastructure and to guarantee hydrogen's viability as a clean fuel for electric vehicles. Various drying methods are employed to ensure that hydrogen and oxygen reach the necessary dryness and purity standards for their intended use.

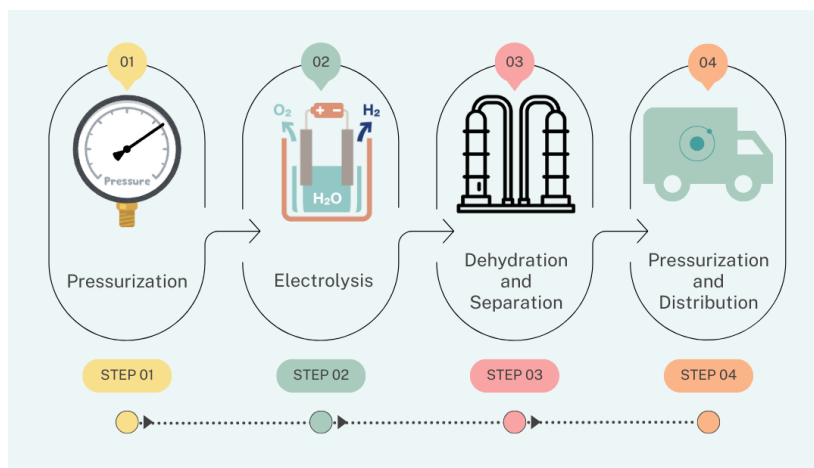


Fig. 1. Steps of green hydrogen production unit

Dehydration methods are essential for purifying hydrogen and oxygen after electrolysis. Techniques such as desiccators, adsorption, membrane separation, and other specialized processes are commonly employed. A notable method involves cooling the gases post-electrolysis with a refrigeration cycle, leading to the condensation of water impurities. These condensed impurities can then be easily removed through knock-out drums. This method of cooling and condensation stands out for its simplicity and efficiency, offering a more straightforward solution than other dehydration techniques that might necessitate regeneration or the use of bulkier, costlier equipment [4].

2.2. Assumptions and simulation

To model the generation of green hydrogen, DWSIM v8.7.1 was employed under specific presumptions. It was hypothesized that the system would maintain a steady state throughout the process. All gases in the simulation were assumed to exhibit ideal gas behavior. The procedures were simulated in a standard mode, foregoing any optimization. The Non-Random Two-Liquid (NRTL) property model was applied across all stages of the simulation, with binary interaction coefficients fine-tuned using additional simulation tools for accuracy. The simulation commenced with the introduction of deionized water at a standard temperature of 25°C. Default settings in DWSIM dictated that pump and compressor efficiencies be set at 75%. Solar panel and wind turbine efficiencies were presumed to be 30% and 80%, respectively, in line with DWSIM's standard values. Cooling towers supply water at 38°C and 6.5bar to act as the cooling agent in condensers and coolers. A nominal pressure drop of 0.1bar was accounted for in both knock-out drums and heat exchangers.

Fig. 2 serves as the foundation for a DWSIM simulation demonstrating green hydrogen production via electrolysis. In the presented Figure, the blue-colored stream numbers show the pure water streams, the green-colored stream numbers identify the hydrogen-rich streams, and the red-colored ones represent the oxygen-rich streams. The process initiates with pure water at 25°C and 1.013bar entering as the feed, which is then pressurized to 30.4bar. The reason for such pressure is that the adsorption tower operates at 30bars, with an extra 0.4bar to avert vacuum conditions. Additionally, the unreacted water, recycled at 30bars, is pressurized to 30.4bar and merged with the feed. Before entering the electrolyzer, the feed is heated to 60°C by a heat exchanger using the electrolyzer's outlet streams. Within the electrolyzer, water is decomposed into hydrogen and oxygen, a reaction that consumes a substantial 600MW of energy for the intended hydrogen output.

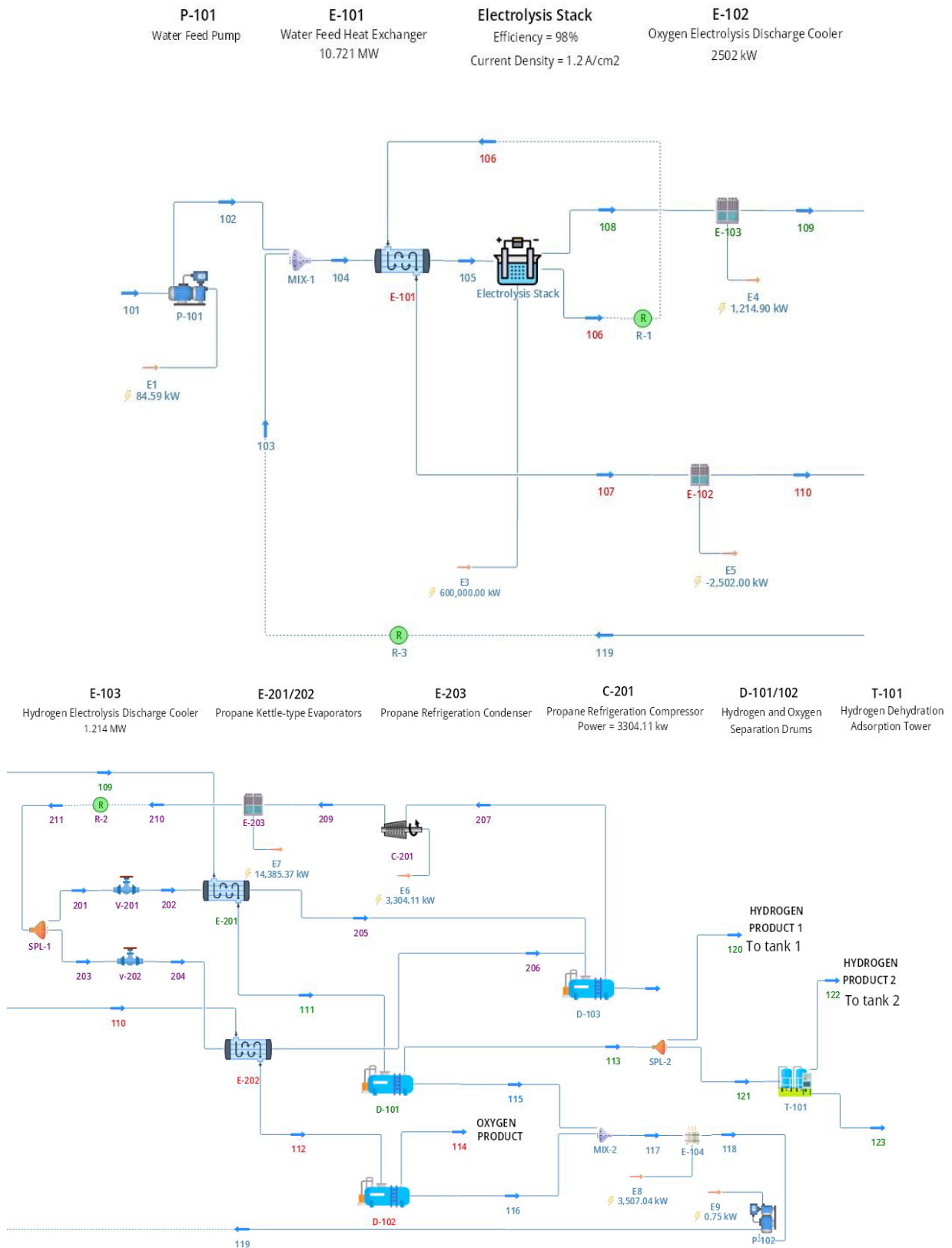


Fig. 2. Green hydrogen process simulation in DWSIM

The electrolyzer emits hydrated hydrogen and oxygen streams, which are then purified through a refrigeration cycle to achieve pure end products. This simulation encapsulates the intricate steps of green hydrogen production, highlighting the energy-intensive nature of electrolysis. The hydrogen and oxygen flows were cooled to 45°C using the heat exchangers connected to the incoming streams. Yet, to dehydrate these flows to yield predominantly pure hydrogen and oxygen, it was necessary to cool them further to 10°C to avert solidification within the conduits. To accomplish this, the system employed a simulated propane refrigeration process, which was incorporated into the

overarching simulation. This process involved compressing and then expanding pure propane through a single-stage cycle, which allowed the temperature to drop to 3°C, maintaining an approach temperature of 7°C.

In the refrigeration cycle, the generated energy and reduced temperatures are harnessed to cool the cathode and anode flows. These cooled streams are then conveyed to knock-out drums, which play a crucial role in separating the condensed water from the hydrogen and oxygen flows. This separation is pivotal in producing hydrogen and oxygen streams of high purity. Following dehydration through the utilization of knock-out drums, the oxygen stream attains a purity level exceeding 99.98wt%. This stream can be stored or employed as oxyfuel for cement production. The use of oxyfuel in cement manufacturing eliminates the need to burn nitrogen and results in reduced NO_x emissions, thereby mitigating global warming effects [7]. On the other hand, the hydrogen stream achieves a purity of 99.95wt%. Since hydrogen is utilized in diverse applications that require varying levels of purity, the stream is divided into two parts.

The first portion is directly directed to storage and becomes readily available for transportation. This hydrogen product finds applications in various industries such as petroleum, food, fine chemicals, artificial gems, metal smelting, cutting, and welding. To achieve an exceptional purity level surpassing 99.999wt%, the second portion of the hydrogen stream undergoes further processing in a dryer operating as adsorption tower. These towers play a critical role in eliminating any remaining moisture. The water discharged from these towers, characterized by its varying composition and pressure, is released into the atmosphere as a necessary step to maintain system equilibrium. Following the drying process, the hydrogen stream, now boasting a purity exceeding 99.999 wt%, becomes suitable for utilization in fuel cells [8].

3. Results and discussion

In the DWSIM simulation for green hydrogen production via electrolysis, determining the optimal parameters such as input flow rate, electrolyzer energy, cell count, and voltage is crucial for precise outcomes. The trial-and-error approach revealed a correlation among these factors. It was found that higher water inlet flow rates can prevent high utility costs, yet they also elevate the mass flow of unreacted water, which can diminish electrolyzer efficiency. Through extensive simulation, a balance between energy input and inlet mass flow was sought to maximize hydrogen yield while maintaining energy efficiency and controlling outlet temperature.

This balance is essential for the electrolyzer's effective operation, ensuring a sustainable production process. The simulations underscore the delicate interplay between operational efficiency and cost-effectiveness in hydrogen production systems. In the simulation, a single-stage propane refrigeration cycle was utilized. Propane is condensed at a pressure of 15.43bar when the temperature reaches 45°C. This pressure determines the compressor's outlet pressure. The propane is then split into two flows, each regulated by control valves to create a two-phase stream. This stream is instrumental in cooling both hydrogen and oxygen streams. After cooling to 10°C, the streams pass through knock-out drums to eliminate excess water.

Subsequently, propane is cycled back to the compressor for recompression and condensation before returning to the heat exchangers. The design also specifies the water flow into the filtration unit, calculated at 271.41 cubic meters based on available data. During sedimentation, a 20% loss of discharge is anticipated, along with particle loss. The Total Dissolved Solids (TDS) level in the water is approximately 7500mg/L, and the operating flux is determined to be 69 LMH. Details of the ultrafiltration section configuration are depicted in Fig. 3.

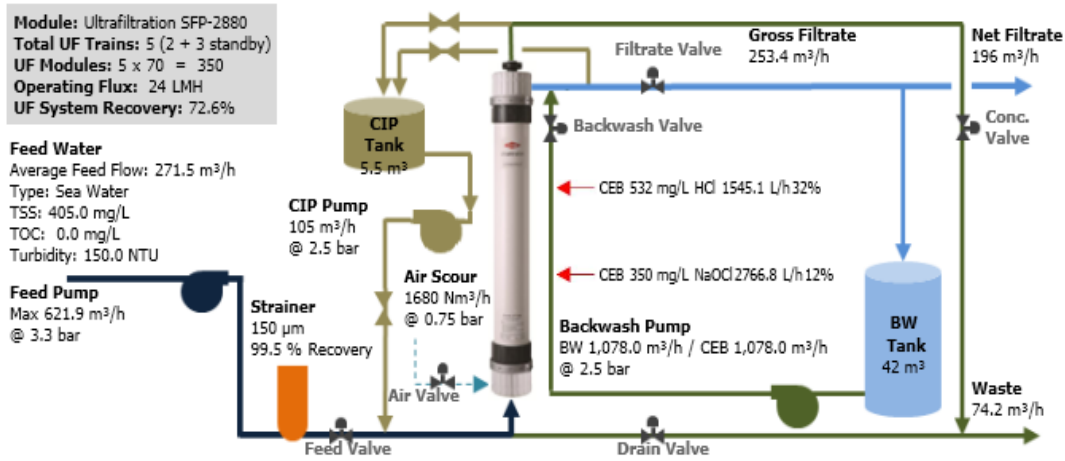


Fig. 3. Ultrafiltration configuration

3.1. Balance of plant

The balance of the plant contains all the equipment included in the green hydrogen production unit. The equipment included are mixer, pumps, heat exchangers, stack, compressor, evaporator, and adsorption tower.

In general, the mass balance for an open system is as expressed in Eq. (1).

$$\sum m_{in} - \sum m_{out} + \sum m_{gen} - \sum m_{cons} = m_{acc} \quad (1)$$

For the hydrogen production unit, the process is being performed in a steady state which means that the mass accumulation is zero. In equipment no reaction occurred, which means that no mass is generated or consumed, the mass balance becomes as expressed in Eq. (2).

$$\sum m_{in} = \sum m_{out} \quad (2)$$

According to the first law of thermodynamics, the energy balance for open systems at steady state is as expressed in Eq. (3).

$$\sum E_{in} + Q + W = \sum E_{out} \quad (3)$$

For all equipment utilized, the energy balance equation has been applied. However, for the electrolyzer, the energy balance is performed differently. To effectively examine the mass equilibrium surrounding the electrolyzer, understanding the electrochemical performance of the cells is crucial. This performance directly influences the rate at which hydrogen is generated at the cathode. The calculation of this rate can be accomplished by employing Faraday efficiency, as outlined in Eq. (4).

$$n_{H_2, produced} = \eta_f \cdot \frac{1}{z \cdot F} \cdot N \quad (4)$$

To maintain the energy balance during electrolytic hydrogen production, the total energy requirement can be determined using the enthalpy of reaction, as described by Eq. (3). If the cell potential exceeds the thermoneutral voltage, the electrochemical reaction can proceed without the need for external heating. Conversely, Eq. (5) states that the heat generated during the process is directly proportional to the difference between the cell voltage and the thermoneutral voltage. For a specific reason, Eq. (6) provides the net excess heat, considering the assumption that some of the heat generated will be lost through heat radiation from the electrolysis cells (Q_{loss}) [9].

$$Q_{gen} = N \cdot I \cdot (V_{cell} - V_{th}) \quad (5)$$

$$Q_{excess} = Q_{gen} - Q_{loss} \quad (6)$$

Furthermore, by considering the input power, the effective power utilized for hydrogen production, as well as the sensible enthalpies of the reactant and product, the quantity of heat generated can be computed according to Eq. (7).

$$Q_{excess} = H_{ca,inlet} + W_{stack} + H_{ca,outlet} - H_{an,outlet} \quad (7)$$

W_{stack} can be calculated according to Eq. (8) where V_{cell} represents the voltage of the cell, j is the current density (A/cm^2), A is the current, and N is the number of cells.

$$W_{stack} = V_{cell} \cdot (j \cdot A) \cdot N \quad (8)$$

Because of the surplus heat, both the electrolyte circulation and the gases produced within the stack experience elevated temperatures. This necessitates the continuous removal of the excess heat to maintain a consistent operating temperature. Mathematical modeling of the AEM electrolyzer is an essential tool for analyzing cell performance and understanding the complex physicochemical processes at play, such as electrochemical reactions and charge transport at the cathode and anode. The presented model offers a detailed account of electrochemical reactions, system thermodynamics, and electrical circuit losses.

The AEM cell voltage (V_{cell}) is determined by the sum of the activation overpotential voltage (V_{act}), the ohmic overpotential voltage (V_{ohm}), and the reversible cell voltage (V_{rev}) according to Eq. (9). The cell voltage (V_{cell}) represents the total electrical energy required for water splitting, which is the sum of the reversible voltage (V_{rev}) and all irreversible losses within the cell [10].

$$V_{cell} = V_{act} + V_{ohm} + V_{rev} \quad (9)$$

The activation overpotential, which arises from the kinetics of electrochemical reactions, depends on factors such as temperature, the properties of the electrodes, and the composition of the electrolyte. It follows Arrhenius law and is described by Butler-Volmer equation for redox reactions in the electrochemical cell, as shown in Eq. (10).

$$i = i_0 \left[\exp\left(\frac{\alpha}{RT} nFV_{act}\right) - \exp\left(\frac{(1-\alpha)}{RT} nFV_{act}\right) \right] \quad (10)$$

In Eq. (10), i represents the current density, i_0 is the exchange current density at equilibrium, and α denotes the charge-transfer coefficients, which indicate the distribution of the energy barrier between the electrodes [10].

3.2. Data extracted from simulation

Table 2 shows the results derived from the energy and mass balance performed by the DWSIM around the electrolysis stack.

Table 2. Results extracted from the DWSIM electrolyzer using the analysis mentioned

Parameter	Value	Unit
Cell voltage	1.5	V
Reversible voltage	1.22869	V
Thermoneutral voltage	1.481	V
Electron Transfer	21021.2	kmol/h
Calculated Efficiency	0.987335	

Table 3 shows the significant results derived from the unit simulation. The electrical energy needed to produce the required amount of green hydrogen is 3389.44kW, where 84.59kW is for P-101, 0.75kW is for P-102, and 3304.11kW is needed for C-201 to provide the required pressure increases of the system. The renewable energy needed is directly provided to the electrolyzer and represents 600,000kW. The renewable energy is provided by

solar panels and wind turbines where their percentages will be discussed in future work. The amount of water needed for the system is 77439.4kg/h.

Table 3. Simulation results

Parameter	Value	Unit
Electrical energy	3389.44	kW
Renewable energy	600000	kW
Pure water needed	77439.4	kg/h
Renewable energy needed per 1 ton of H ₂	40	MW
Electrical energy needed per 1 ton of H ₂	242.19	kW
Pure water needed per 1 ton of H ₂	5.5314	ton/h

Moreover, the amount of renewable energy required to produce 1ton of hydrogen is about 40MW which is an acceptable amount in comparison with previous work. Also, the amount of electrical energy needed to produce 1 ton of hydrogen is 242.19kW.

To produce one ton of green hydrogen, the energy and water requirements are crucial factors. Fig. 4 provides a visual representation of these requirements. It illustrates the quantities of water, renewable energy, and electrical energy needed for the production process. The purity of the streams produced compared to the feed is also presented in Table 4.

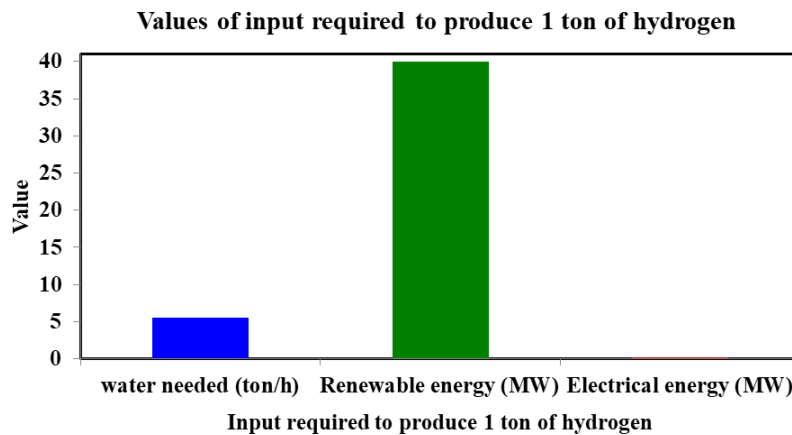


Fig. 4. Values of input required to produce 1 ton of green hydrogen per hour

Table 4. Material content of important streams

Stream number	Water content (wt%)	Hydrogen content (wt%)	Oxygen content (wt%)
104	97	2.86	0.11
107	77.8	0	22.2
108	5.58	94.4	0
114	0.023	0	99.97
120	0.37	99.6	0
122	3.69E-10	1	0

3.3. Sensitivity analysis

A parametric study was considered to recognize the impact of several electrolyzer conditions on the production process of oxygen and hydrogen.

Fig. 5 shows how voltage affects the current passing through an electrolyzer. The graph clearly demonstrates that when the voltage increases, the current falls. This illustrates an inverse relationship between the voltage applied to the electrolysis stack and the current produced. The explanation for this behavior is that the power supplied to the electrolyzer remains constant during the sensitivity analysis. According to Eq. (11), keeping a constant power output (Q) requires that if the voltage increases the current decreases in order to balance the equation and keep the power steady.

$$Q = V \times I \quad (11)$$

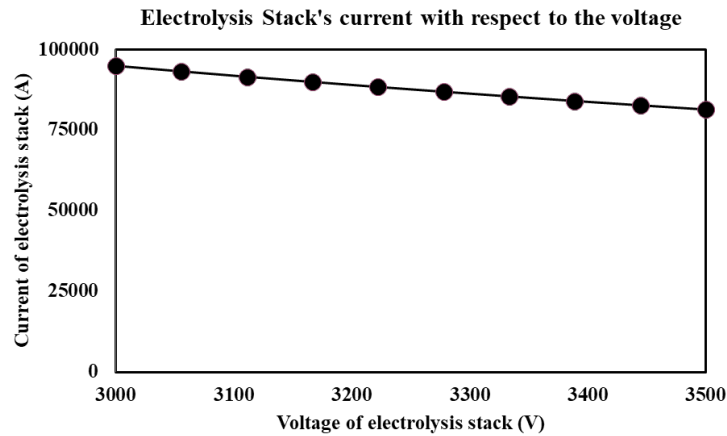


Fig. 5. Electrolysis stack's current concerning voltage

Fig. 6 shows how the voltage given to the electrolyzer influences the mass flow rates of hydrogen and oxygen, which can be explained using electrolysis principles and the electrolyzer's behavior. This phenomenon is directly related to the effect depicted in Fig. 5, where an increase in voltage results in a decrease in current.

Because the generation of hydrogen and oxygen depends on current, reducing the current will result in a lesser output of these gases. Eq. (4) further supports this relationship, as it shows that when the current (I) falls, so does the molar flow rate of hydrogen generated, demonstrating a clear correlation between these two variables. Therefore, to find the optimized value of voltage needed to be provided by the electrolyzer, more simulations and analysis were performed.

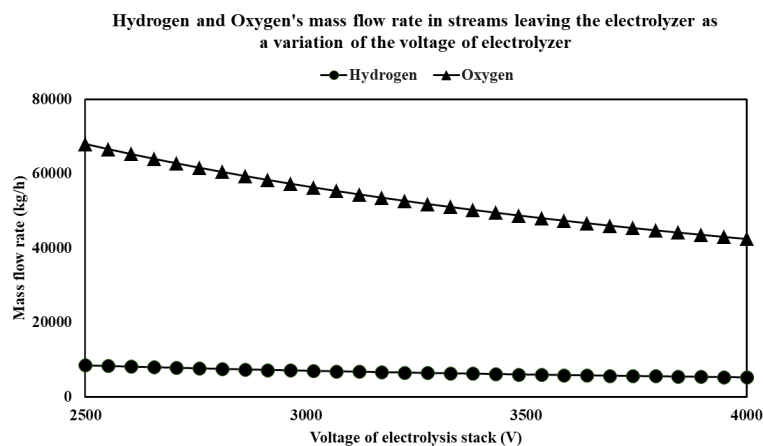


Fig. 6. Hydrogen and oxygen's mass flow rate in hydrogen-rich stream and oxygen-rich stream leaving the electrolyzer with respect to the voltage of the electrolysis stack

A relation between the number of cells in an electrolyzer and the voltage provided was deduced to keep them optimized, as shown in Eq. (12).

$$\frac{V}{N} = 1.5V \quad (12)$$

The number of cells and the voltage required by the electrolyzer do not influence the electrolyzer's efficiency. Indeed, this relation should always be preserved between these two parameters for the simulation to be performed correctly. On the other hand, the number of cells which are connected to the total voltage parameter is directly proportional to the current and electron transfer in the electrolyzer. An increase in the number of cells which affects the increase of cell voltage decreases the current needed. Less current is more feasible for the electrolyzer.

Fig. 7 illustrates the impact of the energy supplied to the electrolyzer on the amount of hydrogen produced. It is evident that as the energy input to the electrolyzer increases, the hydrogen production also rises, indicating a direct relationship between the two. This trend highlights the importance of optimizing energy supply to maximize hydrogen yield, which is crucial for scaling up green hydrogen production in a cost-effective manner. The curve clearly shows that to achieve a production rate of 15,000kg/h, as considered in this study, 600MW of energy is required. This observation aligns with the comparison discussed in the following paragraph and further supports the consistency and reliability of the data presented. The presented results are close to results extracted from Qusay Hasan et al.'s work [11].

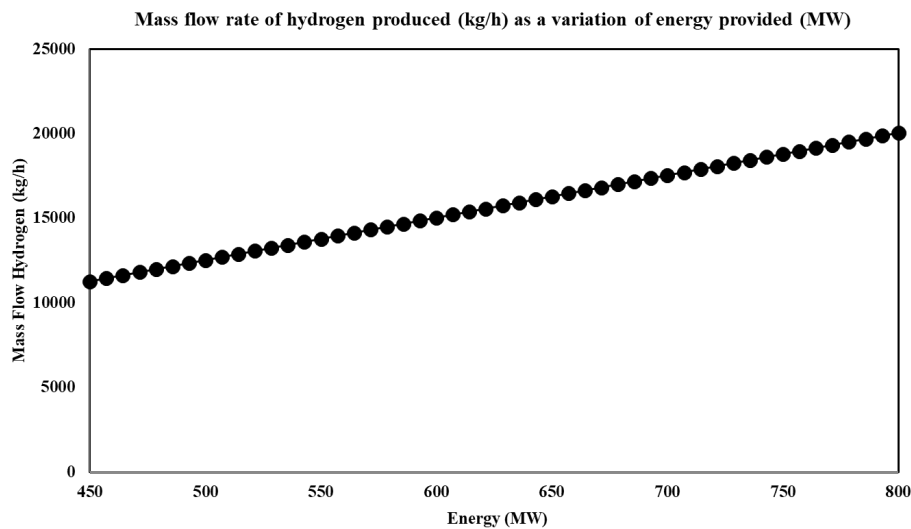


Fig. 7. Mass flow rate of produced hydrogen as a function of the energy provided to the electrolysis stack

Table 5 represents the results of the simulation present in the current study compared to the standards of IRENA's report proposed in 2020 [12]. These results show that the simulation results are confirmed and close to reality. It can also clearly justify that the AEM technology is very good one compared to other technologies like PEM and AWE. Additionally, further analyses were conducted to compare the current study with previous research. For example, the "Green Hydrogen Book" by the Green Hydrogen Coalition indicates that producing 1kg of green hydrogen requires 9 liters of water and between 45-78kWh of energy [13].

Table 5. Simulation results compared to IRENA's report 2020 [12]

Factor	IRENA's report	Presented simulation	Units
Temperature	40 - 60	60	°C
Pressure	< 35	30.4	bar
Hydrogen purity	99.9 - 99.999	> 99.999	%
Electrical efficiency (2050's goal)	< 42	20.357	kWh/kg _{H₂}
Nominal current density	0.2 - 2	1.7	A/cm ²

Similarly, a study by Yannis et al. [14] involved a simulation for producing 1,100kg/h of hydrogen, where the electrolysis system consumed 55.3MW, translating to 50.2kWh per kilogram. The "Green Hydrogen Guidebook" by the "Green Hydrogen Coalition" clearly states that producing 1kg of hydrogen requires 45-78kWh of energy. In this case, 40MW was consumed to produce 1 kg of hydrogen, equivalent to 40 kWh per kilogram. The results are quite similar. With further refinement of the DWSIM software analysis, the difference between the current work and the findings of Yannis et al. as well could be minimized even further.

The comparison results highlight several key points regarding the performance and efficiency of technology in hydrogen production. The simulation results align closely with the standards outlined in IRENA's 2020 report, suggesting that the findings are reliable and reflective of real-world conditions. AEM technology is positioned as superior to other methods, specifically PEM (Proton Exchange Membrane) and AWE (Alkaline Water Electrolysis). This implies it may offer advantages in efficiency, cost, or sustainability. The text references the water and energy requirements for hydrogen production from other sources. Overall, the results suggest that AEM technology is a promising option for efficient hydrogen production, particularly when considering larger-scale applications. This could have significant implications for the future of green hydrogen as a renewable energy source.

4. Conclusion

Green hydrogen emerges as a crucial energy carrier and fuel, offering a promising solution for reducing pollution and mitigating global warming. This study employed AEM (Anion Exchange Membrane) technology, which integrates the benefits of both alkaline water electrolysis and Proton Exchange Membrane technologies while avoiding their limitations. The simulations conducted using DWSIM v8.7.1, highlighted both the strengths and areas for improvement of this relatively new simulation tool. Notably, DWSIM v8.7.1 was the only simulator capable of effectively integrating solar and wind energy inputs with electrolysis processes. Several insights emerged from the study. It would be advantageous for the simulator to include current density in its outputs and to offer an energy stream mix feature, allowing both solar and wind energy to simultaneously power the electrolysis stack. Future research could focus on optimization analyses for both the utilization of renewable energy sources and the energy consumption of the electrolyzer.

Additionally, developing a mathematical model linking the electrolyzer's energy consumption with hydrogen production could streamline calculations. Key findings include that producing 1 ton of hydrogen requires 40MW of renewable energy and 5tons of water, while the required seawater for purification via ultrafiltration and ion exchange technology was estimated at 339tons.

The sensitivity analysis further confirmed that increasing the energy supplied to the electrolyzer enhances hydrogen production efficiency. The energy needed to produce 15,000kg/h of hydrogen was calculated to be 600MW, demonstrating efficiency compared to other studies. The simulation also revealed two grades of hydrogen products

with purities of >99.999wt% and 99.6wt%, respectively, along with oxygen at 99.97wt% purity. Overall, the study underscores the potential of AEM technology and DWSIM simulations in optimizing green hydrogen production and highlights areas for future research and development.

Nomenclature

Abbreviation		n	Molar flow rate (mol/s)
SE	System efficiency (%)	N	Number of cells (-)
TDS	Total dissolved solids (mg/L)	P	Pressure (bar)
Symbols		T	Temperature (°C)
i	Current density (A/cm ²)	V	Voltage (V)
I	Current (A)	α	Charge-transfer coefficient (-)
m	Mass flow rate (kg/s)	z	Electrons transformed per ion (-)

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