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Hydrogen Powered Submarines

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Abstract:

This project aims to design and develop a hybrid submarine that is capable of generating its own fuel, breathable air, and drinkable water from the seawater surrounding it. The submarine will be powered by a combination of conventional diesel propulsion and hydrogen combustion, which will provide the necessary energy to power the onboard systems and propulsion. The submarine will be equipped with a desalination system that will convert seawater into drinkable water using reverse osmosis and electrolysis technology. Additionally, the submarine will have an air purification system that will extract oxygen from the seawater and remove any impurities, providing the submarine with breathable air. The submarine will also be equipped with a fuel generation system that will use seawater to produce hydrogen fuel. This will be achieved through a process called electrolysis, where seawater is split into hydrogen and oxygen using an electric current. The hydrogen will then be stored in onboard tanks and used to power the secondary hydrogen engine, providing the submarine with a sustainable and renewable energy source. The project will also focus on the optimization of the submarine's design and systems to ensure maximum efficiency and minimize the impact on the environment. This will include the use of advanced materials, such as composites, to reduce weight and increase the submarine's stealth capabilities. Overall, this project aims to develop a hybrid submarine that is self-sufficient and able to operate in a sustainable and environmentally friendly manner. This technology has the potential to revolutionize the way submarines are designed and operated, making them more efficient and reducing their reliance on finite resources. This paper gives an overview of the systems onboard to operate the fuel cell, namely, hydrogen and oxygen storage, as well as the safety aspects related to fuel cell operation inside the closed atmosphere and sustainability.

Keywords — *Hydrogen propulsion, hydrogen submarines, proliferation of hydrogen, water as fuel, nuclear submarine, hydrogen engine, hydrogen generator, hydrogen fuel, hybridization of diesel, dual engine submarines, marine propulsion, hydrogen fuel cells*.

Introduction

The biggest challenge in front of the human race is anthropogenic climate change and it is inextricable. The present and future energy needs of our global society are the greatest challenge we are facing at this very moment. From the periodic table, Hydrogen is regarded as the best energy solution. It is also capable of assisting major environmental emission issues. Hydrogen has a humongous potential to provide solutions in the energy sector, transportation, and sustainability. It can be claimed that hydrogen has very little or no impact on the environment for its uses as compared to other fossil fuels. All modern-day evaluations of global energy futures must meet a diverse mixing of energy, including renewable and sustainable energy sources. The current emissions from the burning of fossil fuels are now unquestionably going above the required levels and they are deemed to be responsible for the rise in the globe's average temperature. Hydrogen, despite being an attractive element, is not a primary energy source. Its primary use is as an electricity generator and its secondary use is as an energy carrier. Hydrogen can be extracted from numerous resources such as wind, wave hydro, and biomass, geothermal and solar. Hydrogen has the greatest ability to replace the existing fossil fuels for the transportation sector and to address one of the world's major environmental problems. Automotive exhausts are the largest sources of air pollution and contribute significantly to carbon dioxide emissions. The 'International Journal of Hydrogen Energy' summarizes various factors that recommend the use of hydrogen as a secondary source of energy that can be produced using some unconventional technologies:

- Hydrogen is a concentrated primary energy source, which can be conveniently delivered to the consumer.
- It offers the possibility of conversion into different forms of energy through the high-efficiency conversion process.
- Hydrogen is an inexhaustible source.
- It is the easiest and cleanest fuel. It is almost entirely devoid of any pollutant emissions.
- Hydrogen has much higher gravimetric energy density as compared to other fuels.
- Hydrogen can be transported over long distances.
- Hydrogen-based fuel cells have efficiencies of up to 60%.
- Hydrogen can be stored in various ways such as gas at normal or high pressure, in the form of liquid hydrogen, or as solid hydride.

According to research, hydrogen has very high diffusivity. This helps it to disperse in the air and it is advantageous for two main reasons. Firstly, it forms a uniform mixture of fuel and air. Secondly, if there is leakage in hydrogen pipelines, it disperses quickly without causing any unsafe conditions.

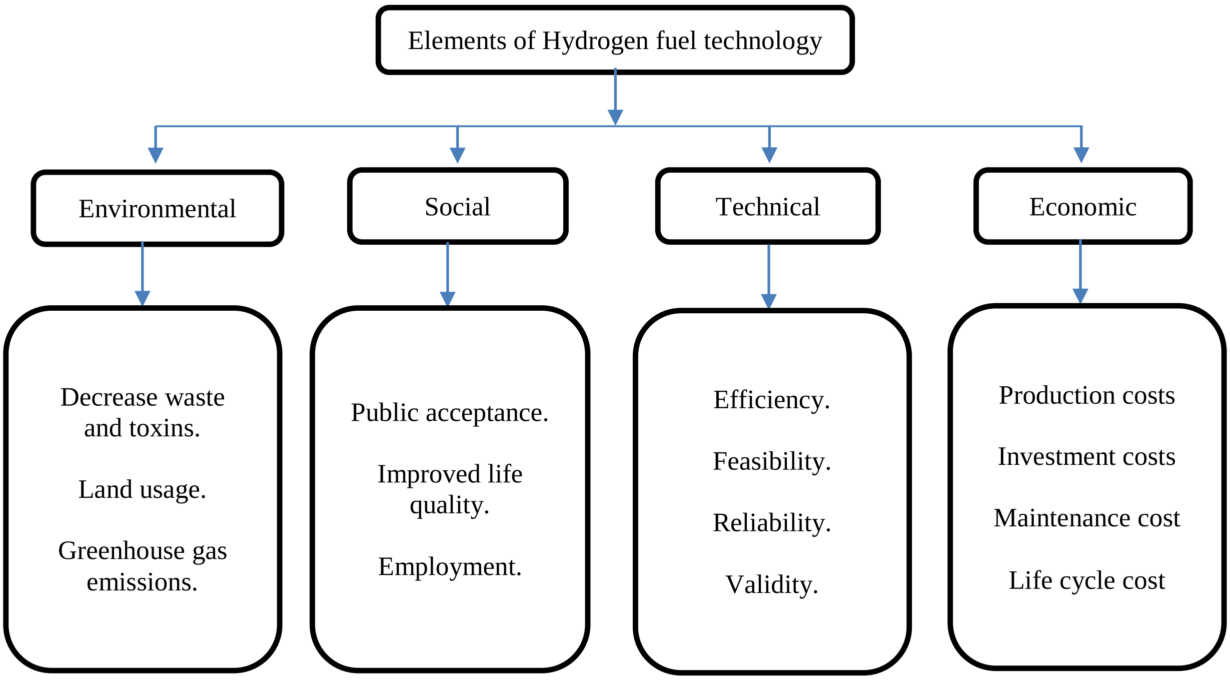

Fig. 1. Elements of Hydrogen fuel technology.

Concept

To utilize all the above-stated advantages of hydrogen for hybridization in submarines, we are working to hybridize the powertrain systems of conventional submarines which will enable them to run both on conventional fuel as well as hydrogen fuel. The simplest and the most convenient way of producing hydrogen is by electrolysis of water. As the submarine would be submerged in seawater there won't be any shortage of H2O for the operation of electrolysis. Hydrogen is a product of electrolysis and electrolysers. Most widely used electrolyser is polymer electrolyte membrane (PEM) which operates at temperatures of 70-100^{o} C. Another reason they are widely used for operation is their ability to produce 99.99% pure hydrogen and low maintenance. The water used in PEM should be free from other toxins and minerals and should be treated well before undergoing electrolysis.

The efficiency of water electrolysis process could be defined as ratio of theoretical amount of energy Et to the actual amount of energy Er required to split 1 mol of water into hydrogen and oxygen.
$\eta = Et / Er$

The reaction of electrolysis process is –
$2\ H_2O(l) \rightarrow 2\ H_2(g) + O_2(g)$ this is when water is in liquid state and oxygen and hydrogen are in liquid state.

To maintain the balance in electrolysis process, it is necessary to supply proper amount of heat and electricity. The minimum amount of electrical energy required to split 1 mol of water is equivalent to Gibbs free energy ΔG˚ and E0 for voltage. The equation becomes –
$\Delta G_0 = n.F.E0 = 237.2$ kJ/mol
n = number of electrons transferred during process.
F = Faraday's constant (96,485 C/mol)
E_0 = Electrolysis potential ≈ 1.23 V

Heat required for the entire process is the change of the entropy and temperature at which the water is supplied. ΔS = 163.15 J (mol. K). Therefore, total energy required to split 1 mol of water is the algebraic sum of Gibbs free energy and heat required which corresponds to the enthalpy change of hydrogen ΔH0
$\Delta H_0 = \Delta G_0 + T.\ \Delta S(T) = 285.84$ kJ/mol.

The main hybrid optimization in the entire process is mainly focused on conventional CI engine, alternator, hydrogen engine, electrolysers and battery. These 5 components will be interconnected to each other with the help of a closed loop monitoring system. The above diagram shows the network and working of electrolyser and its flow path. The output shafts of both CI engine and hydrogen engine would be coupled to alternator. The power to electrolyser would be given by alternator and batteries and the entire system would be completely closed loop. All the parameters would be electronically managed and controlled according to required needs, inputs and outputs. Below mentioned figure show the representation of hybrid framework of the process.

The combustion of hydrogen with oxygen produces water as its only product –
$2H_2 + O_2 = 2H_2O$

The combustion of hydrogen with air can also produce oxides of nitrogen –
$2H_2 + O_2 + N_2 \rightarrow H_2O + N_2 + NO_x$

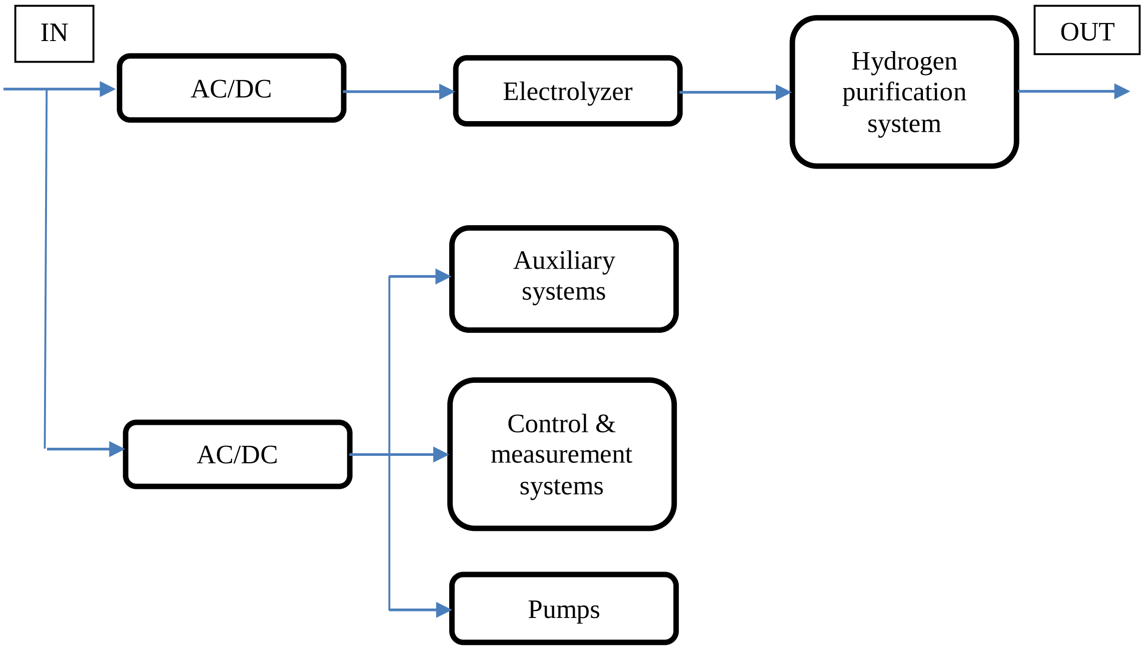

Fig. 2 Schematic representation of hydrogen generator.

Hydrogen storage and safety

The storage system for hydrogen in submarines is generally made up of metal hydride cylinders. This type of storage solutions ideally fulfils specific requirements of the applications. These types of storage containers offer more volumetric storage densities. The modern metal hydride storage tanks offer highest safety for the crew members and submarine. The most important advantage of metal hydride tanks is any lead for installation as compared to nuclear submarines for weight balance (Archimedes principle). It is relatively simple and less time consuming. The biggest challenge for these containers is, they have to withstand very harsh conditions such as shock loads, surrounded by salt water, sustain diving pressure as they are placed outside the pressure hull. The approximate dimensions of these cylinders are around 4-5m long and diameter varying from 400-500mm. These storage cylinders have to activate by charging and discharging cycles. The number of hydrogen storage cylinders varies from submarine to submarine and also customer specific requirements. These are high pressure gas containers with hydrogen stored at 200bar. In new technological advancements, ultra-high-density containers are being made to withstand pressures up to 600 – 1000 bars. Apart from hydrogen storage, the design also includes parameters such as tank capacity, maximum storage temperature, and injection and outflow velocities, maximum amount of hydrogen delivered to the network in a single operation cycle. Hydrogen is considered as a safe component as compared to other fuels and by chemical composition. Hydrogen has a safety record of use in industrial applications. Any chances of hydrogen and oxygen mixing and uncontrolled flow of reactants into submarines atmosphere should be avoided. The basic design requirement in safety system is to have a double barrier between hydrogen/oxygen and submarines atmosphere.

Literature Review

In the following paper, findings related to hydrogen propulsion, hybridization of diesel, hydrogen fuel cells are presented and the present status about numerical, theoretical and experimental researches carried out globally through various learned researchers are concluded. Based on the current findings, some gaps are identified and objectives of present case study are framed below.

White et. al. [1] have been overviewed of the technical aspects of hydrogen-fueled internal combustion engines (ICEs). The authors begin by discussing the history and current state of hydrogen-fueled ICEs, including the challenges that have been encountered and the progress that has been made. They then go on to examine the various components of a hydrogen-fueled ICE, including the fuel system, combustion chamber, and exhaust system, and discuss the unique challenges and considerations associated with each component. The authors also review the performance and emissions characteristics of hydrogen-fueled ICEs, comparing them to traditional gasoline- and diesel-powered ICEs. They find that hydrogen-fueled ICEs have the potential to achieve high thermal efficiencies and low emissions, but that further research and development is needed to fully realize this potential. Overall, the article provides a valuable technical review of hydrogen-fueled ICEs and highlights the potential of this technology as a clean and efficient alternative to traditional gasoline and diesel engines. Shadidi et.al. [2] have observed that the current state of hydrogen as a fuel source for internal combustion engines (ICEs). The authors begin by discussing the advantages of hydrogen as a fuel, including its high energy density, low emissions, and ability to be produced from renewable sources. They then go on to review various types of hydrogen ICEs, including spark-ignition engines, compression-ignition engines, and hybrid systems. The authors also examine the challenges of using hydrogen as a fuel in ICEs, including issues with storage, distribution, and safety. They note that while progress has been made in recent years, there is still a need for further research and development in these areas. The authors also discuss the potential for hydrogen to be used as a fuel in transportation, including cars and buses. They note that while there have been some successful demonstrations of hydrogen fuel cell vehicles, the lack of infrastructure and high costs have hindered widespread adoption. Overall, the authors provide a comprehensive overview of the current state of hydrogen as a fuel source for ICEs. They highlight both the potential benefits and the challenges that need to be addressed in order for hydrogen to become a viable alternative to traditional fossil fuels in the transportation sector. Boretti et. al [3] "Hydrogen internal combustion engines to 2030." *International Journal of Hydrogen Energy* 45.43 (2020): 23692-23703. In his article "Hydrogen internal combustion engines to 2030," Alberto Boretti examines the potential for hydrogen internal combustion engines (HICE) as a sustainable alternative to traditional gasoline engines in the transportation sector. He notes that HICE have several advantages over traditional engines, including lower emissions and the ability to use renewable energy sources for hydrogen production. Boretti cites several studies that have been conducted on HICE, including research on the performance and emissions of HICE vehicles and the development of hydrogen storage and refuelling infrastructure. He also highlights the challenges facing the widespread adoption of HICE, such as the high cost of hydrogen fuel and the lack of infrastructure for hydrogen storage and refuelling. The author concludes that HICE have the potential to be a viable alternative to traditional gasoline engines, but that further research and development is needed to address the challenges facing the widespread adoption of HICE. He suggests that government support and investment in research and development, as well as the development of hydrogen infrastructure, will be essential for the successful deployment of HICE. Overall, Boretti's article provides a comprehensive overview of the current state of HICE research and highlights the potential benefits and challenges facing the widespread adoption of HICE in the transportation sector. The article serves as an important resource for researchers and policymakers interested in the future of sustainable transportation. Yip et al [4] "A review of hydrogen direct injection for internal combustion engines: towards carbon-free combustion." *applied sciences* 9.22 (2019): 4842. In the article "A review of hydrogen direct injection for internal combustion engines: towards carbon-free combustion," Yip, Ho Lung, et al. provide an overview of the current state of hydrogen direct injection (HDI) for internal combustion engines (ICEs). They begin by discussing the limitations of traditional ICEs, including their high emissions of carbon dioxide and other pollutants. They then explore the potential of HDI as a means of reducing these emissions and increasing the efficiency of ICEs. The authors note that HDI has several advantages over traditional fuel injection methods, including a higher combustion efficiency, lower emissions of pollutants, and the ability to use hydrogen as a clean and renewable fuel source. They also highlight the challenges associated with HDI, such as the need for high-pressure storage and delivery systems and the lack of a suitable combustion chamber design. The authors review various studies and research on HDI and conclude that it is a promising technology for reducing emissions and increasing efficiency in ICEs. They also suggest that further research is needed to address the challenges associated with HDI and to optimize its performance in ICEs. Overall, this literature review provides a comprehensive overview of the current state of HDI for ICEs and highlights the potential of this technology to reduce emissions and increase efficiency. It also highlights the need for further research to address the challenges associated with HDI and to optimize its performance in ICEs. Szwaja et. al [5] "Hydrogen combustion in a compression ignition diesel engine." *International journal of hydrogen energy* 34.10 (2009): 4413-4421. The article "Hydrogen combustion in a compression ignition diesel engine" by Szwaja and Grab-Rogalinski explores the potential of using hydrogen as a fuel source in compression ignition diesel engines. The authors begin by discussing the advantages of hydrogen as a fuel, including its high energy density and clean combustion. They then go on to discuss the challenges of using hydrogen in a diesel engine, including the need for high compression ratios and high ignition temperatures. The authors conduct experiments using a single-cylinder diesel engine, with the goal of achieving stable combustion of hydrogen. They find that the engine can operate on hydrogen with an air-to-fuel ratio of 2.5, and that the hydrogen combustion process is similar to that of diesel fuel. They also note that the engine's performance is improved when using hydrogen, with higher power output and lower emissions. Overall, the authors conclude that hydrogen can be successfully used as a fuel in compression ignition diesel engines, and that it has the potential to be a viable alternative to traditional diesel fuel. They suggest that further research is needed to optimize the use of hydrogen in diesel engines, including the development of new technologies to improve compression ratios and ignition temperatures. In conclusion, the study conducted by Szwaja and Grab-Rogalinski presents a promising outlook for the use of hydrogen as an alternative fuel source for compression ignition diesel engines. The study highlights the potential for hydrogen to improve engine performance and reduce emissions. Further research is needed to develop technologies to optimize the use of hydrogen in diesel engines.

Jamrozik et. al [6] "Hydrogen effects on combustion stability, performance and emission of diesel engine." *International Journal of Hydrogen Energy* 45.38 (2020): 19936-19947."Hydrogen effects on combustion stability, performance and emission of diesel engine," published in the International Journal of Hydrogen Energy in 2020, examines the effects of hydrogen on the combustion stability, performance, and emissions of diesel engines. The study found that the addition of hydrogen to diesel fuel improves combustion stability and increases engine performance, leading to a reduction in nitrogen oxide (NOx) emissions. Specifically, the study found that the addition of hydrogen to diesel fuel in a ratio of 20% hydrogen to 80% diesel fuel resulted in a 30% reduction in NOx emissions. The study also found that hydrogen addition leads to an increase in the combustion rate and a decrease in the combustion duration, which results in a significant increase in engine power output. Additionally, the study found that the addition of hydrogen did not have a significant impact on carbon monoxide (CO) and hydrocarbon (HC) emissions. Overall, the study provides evidence that the addition of hydrogen to diesel fuel can be an effective means of reducing NOx emissions while improving engine performance. However, further research is needed to understand the potential long-term effects of hydrogen addition on engine components and the potential for widespread adoption of hydrogen-diesel fuel blends. Feng, C., et al [7] "Production of drinking water from saline water by air-gap membrane distillation using polyvinylidene fluoride nanofiber membrane." Journal of Membrane Science 311.1-2 (2008): 1-6 The study by Feng et al. (2008) explores the use of air-gap membrane distillation (AGMD) with a polyvinylidene fluoride (PVDF) nanofiber membrane to produce drinking water from saline water. The authors note that traditional desalination methods, such as reverse osmosis, have limitations in terms of energy consumption and cost. AGMD, on the other hand, utilizes a temperature difference between the feed water and the permeate side to drive water vapor through the membrane, resulting in a higher water recovery rate and lower energy consumption. The study found that the PVDF nanofiber membrane was able to achieve a high-water flux and salt rejection rate in AGMD. The authors also found that the membrane had a high thermal stability, which is important for AGMD processes. The study also found that the PVDF nanofiber membrane was able to maintain its performance even when the feed water had high concentrations of dissolved salts and organic pollutants. The authors conclude that AGMD with PVDF nanofiber membrane is a promising technology for the production of drinking water from saline water. The study provides valuable information on the potential of AGMD with PVDF nanofiber membrane as a cost-effective and energy-efficient desalination method. The study also highlights the importance of considering the thermal stability of the membrane in the design of AGMD systems. Overall, the study by Feng et al. (2008) demonstrates the potential of AGMD with PVDF nanofiber membrane as a promising desalination technology. Further research is needed to investigate the long-term performance and scalability of the technology. Nam, Wonsik, et al [8] "Preparation of anodized TiO2 photoanode for photoelectrochemical hydrogen production using natural seawater." *Solar energy materials and solar cells* 94.10 (2010): 1809-1815. In the study "Preparation of anodized TiO2 photoanode for photoelectrochemical hydrogen production using natural seawater," Nam, Wonsik, et al. explore the potential of using anodized titanium dioxide (TiO2) as a photoanode for photoelectrochemical hydrogen production using natural seawater as the electrolyte. The authors first discuss the importance of developing efficient and low-cost methods for hydrogen production, as hydrogen has the potential to be a clean and renewable energy source. They then explain the process of anodization and its effects on the surface properties of TiO2, including the formation of a porous structure that can improve the efficiency of hydrogen production. The study goes on to present the results of experiments in which the authors prepared anodized TiO2 photoanodes and tested their performance in photoelectrochemical hydrogen production using natural seawater as the electrolyte. They found that the anodized TiO2 photoanodes had higher photocurrent densities and lower overpotentials than non-anodized TiO2 photoanodes, indicating improved performance in hydrogen production. Overall, the study demonstrates the potential of using anodized TiO2 as a photoanode for photoelectrochemical hydrogen production using natural seawater, and highlights the importance of surface properties in improving the efficiency of this process. The study also suggests that anodized TiO2 could be a promising material for large-scale hydrogen production. Bolar, Saikat, et al [9] "Progress in theoretical and experimental investigation on seawater electrolysis: opportunities and challenges." *Sustainable Energy & Fuels* 5.23 (2021): 5915-5945. Bolar, Saikat, et al.'s article "Progress in theoretical and experimental investigation on seawater electrolysis: opportunities and challenges" examines the current state of research and development in the field of seawater electrolysis as a means of producing hydrogen fuel. The authors begin by discussing the potential benefits of seawater electrolysis as a sustainable and renewable source of hydrogen, including its abundance and the ability to use it in remote locations. The article then discusses the current challenges facing seawater electrolysis, including the high cost of materials and the need for improved efficiency. The authors also review recent advances in the field, including the development of new materials and catalysts, and the use of renewable energy sources to power the electrolysis process. The authors also discuss the potential applications of seawater electrolysis, such as in the production of hydrogen fuel for transportation and in the production of chemicals and fuels for industrial use. They also highlight the need for further research and development in the field, in order to address the remaining challenges and fully realize the potential of seawater electrolysis. Overall, the article provides a comprehensive overview of the current state of research and development in the field of seawater electrolysis, highlighting the potential benefits and challenges of this technology. It also highlights the need for continued research and development in order to fully realize the potential of seawater electrolysis as a sustainable and renewable source of hydrogen fuel. Dresp, Sören, et al [10] "Direct electrolytic splitting of seawater: activity, selectivity, degradation, and recovery studied from the molecular catalyst structure to the electrolyser cell level." *Advanced Energy Materials* 8.22 (2018): 1800338. In the article "Direct electrolytic splitting of seawater: activity, selectivity, degradation, and recovery studied from the molecular catalyst structure to the electrolyser cell level," Dresp et al. examine the potential of using electrolysis to directly split seawater into hydrogen and oxygen. The authors focus on the activity, selectivity, degradation, and recovery of the molecular catalyst structure used in the electrolysis process. The study found that the use of a ruthenium-based catalyst showed high activity and selectivity in the electrolysis of seawater. However, the authors also observed degradation of the catalyst over time, which may limit the long-term efficiency of the process. They suggest that further research is needed to improve the stability of the catalyst and increase the lifetime of the electrolyser cell. The authors also note that the recovery of the catalyst after degradation is an important consideration for the practical application of seawater electrolysis. They propose a regeneration method that involves the use of a reducing agent to restore the activity of the catalyst. Overall, the study highlights the potential of direct electrolytic splitting of seawater for hydrogen production, but also highlights the need for further research to improve the stability and lifetime of the electrolyser cell. The authors suggest that the use of a ruthenium-based catalyst shows high activity and selectivity, but further research is needed to improve the stability of the catalyst and increase the lifetime of the electrolyser cell.

Bennett et. al [11] "Electrodes for generation of hydrogen and oxygen from seawater." *International Journal of Hydrogen Energy* 5.4 (1980): 401-408. The literature review by Bennett, J. E. in the International Journal of Hydrogen Energy from 1980, entitled "Electrodes for generation of hydrogen and oxygen from seawater" examines the use of electrodes for the production of hydrogen and oxygen from seawater through electrolysis. The author discusses the different types of electrodes that can be used, including platinum, nickel, and titanium, and the advantages and disadvantages of each. The study also examines the influence of various parameters such as temperature and pH on the performance of the electrodes. The author found that platinum electrodes have the highest efficiency, but are also the most expensive. Additionally, he found that the pH of the seawater and the temperature have a significant effect on the efficiency of the electrolysis process. Overall, the literature review provides an in-depth analysis of the different types of electrodes that can be used for the production of hydrogen and oxygen from seawater through electrolysis and their advantages and disadvantages. Fukuzumi et. al [12] "Fuel production from seawater and fuel cells using seawater." *ChemSusChem* 10.22 (2017): 4264-4276. The literature review by Fukuzumi, Lee, and Nam in the journal ChemSusChem (2017) explores the potential of producing fuel from seawater and using fuel cells powered by seawater. The authors discuss the various methods for producing hydrogen from seawater, including electrolysis and photocatalytic methods, and highlight the advantages and disadvantages of each method. They also discuss the potential of using seawater as a source of fuel for fuel cells, including the use of seawater as an electrolyte in proton exchange membrane fuel cells. The study concludes that while there are still challenges to overcome, such as high costs and low efficiency, the potential for producing fuel from seawater and using fuel cells powered by seawater is promising for sustainable energy production. Oh, SeKwon, et al. [13] "Design of Mg–Ni alloys for fast hydrogen generation from seawater and their application in polymer electrolyte membrane fuel cells." *international journal of hydrogen energy* 41.10 (2016): 5296-5303. The literature review by Oh, SeKwon et al. (2016) published in the International Journal of Hydrogen Energy focuses on the design of Mg-Ni alloys for fast hydrogen generation from seawater and their application in polymer electrolyte membrane fuel cells. The study found that the Mg-Ni alloys had high hydrogen generation rate and stability, making them a promising material for hydrogen production from seawater. The authors also investigated the performance of the Mg-Ni alloys in polymer electrolyte membrane fuel cells and found that they had good performance and long-term stability. Overall, the study demonstrates the potential of Mg-Ni alloys as a cost-effective and sustainable material for hydrogen production and fuel cell application. Shafieian et. al. [14] "A multipurpose desalination, cooling, and air-conditioning system powered by waste heat recovery from diesel exhaust fumes and cooling water." *Case Studies in Thermal Engineering* 21 (2020): 100702. The literature review by Shafieian, Abdellah, and Mehdi Khiadani in the journal Case Studies in Thermal Engineering presents a new multipurpose desalination, cooling, and air-conditioning system that utilizes waste heat recovery from diesel exhaust fumes and cooling water. The system is designed to improve the energy efficiency of desalination and cooling processes by utilizing waste heat as a source of energy. The authors found that the system had a high thermal efficiency and was able to produce both fresh water and cool air simultaneously. They also noted that the system could be applied in various industrial settings, such as ships and power plants. Overall, the study demonstrates the potential of utilizing waste heat recovery in desalination and cooling systems to improve energy efficiency and reduce environmental impacts. Delpisheh Mostafa, et al. [15] "Desalinated water and hydrogen generation from seawater via a desalination unit and a low temperature electrolysis using a novel solar-based setup." *international journal of hydrogen energy* 46.10 (2021): 7211-7229. The study found that the solar-based setup was able to efficiently produce desalinated water and hydrogen from seawater. The desalination unit was able to reduce the salt content of seawater by more than 99%, while the low-temperature electrolysis system was able to produce hydrogen with a high purity of more than 99%. Additionally, the study found that the solar-based setup had a high thermal efficiency of more than 80%, which is significantly higher than traditional desalination and electrolysis systems. The authors also discussed the potential of the solar-based setup for the simultaneous production of desalinated water and hydrogen from seawater in coastal areas where seawater is readily available. They highlighted the importance of developing sustainable and cost-effective technologies for the production of desalinated water and hydrogen, as these resources are becoming increasingly important for a variety of applications such as drinking water, irrigation, and energy storage. Overall, the study by Delpisheh, Mostafa et al. provides valuable insights into the performance and potential of a solar-based setup for the simultaneous generation of desalinated water and hydrogen from seawater. The study demonstrates the potential of using solar energy to develop sustainable and cost-effective technologies for the production of desalinated water and hydrogen, which can have significant impacts on the environment and the economy.

Result and discussion

Hydrogen energy is one of the renewable energies available and it is ecological as well as economical in nature. Due to rising social awareness of the environment, the shipping industry is becoming more and more visible on a vast scale, forcing the industry to be more environmentally friendly and energy efficient than in the past. Through hydrogen technology, it is an efficient way to convert chemical energy into electrical energy. They are best suited for the energy requirements because of their 3 major properties – they are clean, efficient and quiet. Submarines which are non-nuclear generally have diesel-electric power supply systems. Generally, a diesel generator is coupled with lead-acid batteries to supply power to the entire submarine. Charging of the batteries is done during the snorkeling operation. The major drawback of this operation is the submarine would be easily detectable to others. This major drawback enabled the researchers to spend some decades developing hydrogen-powered submarines. A hydrogen-powered submarine has numerous performance advantages over a conventional diesel-electric submarine. In this complete chemical reaction, only water is formed as a reaction product. There are various systems such as Air Independent Propulsion systems which have the potential to ameliorate the performance of conventional diesel submarines. Following table shows the SWOT analysis of using hydrogen as an alternative fuel source.

	Strengths	Weakness
Opportunities	1. Develop hydrogen economy with comprehensive legislation. 2. Promote utilization of hydrogen energy. 3. Public acceptance.	1. Increase developments, innovations and research. 2. Increase development in hydrogen infrastructure. 3. Government funding.
Threats	1. Continued R&D funding to explore potential applications. 2. Co-operation between other energy sectors and hydrogen R&D centers.	1. Promote regulated hydrogen economy. 2. Implementation of specific laws and safety for usage.

Conclusion

Hydrogen has an outstanding potential for becoming a major factor in catalyzing the transition of our carbon-based global energy economy ultimately to a clean, renewable and sustainable economy. Hydrogen has superior performance in comparison with all kinds of carbon-based fuels for marine engines due to higher ignitability, high diffusivity, low dynamic viscosity, high heat capacity and better cooling characteristics at high combustion temperatures. Hydrogen and its fuel cells should be considered as an important alternative energy vector in transportation, industrial and residential sectors. All the advantages and challenges of using hydrogen as an alternative fuel source and metal hydride storage have been addressed resulting in a proven system for submarine use. There is still a long way to cover before true hydrogen revolution can occur.

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