engineering proceedings

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Green Hydrogen as a Clean Energy Resource and Its Applications as an Engine Fuel †

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† Presented at the International Conference on Recent Advances in Science and Engineering, Dubai, United Arab Emirates, 4–5 October 2023.

Abstract: The world's economy heavily depends on the energy resources used by various countries. India is one of the promising developing nations with very low crude reserves actively looking for new renewable energy resources to power its economy. Higher energy consumption and environmental pollution are two big global challenges for our sustainable development. The world is currently facing a dual problem of an energy crisis as well as environmental degradation. So, there is a strong need to reduce our dependency on fossil fuels and greenhouse gas emissions. This can be achieved to a great extent by universally adopting clean fuels for all daily life uses, like ethanol or liquified natural gas (LNG), as these burn very clean and do not emit many pollutants. Nowadays, green hydrogen has emerged as a new clean energy source, which is abundantly available and does not pollute much. This article explores the various benefits of green hydrogen with respect to fossil fuels, various techniques of producing it, and its possible use in different sectors such as industry, transport, and aviation, as well as in day-to-day life. Finally, it explores the use of green hydrogen as fuel in automobile engines, its blending with CNG gas, and its benefits in reducing emissions compared to fossil fuels. On combustion, green hydrogen produces only water vapours and is thus a highly clean fuel. Thus, it can potentially help humanity preserve the environment due to its ultra-low emissions and can be a consistent and reliable source of energy for generations to come, thereby ending the clean energy security debate forever.

Keywords: green hydrogen; renewable energy; clean engine fuel; energy security

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Citation: Taneja, S.; Jain, A.; Bhadoriya, Y. Green Hydrogen as a Clean Energy Resource and Its Applications as an Engine Fuel. *Eng. Proc.* **2023**, *59*, 159. https://doi.org/10.3390/engproc2023059159

Academic Editors: Nithesh Naik, Rajiv Selvam, Pavan Hiremath, Suhas Kowshik CS and Ritesh Ramakrishna Bhat

Published: 15 January 2024

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1. Introduction

Nowadays, there is a dire need for energy for each one of us, even for doing small tasks like mobile charging. We may not be able to efficiently live and work without energy today due to hugely technology-supported lifestyles and high-tech appliances that all run on electric energy. A recent study showed that energy consumption is increasing more rapidly than population growth in the United States [1]. In the 20th century, fossil fuels such as coal, gasoline, diesel, natural gas, etc., were considered the main source of energy. The limited stocks of these resources and their faster depletion have led to the search for future energy sources. This is a huge challenge for the whole world, namely the difficulties of how to run our industries, generate electricity, manage gadgets or systems, as well as fulfil the daily needs of life. Another drawback of fossil fuels is that they produce greenhouse gases on burning, which are very harmful to the environment. Thus, the focus has shifted to exploring and tapping new renewable sources of energy like wind, solar, geothermal, tidal, etc.

To minimise GHG production, several new alternatives have been studied. The addition of anhydrous ethanol to petrol is a viable alternative that has the ability to control

engine emissions. The torque, braking power, and thermal efficiency of engines have all increased as a result of ethanol–gasoline mixtures. Modern engines perform better when bioethanol is used instead of anhydrous ethanol, thanks to lower NO_x emissions [2].

In the 21st century, India has become one of the fastest-growing economies in the world. India is in a transition phase of becoming a developed nation. The current government is concerned with the concept of smart cities, electric transport vehicles, the digital India mission, the solar power system, wind power generation in seashores, and the manufacturing of Lithium-ion batteries. Apart from this, India is continuously inviting developed nations to come and invest in India for utilising the workforce of the youth of India and making them more employable. Also, India has become the most populous nation, and its population is growing much faster than all other countries. So, it would be highly judicious to say that India needs to develop and tap its renewable energy resources much more urgently than anticipated.

The last 10 years saw a huge thrust being given to solar and wind power energy resources than the other renewable resources due to potentially higher manufacturing capability [3]. India's rate of generating wind power almost double with each 5 years of duration. Today, 60% of Indian states are in the process of setting up wind power generation [4]. Similarly, solar energy systems are being installed in farms for running pumps and other machinery used in agriculture. Solar panels are also being installed in highways, institutions, playgrounds, streets, etc., as per the needs of electricity generation. Many solar parks have already been established in different states of India by the Indian government and public –private partnership projects [5]. The growth of the renewable energy capacity in India over the past decade is shown in Figure 1, which highlights the importance the country is giving to renewable energy.

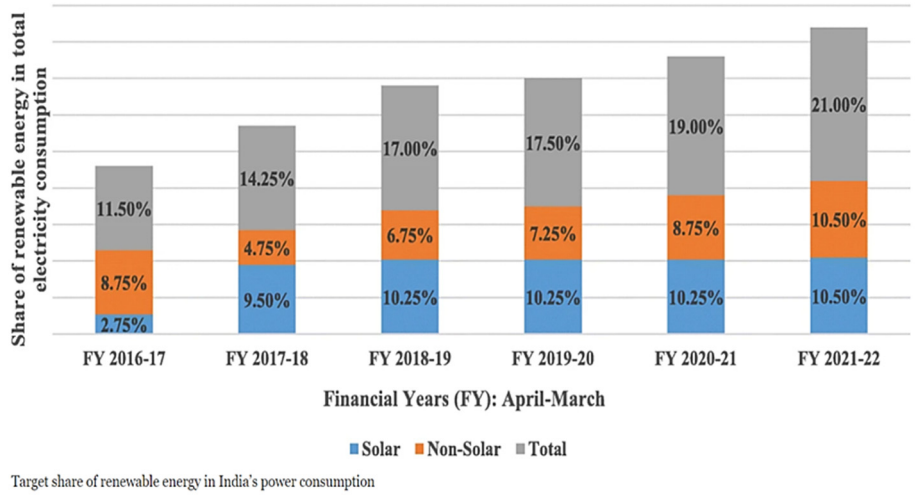


Figure 1. Growth of renewable energy in India [6].

However, both wind- and solar-based generation depend on the atmospheric conditions, i.e., air velocity and sunlight intensity. So, there will always be a problem of continuous and consistent power generation from these sources. Therefore, a more reliable and eco-friendly power generation system should be employed with an efficient energy storage system to power the sectors with consistent energy demand.

Hydrogen is one such potential gas which can be used as a fuel in future. It does not produce any greenhouse gas emissions and thus can be termed as an eco-friendly fuel. Hydrogen is highly combustible and produces water and a small amount of nitrogen oxide on burning. Hydrogen has a high energy density, which is approximately three times that of conventional hydrocarbon fuels [6]. It produces huge power in gas turbines to generate electricity even after mixing with other commonly used gaseous fuels like methane. Hydrogen gas has been researched as one of the substitutes for IC Engine fuel additives. According to studies, mixing hydrogen with conventional fuels can increase

thermal efficiency while lowering emissions of unburned hydrocarbons. Additionally, it has been discovered that oxyhydrogen gas injection into ICE lowers petrol consumption and helps lower CO_2 emissions. Hydrogen-based energy storage systems are one such way of using it. Many storage devices have been invented for renewable energy in the form of mechanical, chemical, electrochemical, thermal, magnetic, and pneumatic systems [7].

2. Hydrogen Production and Storage

There are multiple challenges involved in the generation and storage of hydrogen, which are discussed below, along with the common nomenclature used for hydrogen.

2.1. Types of Hydrogen

- **Grey Hydrogen:** When hydrogen is synthesised from fossil fuels like natural gas, it is called grey hydrogen. During the process of making hydrogen, carbon dioxide is released, which is not captured. It is the most commonly available form of hydrogen.
- **Blue Hydrogen:** Blue hydrogen is produced by the same process as grey and from fossil fuels only, except that the carbon produced is captured here and stored.
- **Green Hydrogen:** The mostly sought-after form of hydrogen is green hydrogen, which utilises green energy or renewable energy for producing hydrogen. It is generally performed via the electrolysis of water using renewable energy.

Due to its zero carbon emissions and a variety of production methods, hydrogen is a promising alternative fuel. Depending on the process used to produce it, hydrogen can be categorised as grey, blue, or green, with green hydrogen being the most environmentally beneficial option because it uses renewable feedstocks and energy sources. The generation of grey and blue hydrogen, which is derived from fossil fuels, greatly increases world CO_2 emissions, amounting to about 830 million tonnes of CO_2 eq annually. Green hydrogen generation, on the other hand, depends on clean energy from sources like the sun and wind. Green hydrogen production frequently uses water-splitting reactions like electrolysis and thermochemical water splitting [8].

2.2. Production of Hydrogen

Based on the research carried out so far, hydrogen can be produced by any one of the six methods: Steam Methane Reforming; Electrolysis; Coal or Biomass Gasification; Microbial Biomass Conversion; and Thermochemical Water Splitting Cycles. Their process details are as follows:

1. **Steam Methane Reforming (SMR) technique**: In this technique, methane produced from natural gas is allowed to heat in the presence of steam, generally in the presence of a catalyst, leading to the production of carbon monoxide and hydrogen and a very minute amount of carbon dioxide.
2. **Natural Gas Reforming:** In this process, a mixture of gases containing hydrogen, carbon monoxide and a very small amount of carbon dioxide, i.e., synthesis gas, is produced by a reaction between high-temperature steam and natural gas. The carbon monoxide that is released further reacts with steam to produce surplus hydrogen.
3. **Electrolysis of water:** An electric current is employed to split water into its constituents' releasing hydrogen and oxygen. If renewable sources of electricity (like solar or wind) are used, the so-produced hydrogen is considered renewable as well, and have several benefits in emissions.
4. **Biomass conversion:** The conversion of biomass into sugar-rich feedstocks is carried out, followed by fermentation in the presence of microorganisms to produce hydrogen. The sources of biomass can be food waste, crop residues, sewage residues, animal residues, or even wastewater [9].

The various sources of hydrogen and the methods of its generation are shown in Figure 2 with the help of a flow diagram.

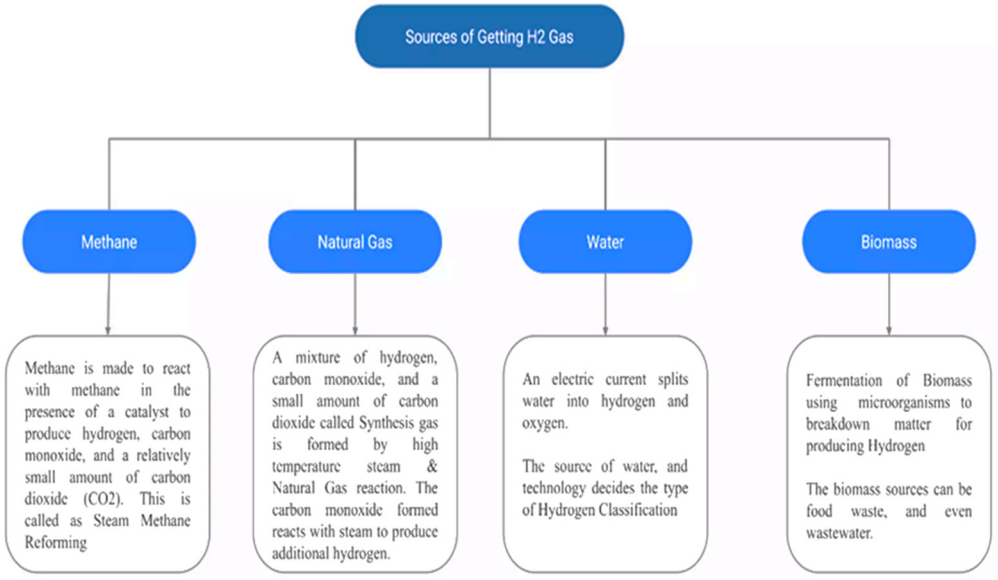


Figure 2. Sources of hydrogen [9].

2.3. Storage of Hydrogen

Although hydrogen gas is an exceptional fuel with a remarkably high calorific value, there are numerous challenges related to the storage of hydrogen gas owing to it being lightweight. Two challenges which need to be addressed while storing hydrogen are as follows:

a. **Low volumetric energy density**: As the simplest element with a very low weight and a very low boiling point, i.e., −253 °C, hydrogen tends to be easily lost in the environment.
b. **Embrittlement of metal cylinders**: Storing hydrogen in its compressed form in metal cylinders is a general practice; however, hydrogen causes the embrittlement of metal cylinders and thus deteriorates the metal surface and is therefore an important safety concern.

Nowadays, the common practices being followed for hydrogen gas storage include the following:

- **Geological hydrogen storage**: A considerably viable solution is to store hydrogen inside the porous rocks in the salt caverns or salt domes wherein it remains in the combined state. Figure 3 shows the salt caverns used for hydrogen storage.
- **Compressed hydrogen storage**: The storage of hydrogen in the compressed state typically requires a very high pressure ranging from 350 to 700 bar and cryogenic temperatures.
- **Liquid hydrogen:** Hydrogen can be liquified by lowering its temperature to −253 °C and can be stored in cryogenic tanks.
- **Material-based storage:** Distinct storage techniques are adopted by combining hydrogen with distinct materials. Combining hydrogen with adsorbent materials, e.g., palladium, which has the capacity to adsorb 900 times of hydrogen than its own volume. Some other alloys, such as those of magnesium and aluminium, can be employed to serve the purpose. Another way involves the usage of ammonia gas as a hydrogen carrier, which can be desirably cracked as per H_2 requirements [8].

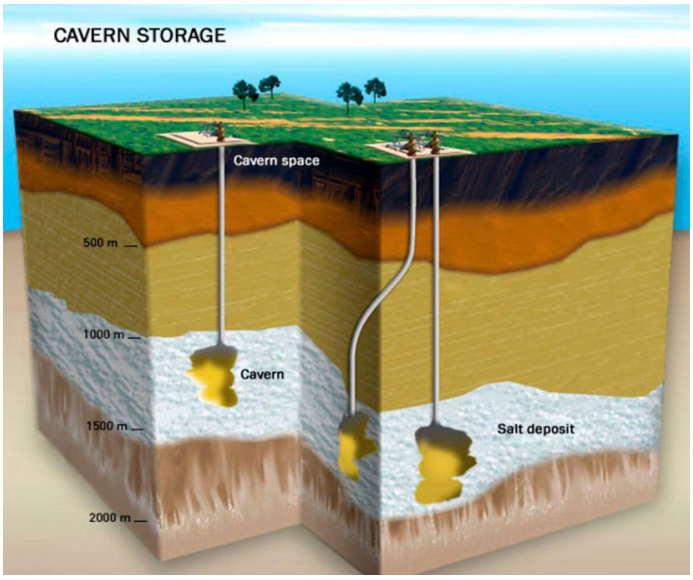


Figure 3. Salt cavern-based hydrogen storage [8].

2.4. Benefits of Hydrogen as Fuel

Some of the key benefits of using hydrogen as a fuel, particularly as an engine fuel, are as follows:

- Infinite Supply: An unlimited amount of hydrogen gas can be produced by the electrolysis of water, which, upon combustion, again yields water; thus, there will be no constraint of hydrogen supply ever.
- High Calorific Value: Hydrogen has a very high heating value of 120 MJ/kg compared to 45 MJ/kg for CNG, suggesting that the mass flow rate of hydrogen supplied to the engine will be much lesser and hence the storage requirements will decrease.
- No Carbon Emissions: The carbon footprint is drastically lower for green hydrogen as compared to fossil fuels. Although the hydrogen-to-carbon ratio varies slightly depending on the type of crude oil, generally, gasoline and diesel contain approximately 84 to 86 wt-% of carbon and 14 wt-% of hydrogen, while there is no carbon content in hydrogen. It helps address one of the vital concerns of environmentalists, which is global warming due to fossil fuels GHG emissions.
- Aviation fuel: Liquified hydrogen gas has a huge potential to be used as a potential aviation fuel also and a lot of active research is going on in this domain.

2.5. Prospects of Green Hydrogen

Due to its high energy and zero carbon emissions, hydrogen is a promising alternative fuel. From 70 million tonnes in 2019 to 120 million tonnes in 2024, the global market for hydrogen is anticipated to increase. Green hydrogen production in future is anticipated to primarily use water splitting reactions electrolysis powered by solar. With the help of 4 GW of renewable energy, a future green hydrogen plant will be able to create 650 tonnes of hydrogen per day by 2025 [9].

3. Literature Review

On the basis of the studies carried out so far previously, green hydrogen can also be used as a fuel to run vehicles. Many researchers have worked on the production of green hydrogen, and many have tested its features when used as engine fuel. This section provides a detailed summary of the findings of such prominent works.

Based on Its Use as Engine Fuel

One study by Bongartz D. et al. (2018) [10] on producing light-duty transportation fuels with renewable hydrogen gas and CO_2 gas. The authors emphasised the importance of finding sustainable fuel alternatives because fossil fuel-based transportation involves significant greenhouse gas emissions. The authors acknowledged that short-distance transit with battery electric vehicles appears feasible but felt that long-distance transit solutions need novel liquid or gaseous fuels. Hydrogen as an engine fuel is a viable solution since hydrogen (H_2) may be produced via water electrolysis using renewable electricity [10].

The authors explored the usage of hydrogen in fuel cells and how it can be changed into organic fuels like methane, methanol, and dimethyl ether (DME) to be compatible with the current engine infrastructure. Four different strategies for introducing renewable hydrogen (H_2) into the car industry were experimented with. The research assumes that extra renewable electricity will be used to electrolyse H_2, which will then be continually delivered to gas/petrol stations through a pipeline. Carbon dioxide (CO_2) created during the upgrading of biogas serves as the source of carbon. For fuel cell vehicles (FCV), the evaluation evaluates methane, methanol, dimethyl ether (DME), and hydrogen. SI engines commonly use methane (CNG); however, FCVs are currently the focus of research and development. DME offers the potential for compression ignition engines, while methanol can be used as a liquid SI fuel or as an addition to petrol. Additionally, three fuel manufacturing methods using renewable carbon dioxide (CO_2) and hydrogen (H_2) were developed: methane, methanol, and dimethyl ether (DME).

Conclusions were drawn for the four methods of using renewable hydrogen (H_2) in transportation, including direct usage in fuel cell cars and conversion to methane, methanol, or DME for cars with internal combustion engines. All choices exhibited large reductions in greenhouse gas and pollutant emissions as compared to fossil fuels, but in order to be competitive economically, affordable H_2 is needed. The anticipated fuel production for Germany in 2035 is expected to stay constrained while using solely restricted renewable electricity because it consumes a lot of dedicated renewable electricity to manufacture large amounts of hydrogen fuel. Although direct H_2 use in fuel cells has advantages in terms of efficiency and emissions, it has drawbacks in terms of fuelling pressure and infrastructure. The methane reported reduced greenhouse gas emissions as compared to other combustion engine fuels, but DME has lower fuel costs and electrical requirements. The authors finally concluded that systems that combine steady-state conversion and dynamic electrolysis may increase overall efficiency and reduce fuel costs. They suggested that future fuel contenders must utilise low enthalpy fuels like DME and efficient engine designs for reliable outcomes [10].

Table 1 shows the properties of commonly used fuel in gasoline engines.

Table 1. Fuel properties.

	Gasoline	**Ethanol**
Chemical formula	C_2–C_{14}	C_2H_6OH
H/C ratio	1.795	3
O/C ratio	00	0.5
Oxygen content (%)	00	34.7
Research octane number	95	106
Stoichiometric air–fuel ratio	15:1	9:1
LHV (MJ/kg)	43	27
Density@20 °C (kg/m^3)	744.6	791

Another investigation by Becerra-Ruiz et al. (2019) [11] discussed the use of bioethanol and green hydrogen as fuels in internal combustion engines to reduce emissions. The authors focussed on tackling considerable environmental concerns brought on by greenhouse gas (GHG) emissions, notably those produced by the usage of internal combustion engines (ICE) across a variety of sectors, including energy generation, industry, transportation, and

households. Eighty percent of all global anthropogenic emissions come from these sectors. The authors stressed that due to the prolonged vehicle lifespan in Mexico, 70% are still in operation after 16 to 35 years. This leads to excessive emissions of various hazardous gases due to poor combustion [11].

A solar panel and an Alkaline Electrolyser Reactor (AER), which produces 1 NL/min of mixed gases, including hydrogen and oxygen, were used to create the gH_2 gas (green hydrogen). The used bioethanol was 99.7% pure. The experimental engine was a portable 5500 W generator with a 43 HP four-stroke gasoline piston. The experimental matrix included 36 treatments, varying the electric charge levels (0, 50, and 100% of the generator's operative capacity), petrol and bioethanol mixtures (E20, E50, and E90), and the fuelling of the generator (with and without $gH_{2)}$. To assure consistency, the authors carried out each test three times, yielding a total of 108 measurements.

The authors concluded that reduced gasoline uptake and GHG emissions were produced by the ternary (gasoline-gH_2-bioethanol) and binary (gasoline-gH_2-gH_2) fuel combinations used in the ICE generator. At 100% generator charge, the E90-gH_2 mixture resulted in notable decreases in CO, HC, and NOx emissions (99%, 93%, and 67%, respectively), as well as an increase in CO_2 of 35%. At 50% generator charge, an E90-gH_2 combination led to a reduction in CO, HC, and fuel uptake of 97%, 90%, and 23%, respectively, but an increase in CO_2 and NOx of 64% and 30%. At 0% charge, the E50 mixture increased fuel efficiency by 36%, and at 50% charge, E50-gH_2 burnt about 30% less fuel. Compared to using only petrol, the addition of gH_2 and bioethanol reduced the emission of NOx. Coke adhesion to spark plugs was decreased by gasoline-gH_2-bioethanol combinations, indicating a potential increase in ICE lifespan. The technique for producing hydrogen is both affordable and secure, but more investigation is required to fully grasp the consequences of continuous gH_2 and bioethanol consumption on the engine [11].

One more study by Atilhan et al. (2021) [12] focussed on using hydrogen as a clean fuel for marine vehicles, which can benefit the shipping industry. Around 7–8% of the world's greenhouse gas (GHG) emissions are produced by the maritime transport sector, which highlights the need for sustainable, scalable energy sources with high energy density. With an emphasis on their application in the shipping industry, the authors evaluated the environmental and techno-economic effects of hydrogen generation methods employing renewable and fossil-based energies. The authors also considered the various fuel types and their safety characteristics and felt that the lofty GHG emission reduction targets set by the IMO for the maritime shipping industry may be greatly aided by these efforts [12].

The authors zeroed in on the technological and financial obstacles to the manufacture of green hydrogen that is obtained from CO_2-low/neutral alternative energy sources like solar or wind that must be overcome for it to be feasible. The high electricity requirement for the electrolysis process was found to be the key obstacle, making the cost of solar and wind energy production an important consideration. The price of renewable electricity has, however, dropped dramatically over the previous 10 years, outpacing predictions from experts and suggesting the possibility of future cost reductions. An important portion of the cost breakdown for the production of green hydrogen is due to the expense of electrolysis. Despite this, the improvements in materials and technical solutions will reduce manufacturing costs by roughly 70% over the next decade, making green hydrogen more commercially viable for wider adoption. Due to their limited use at the moment, green production techniques may have disadvantages in terms of cost. However, compared to blue- or grey-based methods, their environmental effect is substantially smaller, making green hydrogen production a possible future option. It is anticipated that as the sector adopts green technology, it will become the next-generation hydrogen production option, resulting in a more ecologically responsible strategy.

It was concluded that for the complete life cycle, grey hydrogen has a significant carbon footprint. Green hydrogen emits the fewest emissions, while blue hydrogen has a smaller carbon impact. A viable solution for achieving the IMO's emission reduction targets is green LH_2. However, 2.2% of the world's CO_2 emissions come from the maritime sector, and

hydrogen-fired power plants might drastically lower emissions. Compared to traditional fuels, the pathways in the hydrogen supply chain emit less CO_2. For the use of LH_2, the authors outlined that improvements in cargo containment and international standards are required. Costs must decrease, and hydrogen storage safety must be improved [12].

Another set of authors [13] reviewed the use of hydrogen as fuel in IC engines. The authors summarised the increase in global population where they found that the use of fossil fuels is driving up the energy demand. Although engines dominate the power and transportation sectors, these generate pollutants that negatively impact the environment. Researchers have been looking into a number of strategies, including additives and renewable biofuels, to enhance the quality and combustion of fuel in IC engines. For IC engines to be viable in the long run, clean-burning fuels from renewable sources must be developed. Given their promise as renewable and clean fuels, the authors intended to examine and summarise how hydrogen fuels affect spark and compression ignition engines. Internal combustion engines can use hydrogen as fuel, but specific adjustments must be made in the combustion system to accommodate this alternative fuel.

Numerous studies have been carried out in the automotive sector to investigate the usage of hydrogen in internal combustion petrol engines. One typical method uses a carburetor or injection system to deliver hydrogen into the combustion chamber, where it reacts with the fuel and air mixture. Conventional internal combustion engines are made to run on liquid fuels like petrol or diesel. They would need major engine modifications to convert to running only on hydrogen. Therefore, new concepts and engine alterations must be created to smoothly mix various sources of energy with hydrogen in order to effectively utilise hydrogen as a direct fuel. As an alternative, hydrogen can be utilised as a backup fuel in addition to regular liquid fuels. With this strategy, integrating hydrogen is made simpler without significantly altering the engine.

Hydrogen was then analysed as a good alternative fuel that can lower the negative effects on the environment and dangerous car emissions. In spark ignition (SI) engines, adding hydrogen can reduce brake thermal efficiency. In CI engines, hydrogen increases the rate of heat release and brake-specific fuel consumption (BSFC). IC engines are found to emit less carbon monoxide (CO) and unburned hydrocarbons (UHC) thanks to hydrogen. Due to its use, the H/C ratio rises, enhancing combustion effectiveness and lowering CO_2 emissions. The characteristics of hydrogen help diesel engines produce less soot and NOx emissions. In general, using hydrogen in internal combustion engines is found to result in fewer emissions and better performance, making it a clean and efficient fuel [13].

Another study in the year 2022 authors [14] examined how hydrogen is produced and used as a renewable fuel for IC engines. The authors acknowledged that the transportation industry makes a sizable contribution to greenhouse gas emissions, thus forcing researchers and automakers to look for cleaner ICE solutions for addressing environmental issues.

Due to its abundance, clean burning characteristics, and capacity to be manufactured from both renewable and non-renewable sources, hydrogen has emerged as a possible alternative fuel for ICEs. The authors mentioned better engine cold starts, less pollutant emissions, and less lubricating oil contamination as a few benefits of hydrogen, while high flame propagation speed, heating value, diffusivity, and short quenching distance are a few of the advantageous characteristics that hydrogen demonstrates. In terms of pollution levels, combustion stability, and lean limit, it performs better than other fossil fuels. The use of hydrogen in ICEs can significantly reduce emissions while offering a driving range that is on par with that of traditional petrol or diesel cars.

Furthermore, the authors demonstrated the implementation of hydrogen usage in both the SI and CI engines using various parameters. Based on the results of the research, it was concluded that even when used as the only fuel, hydrogen considerably increased the thermal efficiency of both SI and CI engines. Fuel and energy consumption were lower for blended hydrogen–diesel fuels. The improved performance was aided by hydrogen's superior qualities, such as its higher calorific value and quick flame speed. However, its lower density and volumetric efficiency decreased the performance. Compared to regular

diesel fuel, hydrogen–diesel dual fuel operation in SI and CI engines produced cleaner emissions. The lack of carbon atoms in hydrogen fuel resulted in a large reduction in carbon-related pollutants such as CO, CO_2, and HC. Additionally, CI engines displayed decreased emissions of smoke, soot, and particulate matter. However, because hydrogen burns quickly, SI engines saw an increase in NOx production. SI engines running on hydrogen demonstrated good combustion stability, increased cylinder pressure and heat release rates. The use of hydrogen fuel in IC engines was concluded as feasible for both single-fuel and dual-fuel operation [14].

In Another latest investigation in 2023, authors [15] demonstrated the huge negative impact of using low-quality fuel with a high viscosity, high sulphur content, and heavy metals in marine engines on the climate and human health. To reduce emissions, a number of exhaust gas treatment methods have been developed, including exhaust gas cleaning (EGC), exhaust gas recirculation (EGR), and selective catalytic reduction (SCR). The authors concluded that to reach emission reduction goals, it is not enough to rely just on exhaust retreatment. Instead, it requires the synthesis and usage of low-carbon, clean marine fuels.

The authors zeroed in on three researched alternative maritime fuels—ammonia, hydrogen, and methanol. These fuels can reach low or zero emissions when made from renewable resources, calling them "green fuels". While renewable methanol, renewable natural gas, bioethanol, bio-dimethyl ether, and biodiesel are categorised as carbon-neutral fuels, green hydrogen and green ammonia are regarded as carbon-free green fuels. Due to its potential for extensive, long-term energy storage, international energy exchange, and minimal environmental impact, the production of green fuel from renewable energy has gained tremendous interest. In the long run, hydrogen is thought to be a more advantageous zero-emission option with negligible environmental impact if leaked. Furthermore, in order to completely remove greenhouse gas emissions from the transportation sector, hydrogen is seen as a viable future fuel. Green hydrogen is created from renewable resources that have low or no carbon emissions and satisfy sustainability standards.

Internationally, "green hydrogen" is defined differently. While some nations place a higher priority on GHG reductions and define those terms to include fossil fuel pathways and CCS, others place more emphasis on carbon-free renewable energy production. With a capacity of 650 t/day of hydrogen production by electrolysis and 4 GW of renewable energy from solar, wind, and storage, the largest green hydrogen factory in the world is expected to start in 2025. Many green hydrogen production systems, including electrochemical water splitting, photocatalytic water splitting, and electrolytic production from saltwater, have been examined. Studies have thoroughly evaluated the possible applications of green hydrogen in the transportation sector, including production methods, performance, storage, and safety. Recent research has concluded that the marine industry may effectively cut carbon emissions by using green fuel, which is created from renewable sources of energy like wind and solar power. The authors concluded that hydrogen storage on ships is a difficulty that calls for the development of supporting infrastructure as well, like a full hydrogen generation and hydrogenation system. The electrolysis of water for hydrogen synthesis using green power shows promise [15].

4. Conclusions

Green hydrogen can be used as a fuel provided its production cost is brought down, storage challenges are sorted out, and its high inflammability is sensibly kept under check. At present, its usage as an independent fuel is challenging. However, CNG gas can be blended with 1–5% green hydrogen to boost its calorific value and can be easily used as engine fuel. This would reduce the fuel storage requirements and thus, more boot space would be available. Pure green hydrogen will also be used in the future as engine fuel independently, but this needs more thorough research and testing as it is still in the early stages of research.

Author Contributions: Conceptualization, S.T.; methodology, S.T. and A.J.; Fuel Synthesis study, Manuscript drafting, S.T. writing—original draft preparation, S.T., A.J. and Y.B.; writing—review and editing, Y.B. and A.J. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: All the data used are made available in the present work.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Khan, I.; Fujun, H.; Hoang, P.L. The impact of natural resources, energy consumption, and population growth on environmental quality: Fresh evidence from the United States of America. *Sci. Total Environ.* **2021**, *754*, 142222. [CrossRef] [PubMed]
2. Taneja, S.; Parmar, A. Analysis of the engine characteristics of a variable compression ratio SI engine fuelled with various gasoline-ethanol blends. *AIP Conf. Proc.* **2019**, *2148*, 030056. [CrossRef]
3. Mehrjerdi, H. Modeling and optimization of an island water-energy nexus powered by a hybrid solar-wind renewable system. *Energy* **2020**, *197*, 117217. [CrossRef]
4. Sitharthan, R.; Swaminathan, J.N.; Parthasarathy, T. Exploration of wind energy in India: A short review. In Proceedings of the National Power Engineering Conference (NPEC), Madurai, India, 9–10 March 2018; IEEE: Piscataway, NJ, USA, 2018.
5. Kumar, C.M.S. Solar energy: A promising renewable source for meeting energy demand in Indian agriculture applications. *Sustain. Energy Technol. Assess.* **2023**, *55*, 102905. [CrossRef]
6. Kumar, J.; Majid, M. Renewable energy for sustainable development in India: Current status, future prospects, challenges, employment, and investment opportunities. *Energy Sustain. Soc.* **2020**, *10*, 2. [CrossRef]
7. Olabi, A.G. Renewable energy and energy storage systems. *Energy* **2017**, *136*, 1–6. [CrossRef]
8. Muhammed, N.S.; Haq, B.; Shehri, D.A.; Zaman, E. A review on underground hydrogen storage: Insight into geological sites, influencing factors and future outlook. *Energy Rep.* **2022**, *8*, 461–469. [CrossRef]
9. Ayodele, T.R.; Josiah, L.M. The potential role of green hydrogen production in the South Africa energy mix. *J. Renew. Sustain. Energy* **2019**, *11*, 044301. [CrossRef]
10. Bongartz, D.; Doré, L.; Eichler, K.; Grube, T.; Heuser, B.; Laura, E.H.; Robinius, M.; Pischinger, S.; Walther, G.; Mitsos, A. Comparison of light-duty transportation fuels produced from renewable hydrogen and green carbon dioxide. *Appl. Energy* **2018**, *231*, 757–767. [CrossRef]
11. Becerra-Ruiz, J.D.; Gonzalez-Huerta, R.G.; Gracida, J.; Amaro-Reyes, A.; Macias-Bobadilla, G. Using green-hydrogen and bioethanol fuels in internal combustion engines to reduce emissions. *Int. J. Hydrogen Energy* **2019**, *44*, 12324–12332. [CrossRef]
12. Atilhan, S.; Park, S.; El-Halwagi, M.M.; Atilhan, M.; Moore, M.; Nielsen, R.B. Green hydrogen as an alternative fuel for the shipping industry. *Curr. Opin. Chem. Eng.* **2021**, *31*, 100668. [CrossRef]
13. Shadidi, B.; Najafi, G.; Yusaf, T. A Review of Hydrogen as a Fuel in Internal Combustion Engines. *Energies* **2021**, *14*, 6209. [CrossRef]
14. Teoh, Y.H.; How, H.G.; Le, T.D.; Nguyen, H.T.; Loo, D.L.; Rashid, T.; Sher, F. A review on production and implementation of hydrogen as a green fuel in internal combustion engines. *Fuel* **2023**, *333*, 126525. [CrossRef]
15. Jie, S.; Zhu, Y.; Feng, Y.; Yang, J.; Xia, C. A Prompt Decarbonization Pathway for Shipping: Green Hydrogen, Ammonia, and Methanol Production and Utilization in Marine Engines. *Atmosphere* **2023**, *14*, 584. [CrossRef]

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