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Green Hydrogen Energy: Fuel of the Future

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Abstract

Green hydrogen, synthesized from the electrolysis of water using renewable energy resources, is emerging as a staple in the world's fight against climate change and the ultimate energy transition. The green electrolyzed version of hydrogen offers the promise of decarbonizing multiple sectors, including industry, transportation, and gas and power production. Several industrial giants have made substantial investments in the green hydrogen ecosystem, including Reliance Industries, Adani Green Energy, and GAIL, among others, recognising the potential of this fuel to decarbonize their activities and help integrate renewables. The large-scale projects include the Dhirubhai Ambani Green Energy Giga Complex and the Adani-Total Energies partnership, which both plan to produce a few million tons annually in the next decade. Despite several hurdles such as storage, transport, and economic constraints, as well as the rapidly growing electrolysed technology, strategic investment, and supportive policies, such as India's National Hydrogen Energy Mission, indicate progress on the horizon. The abstract presents an overview of the current situation and the vast potential that this chemical compound holds for the future.

***Keywords**:* Green Hydrogen, Zero Emission, Carbon Free, Fuel

Introduction

Green hydrogen, the fuel of the future, is a universal, light, and highly reactive energy source. With the world's growing energy needs, we require a sustainable system that effectively reduces CO_2 emissions while addressing environmental impacts. Hydrogen is a solution that offers scalable, efficient, and CO_2-free energy.

Hydrogen, the most abundant chemical element on Earth, has seen its global demand triple since 1975 to 70 million tons annually by 2018, according to the IEA. Green hydrogen, which emits only water vapor, leaves no pollutants in the air, unlike oil or coal. It has a long-standing role in industry, powering cars, airships, and spacecraft since the 19th century. With the urgent need to decarbonize the economy, hydrogen is set to play an even larger role. According to the World Hydrogen Council, if production costs drop by half by 2030, hydrogen will be one of the fuels of the future.

The world is different from what it was centuries ago, with rapid environmental degradation and increasing disasters. Fossil fuel combustion releases greenhouse gases, leading to global warming and climate change. Ecosystems around oil wells and coal mines are severely impacted, and oil spills damage marine life and coastal zones. Coal, which accounts for 36% of global CO2 emissions, is the most damaging fossil fuel to health and the environment.

Hydrogen, however, can be a clean energy source to reduce CO2 emissions and mitigate climate change. What makes it unique is -

Zero Greenhouse Gas Emissions: Hydrogen produced from renewable sources, like wind or solar power, doesn't emit greenhouse gases, unlike conventional methods that rely on fossil fuels.

High Energy Density: Hydrogen has a high energy density, meaning it stores a lot of energy per unit of weight or volume. This quality makes it suitable for transportation and high-energy applications.

Versatility: It has diverse uses, including transportation, power generation, and industrial processes. It can fuel fuel-cell vehicles, act as a feedstock in industry, and store or distribute energy.

High-Efficiency Energy Conversion: Fuel cells can convert hydrogen into electricity with up to 60% efficiency, making it a promising energy source for transport and power generation.

Renewable Energy Storage: Hydrogen can store renewable energy from wind or solar power for later use, helping address intermittency in renewable energy supply.

In 2018, the International Renewable Energy Agency (IRENA) released a report entitled 'Global Energy Transformation: A Roadmap to 2050' gives the global capacities for different forms of renewable energy.

Table 1.1: Showing Renewable resource and their capacity in World and in India

Rank	Type	World Capacity (GW)	India Capacity (GW)
1	Hydropower	1270	50
2	Wind Power	510	33
3	Solar Energy	390	18
4	Bioenergy	108	10

Source: https://www.irena.org/

Literature Review

Several studies, such as by **IRENA (2020),** have detailed the rapid advancements in electrolyzed technologies, including polymer electrolyte membrane (PEM), alkaline, and solid oxide electrolyzes. PEM electrolyzes, noted for their high efficiency and compact design, are emerging as a favorable option **(Wulf et al., 2020).** However, alkaline electrolyzes are still considered the most mature and cost-effective option **(Gupta et al., 2022).** Wind and solar energy are pivotal in reducing carbon emissions in hydrogen production. **Aziz et al. (2021)** emphasized the integration of offshore wind farms with electrolyzes to produce green hydrogen, while **Blanco and Faaij (2018)** reviewed the solar-based hydrogen production potential, highlighting regions like Australia and North Africa. The storage and transportation of hydrogen remain challenging due to its low energy density and potential safety risks. **Wang et al. (2020)** reviewed various storage technologies, emphasizing compressed gas and liquid hydrogen storage as the leading options. Metal hydrides and chemical carriers, though less mature, offer promising efficiency improvements. **Liu et al. (2021)** analysed the transportation network, stressing the need for international standards to facilitate global trade. Green hydrogen has significant potential in grid balancing and power generation. In the power sector, it can store excess renewable energy and provide stable output during peak demands **(Bermúdez et al., 2022).** Hydrogen fuel cells are also emerging as a complementary technology to battery storage. Green hydrogen is finding applications in hard-to-abate industrial sectors like steel production, where it can replace coking coal **(Gielen et al., 2020).** In transportation, fuel cell vehicles are gaining traction, particularly in commercial fleets **(Garg**

et al., 2021). Although green hydrogen offers immense promise, economic and technical challenges remain. The high cost of renewable hydrogen production, due to expensive electrolyzes and intermittent energy supplies is highlighted by **Bartels et al. (2022).** Additionally, policy and infrastructure investments will be crucial to scale up production and establish an international supply chain.

Objectives

1. To explore the potential of Hydrogen Energy as a fuel.
2. To explore the Public/ Private companies involved in exploring the potential of Hydrogen energy.
3. To understand and analyse the common people's perspective and behaviour in this direction.

Methodology

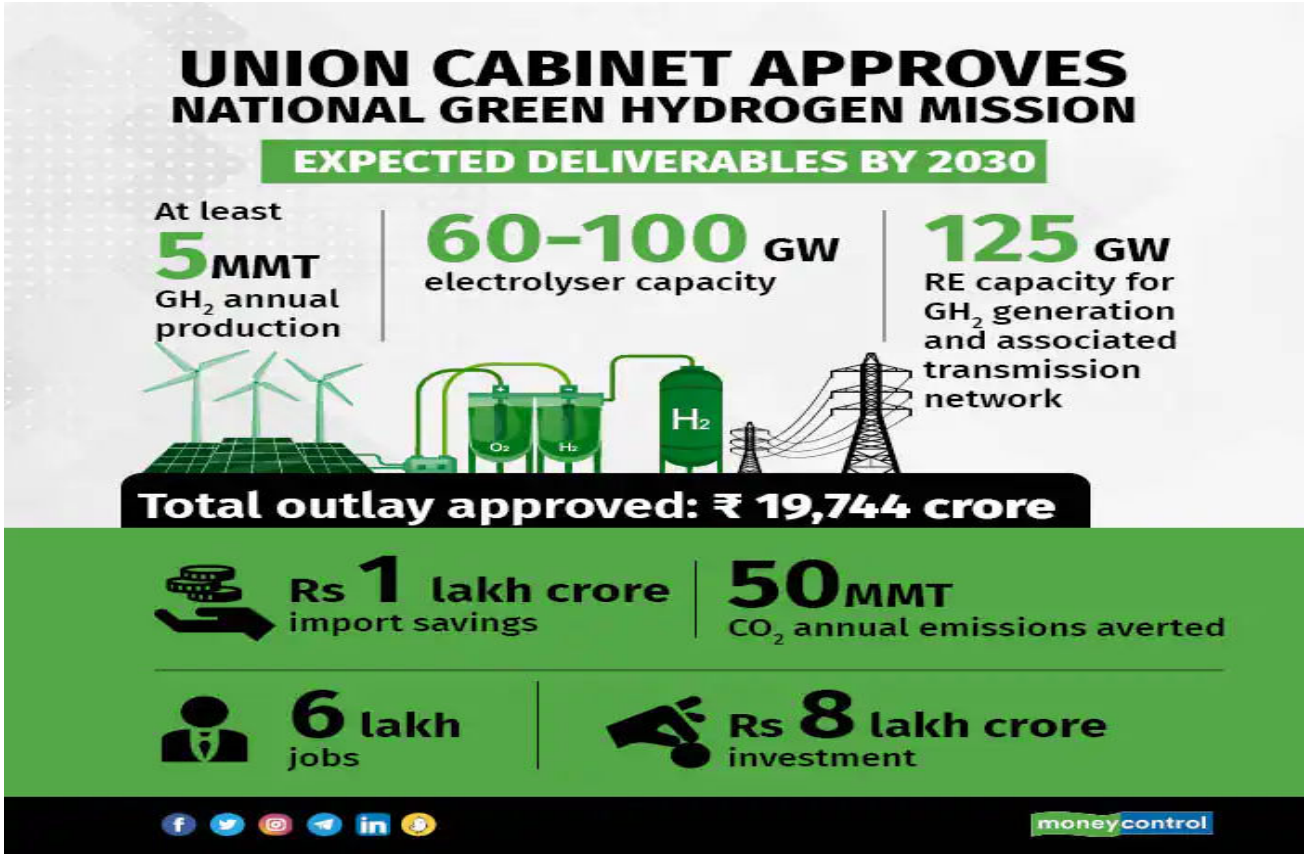
This study is a thorough analytical investigation as the approach utilized to get the result was primary and secondary data collected from common people through questionnaires, government official records, and published data. An extensive Literature review was done to identify the research problem. Analysis and interpretation of the collected data are done and presented in the form of graphs.

Area of Study

To compile this work India has been selected as an area of study. India has set its sights on becoming energy-independent by 2047 and achieving Net Zero by 2070. To achieve this target, increasing renewable energy use across all economic spheres. The National Green Hydrogen Mission was approved by the Union Cabinet on 4 January 2022, with the intended objectives are:

- Making India a leading producer and supplier of Green Hydrogen in the world.
- Creation of export opportunities for Green Hydrogen and its derivatives.
- Reduction in dependence on imported fossil fuels and feedstock.
- Development of indigenous manufacturing capabilities.
- Attracting investment and business opportunities for the industry.
- Creating opportunities for employment and economic development.
- Supporting R&D projects.

Image 1: Showing the National Green Hydrogen Mission



Source: Money control

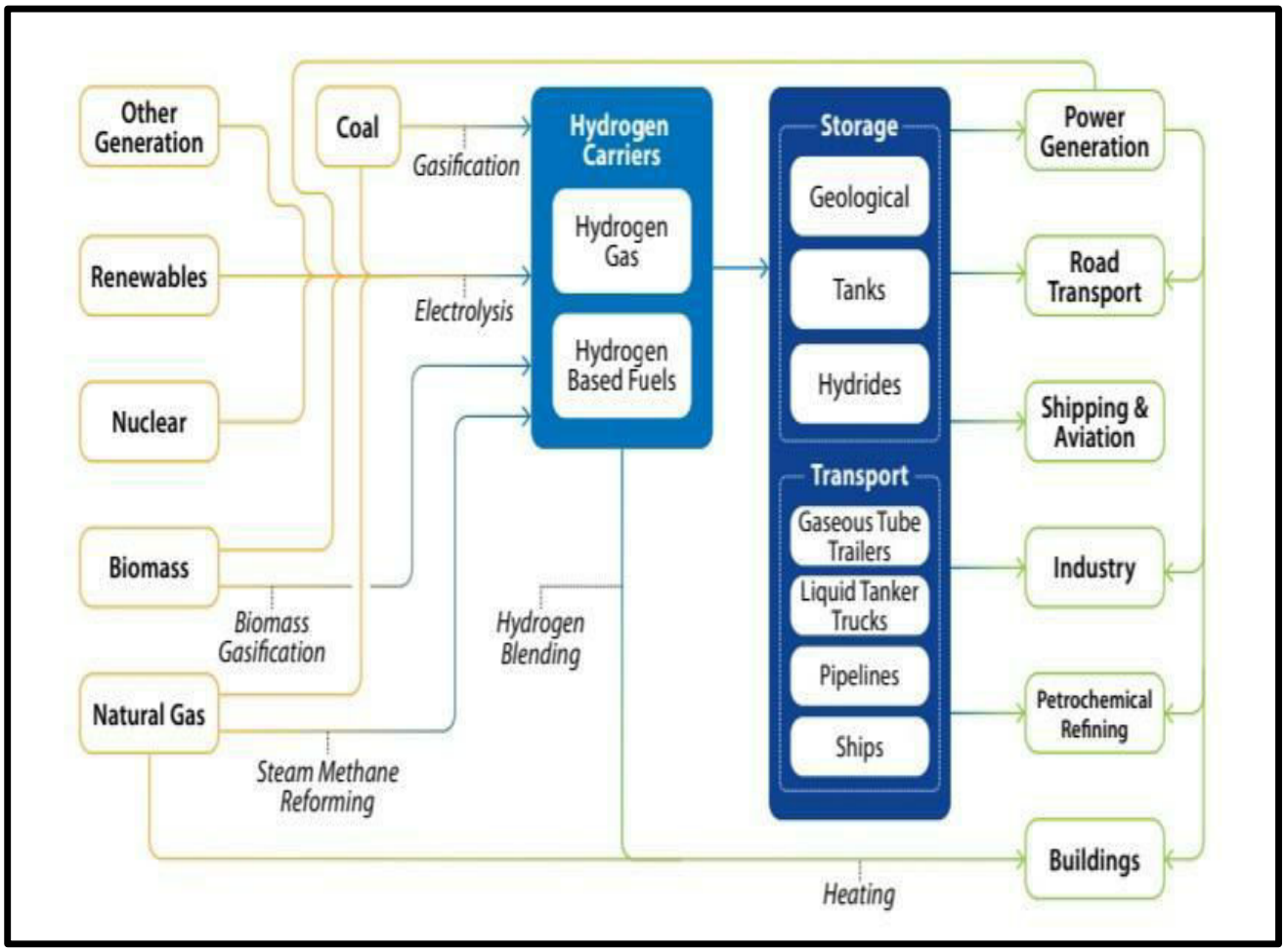
Relevance of the Study

The study of green hydrogen energy opportunities also opens the possibilities for technological progress and economic prosperity. Green hydrogen production and consumption can lead to the creation of new jobs in the fields of renewable energy and acceleration of the development of new technologies and fields of the economy that are closely associated with hydrogen production, storage, and transportation. In the final analysis, the study is topical given that it is centuries on how to combat global warming and move to a cleaner future.

Hydrogen Overview

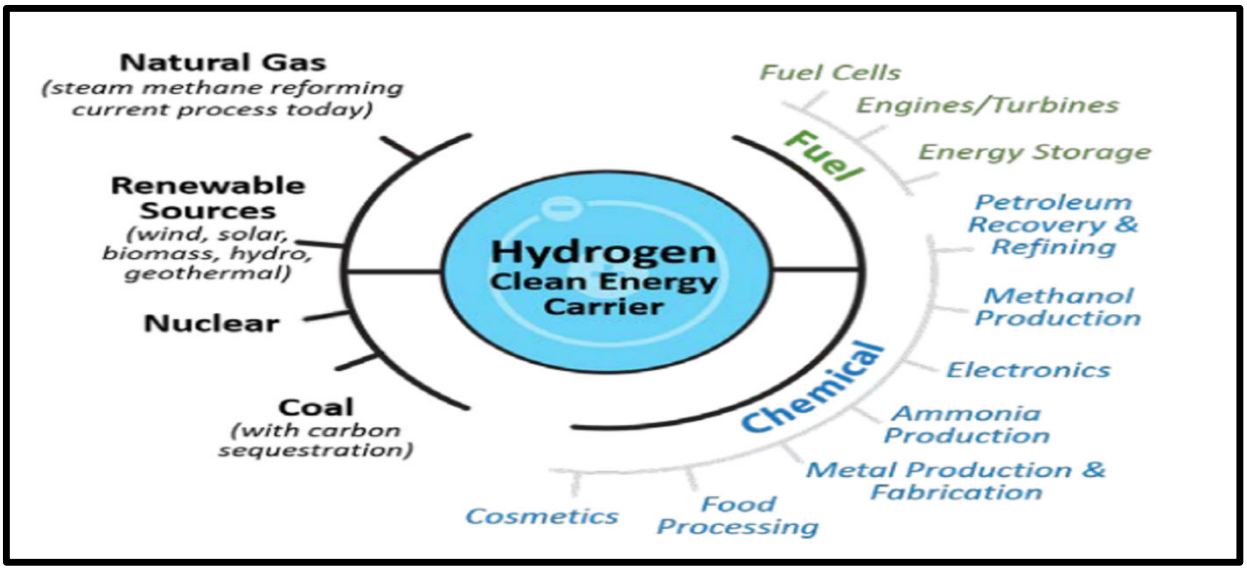
Hydrogen is a chemical element that appears on the periodic table as H with the atomic number 1. Hydrogen is mainly available in the molecular form H_2 and is nontoxic under standard room temperature and pressure. However, hydrogen can be reduced to form a liquid at a very minimum temperature. The compound hydrogen exists in the elemental form, as seen in compounds such as water, ammonia, and hydrocarbons like natural gas, coal, and oil. The gas hydrogen was first discovered in the 16th century with acids reacting with metal. Again, the scientist Henry Cavendish 1766-81 discovered that when this hydrogen gas is burned, it produces water, and that is how it was named, which means, "Water Former".

Image 2.1 Showing the Energy Process Chain of Hydrogen and its Cross - Cross-sectoral linkages



Source: Greening the Grid

Image: 2.2 Showing Hydrogen as an Energy Carrier

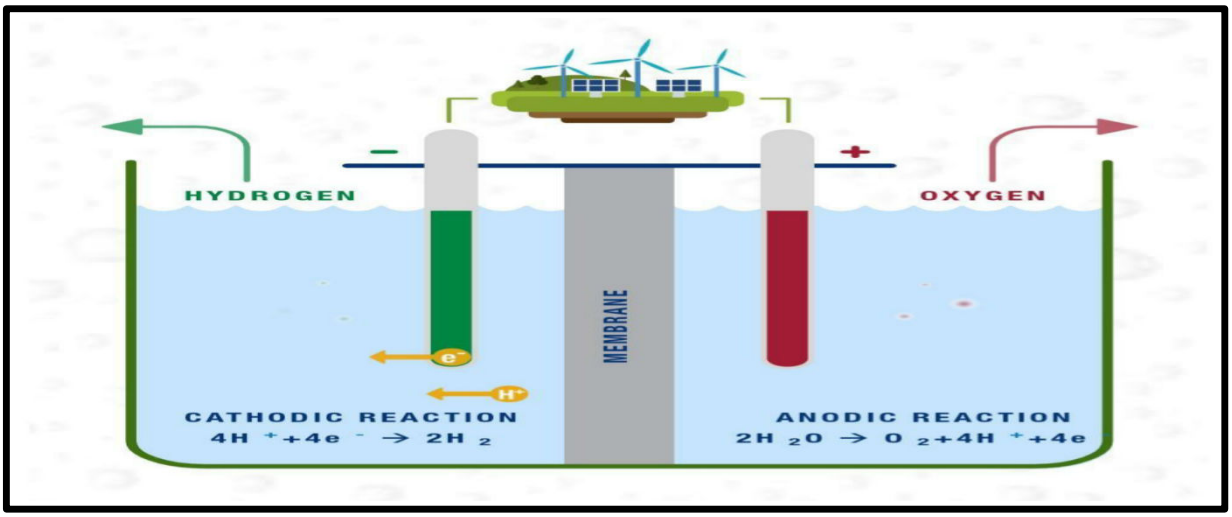


Source: U.S.Department of Energy

How Green Hydrogen is Obtained

Technology is based on the generation of hydrogen, a universal, light, and highly reactive fuel through a chemical process known as electrolysis. This method uses an electrical current to separate the hydrogen from the oxygen in water. Without emitting carbon dioxide, energy can be obtained from renewable sources.

Image: 2.3: Showing Green Hydrogen Production



Source: U.S. Department of Energy and Wood Mackenzie.

Historical Industrial Application of Green Hydrogen

For decades, hydrogen has been used primarily by the chemical and refining industries.

End applications include:

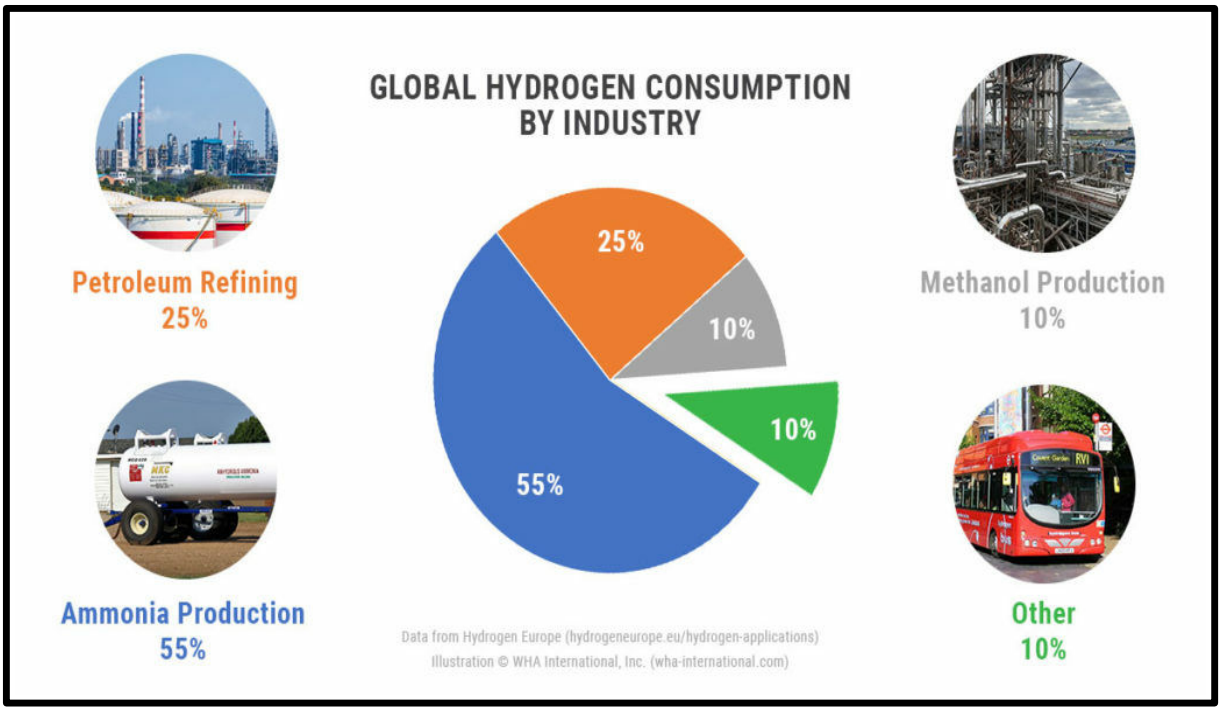
- Agricultural/Chemical Industry:

Hydrogen is a fundamental raw material needed to produce ammonia (NH3), also known as azane, an important part of fertilizers used in agricultural industries around the world. Ammonia can also be used as an affordable, environmentally-friendly refrigerant (R-717).

- Petroleum Refining Industry:

Hydrogen is commonly used in hydrocracking to create petroleum products, including gasoline and diesel. Contaminates like (CH3OH) are also removed.

Image: 3.1 Showing Global Hydrogen Consumption By Industries



Source: wha-international.com

Other Common Industry Applications of Hydrogen

Lastly, hydrogen found a variety of uses in numerous other industries across ages. Some of them are as follows: in food, hydrogen transforms unsaturated fats into saturated fat and oil have resulted in such products as margarine and butter-like spreads; metalworking for a wide range of uses, such as metal alloying and iron flash making; welding, for example, atomic hydrogen welding; flat glass production with the help of a mixture connection of hydrogen and nitrogen avoids oxidation and hence manufacturing defects and agent that hydrogen is used for semiconductors like photovoltaic segments, where hydrogen is used for hydrogen peroxide and finds increased attention as a potential therapeutic gas against a variety of diseases.

Green Transportation

Green transportation must play a significant role in the fight against climate change. Everyone talks about alternative cars, so most of the attention is on electric vehicles. However, hydrogen fuel cells have no less potential. Hydrogen is the most ordinary element in the universe, and fuel cells can turn it into electricity, which can be used to drive electric vehicles. In principle, the most obvious benefit of hydrogen fuel is that it has already decarbonized transport. Fuel cells give us some wave of products. Thus, the car does not emit greenhouse gas emissions. Hydrogen is never found for itself in nature, but rather it is separated from other elements. The process consumes electricity, the majority of which is fossil-fuel-derived. However, as long as green hydrogen is in the mix, it brings hydrogen fuel's total emissions down to zero. Types of Electrical Vehicles for Green Transportation Generally, electrical vehicles can be classified into four types due to several aspects like environmental concerns, greater vehicle choice, improved battery capacity, and price efficiency satisfying the consumer's costs in the future as seen above. First is the Battery Electric Vehicle: powered by electricity, Second Hybrid Electric Vehicle: A vehicle that has two electric and petrol cars having enough power that helps to move from place to place is the perfect example. The petrol engine is used to crank an internal engine and charge when the battery is empty. This option is insufficient because of the effort to conserve non-renewable sources of fuel used. b. Plug-in Hybrid Electric Vehicle: this has plug-in options, different from the hybrid electric vehicle because a charging gadget is added to it. It uses a petrol engine as the main fuel and energy from the battery enables electronic use. 3. Fuel Cell Electric Vehicle: Electric energy is produced from chemical energy. For example, a hydrogen FCEV.

Advantages of Hydrogen Fuel Cell Vehicles

- Hydrogen fuel cell cars provide excellent performance and full torque at low speeds.
- With no internal combustion engine, an FCEV is quiet as a church mouse in operation. It is similar to driving an electric car.
- Another significant advantage of a fuel cell vehicle is fast refueling time. In a few minutes, you can refuel hydrogen.
- A hydrogen-fuelled car has a driving range longer than that of electric vehicles.
- The driving range of a fuel cell vehicle doesn't depend on the atmospheric temperature. So, it isn't affected by low temperatures.
- A hydrogen fuel cell car produces zero carbon emissions. Its emissions load consists of nothing besides water vapor sucked out by the condensation process.

Disadvantages of Hydrogen Fuel Cell Vehicles

- Lack of hydrogen refuelling stations is one of the major defects of an FCEV. The technology is still at its initial stage. The challenge is how to develop infrastructure. This was how Japan originally solved the problem for its first three experimental hydrogen filling stations in 2006 and 2008, for $6.4m each.
- Since it is a new technology, hydrogen fuel cars are more expensive than their EVIL counterparts. So, you have to pay a premium price to own an FCEV.
- The cabin space of an FCEV is compromised by the hydrogen fuel tank. It can eat into your cabin space, particularly if it is a small car.
- The running cost of a hydrogen-powered car is higher than that of an electric car. The reason is that hydrogen is more expensive than electricity. But this may change once we have more of a demand for hydrogen and production levels are higher.
- A fuel-cell car produces zero carbon emissions. However, electricity is needed to make hydrogen and if this power comes from fossil fuels, then you will have a carbon footprint.

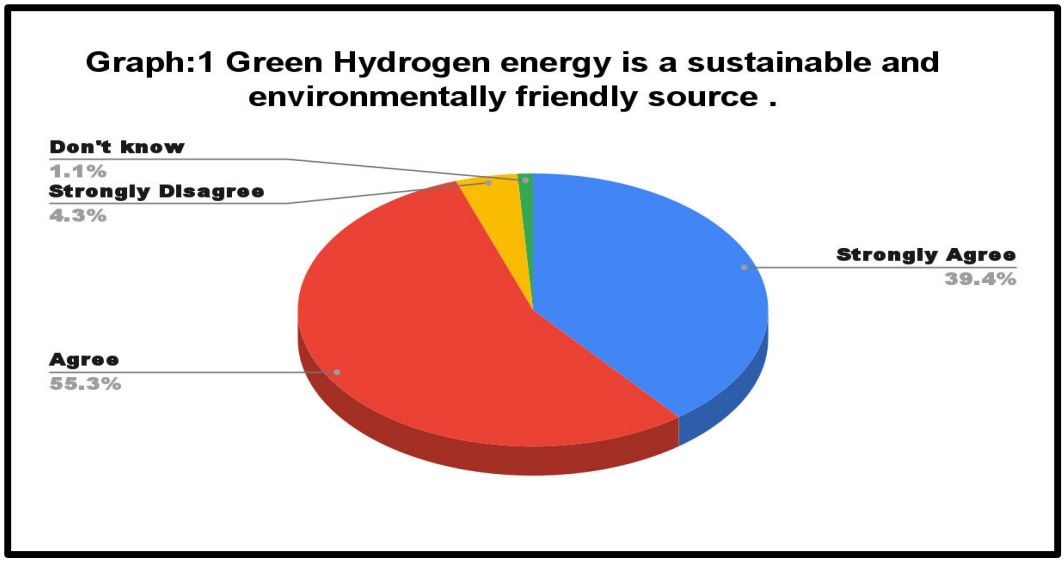
Recent Trends in India

On the global market, there are not many hydrogen-fuel vehicles. Toyota, Honda, and Hyundai sell fuel cars globally. Recently Toyota has launched a project to test FCEV. The Japanese automaker with the Indian government's testing agency, ICAT (International Centre for Automotive Technology). Toyota is using a second-gen Toyota Mirai for testing in India. **Nitin Gadkari drives India's first hydrogen-powered car to Parliament on March 16**, 2023. Nitin Gadkari launched this green hydrogen-based advanced FCEV in the first project in India that aims to bring hydrogen-powered vehicles to the country. The International Center for Automotive Technology (ICAT) has helped in the launch as a part of Toyota Kirloskar Motors. He drove a hydrogen-powered car from his residence to the parliament.

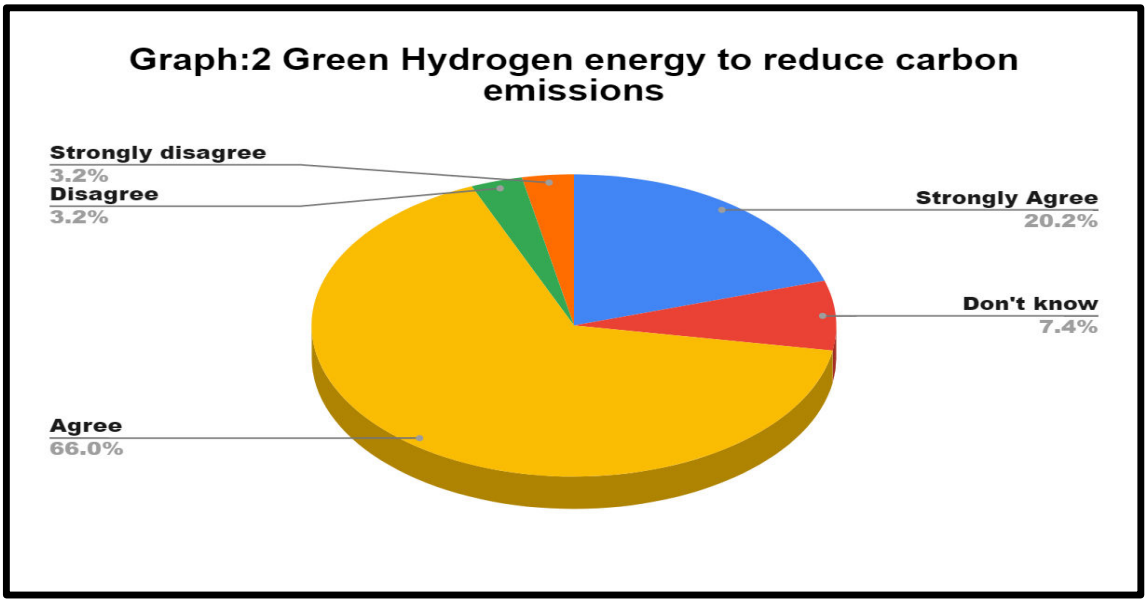
Source:https://www.businesstoday.in/amp/auto/story/nitin-gadkari-drives-indias-first-hydrogen-powered-car-to-parliament-327937-2022-03-30

Result and Discussion

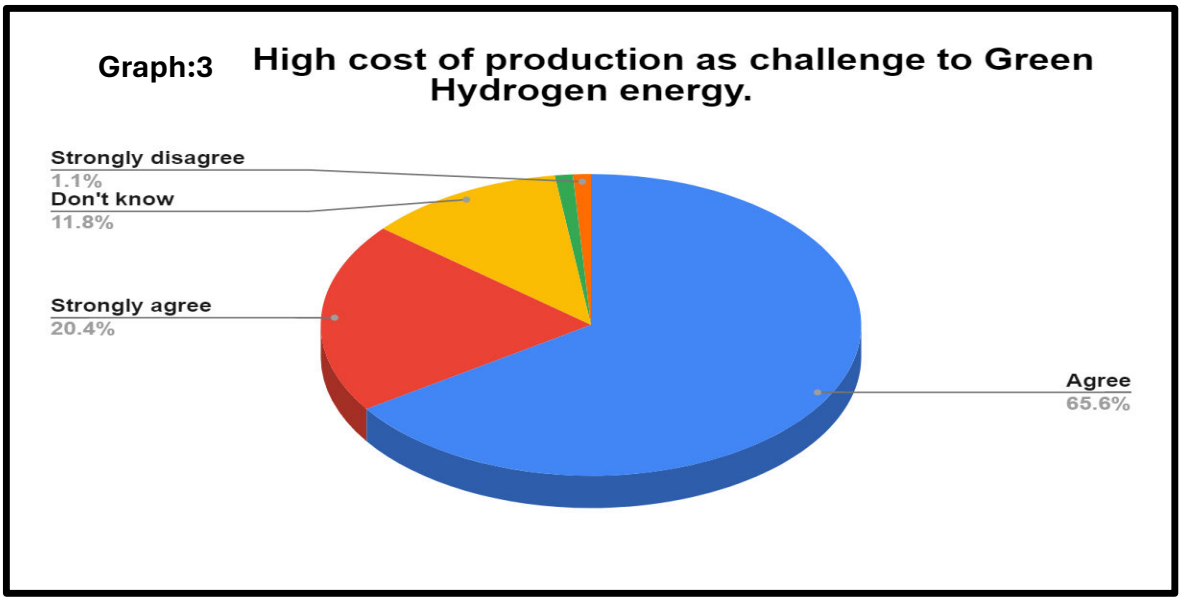
A pilot study was conducted for primary data collection through Google Forms. 94 Responses have been collected and analyzed. A 5-point Questionnaire was prepared and has been analyzed. The received responses were 94. The analysis has been shown with the help of graphs.



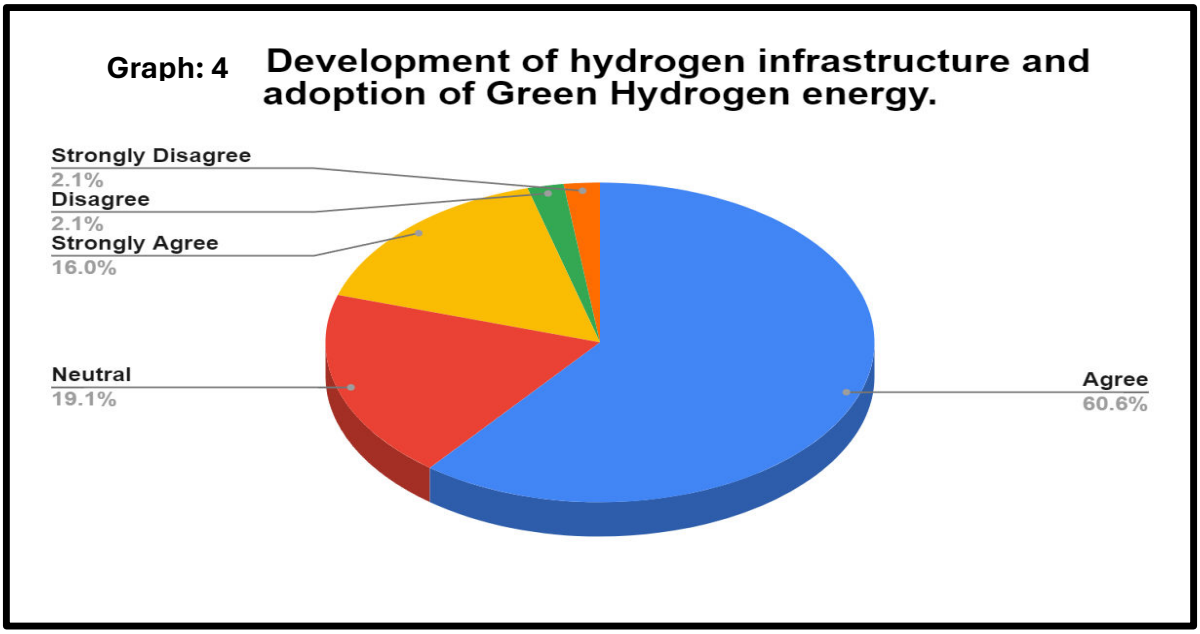
Graph 1: According to the survey, out of 94 responses, 39.4% strongly agree, 55.3% agree that green hydrogen energy is environmentally friendly and sustainable 4.3% strongly disagree and 1.1% don't know.



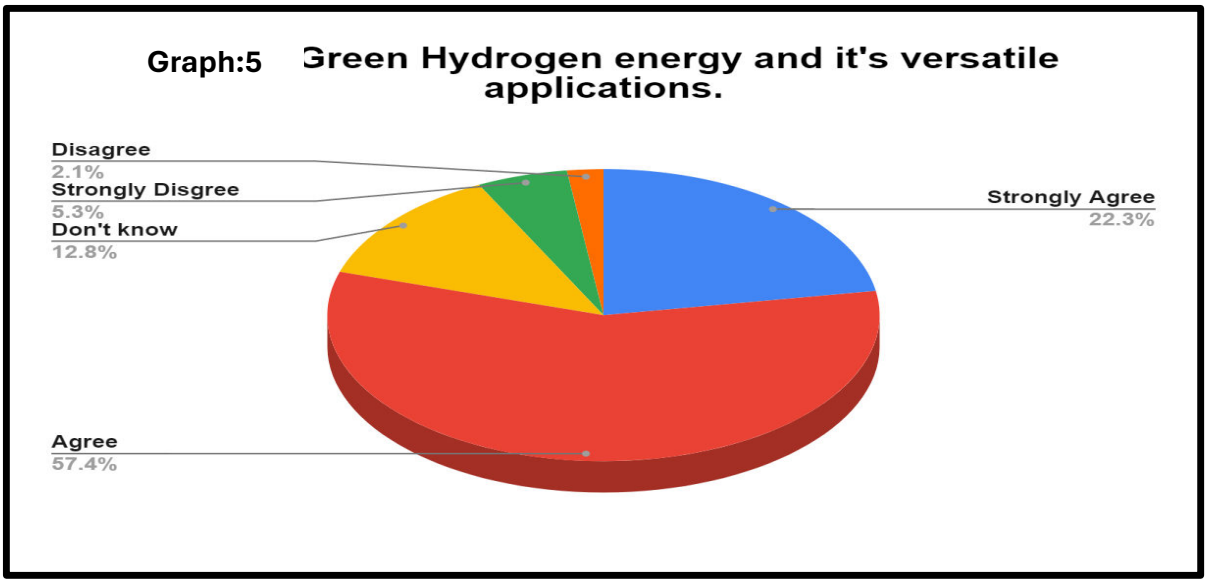
Graph 2: According to the study, 66.0% of people agree but 20.2% strongly agree that green hydrogen energy reduces carbon emission whereas 3.2 % people disagree and 7.4% don't know.



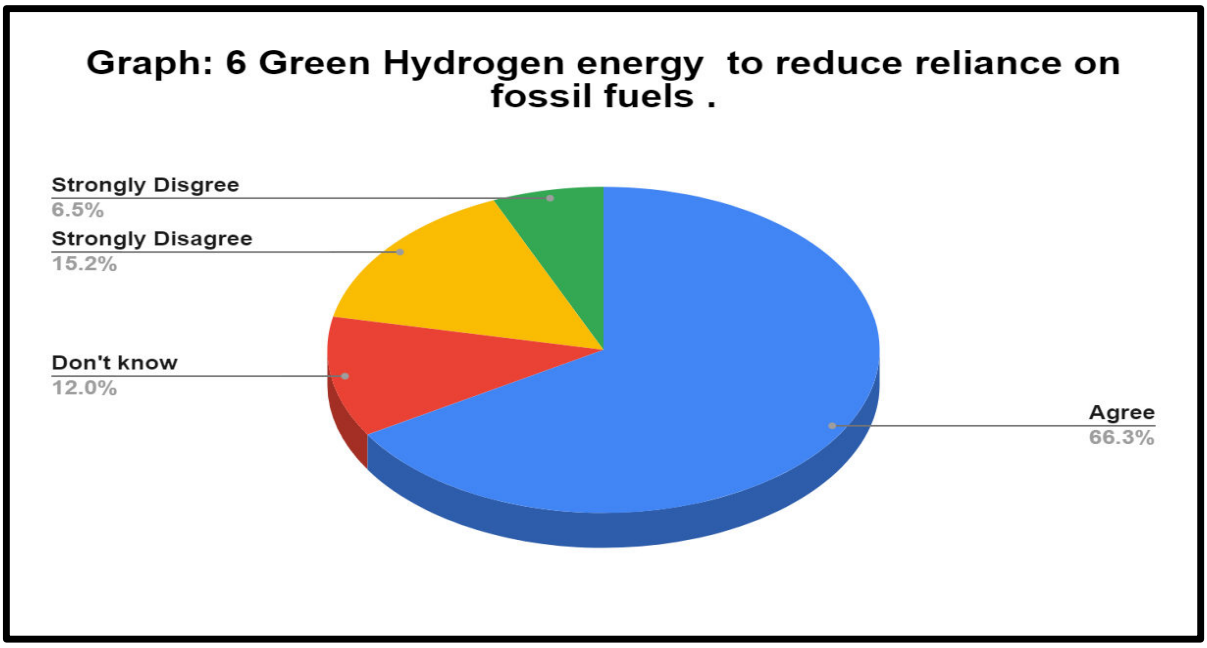
Graph 3: The above graph depicts that 65.6% agree and 20.4% strongly agree that an increase in cost poses a challenge in the development of green hydrogen energy. 1.1% strongly disagree and 11.8% are unaware.



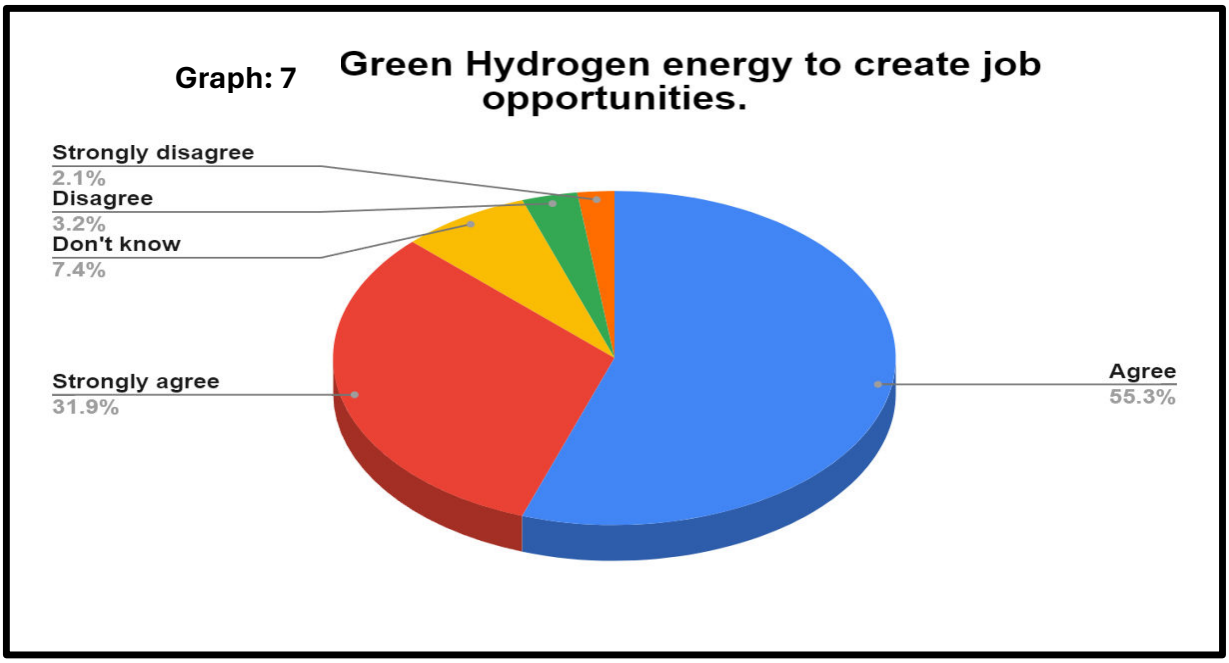
Graph 4: According to the study, 60.6% agree and 16.0% strongly agree that the development of hydrogen is necessary for the adoption of green hydrogen energy whereas 2.1% disagree and 19.1 % are unaware.



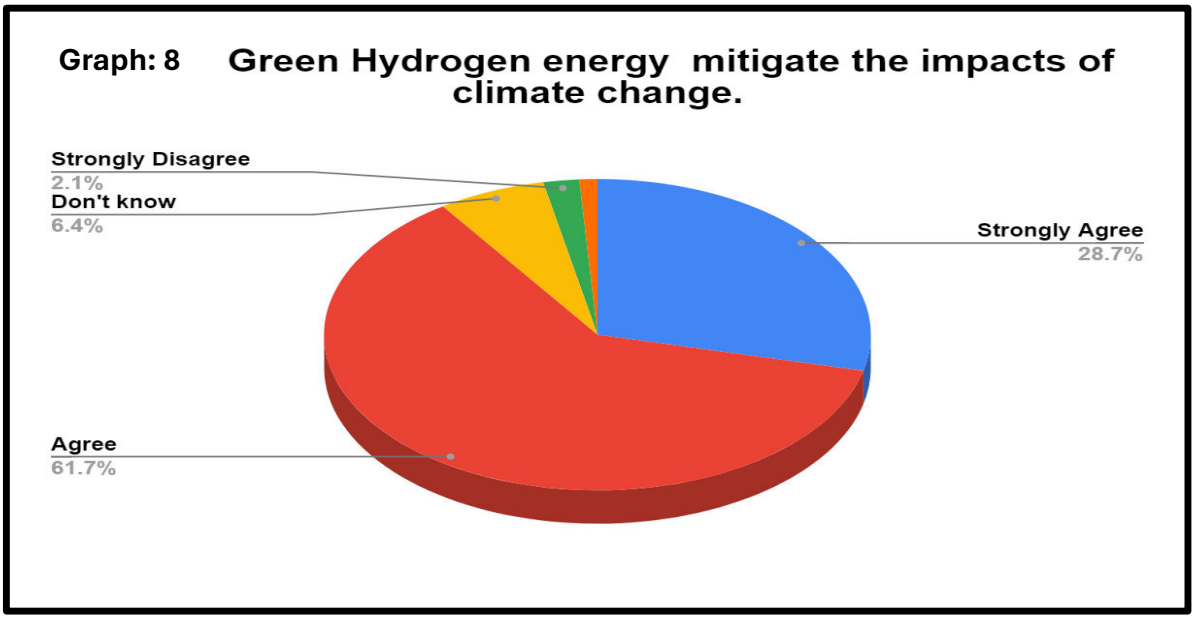
Graph 5: 57.4% agree and 22.3% strongly agree that Green Hydrogen energy has the versatile advantage of fuel, feedstock, and energy storage solutions .5.3% strongly disagree and 2.1% disagree for the same whereas 12.8% don't know.



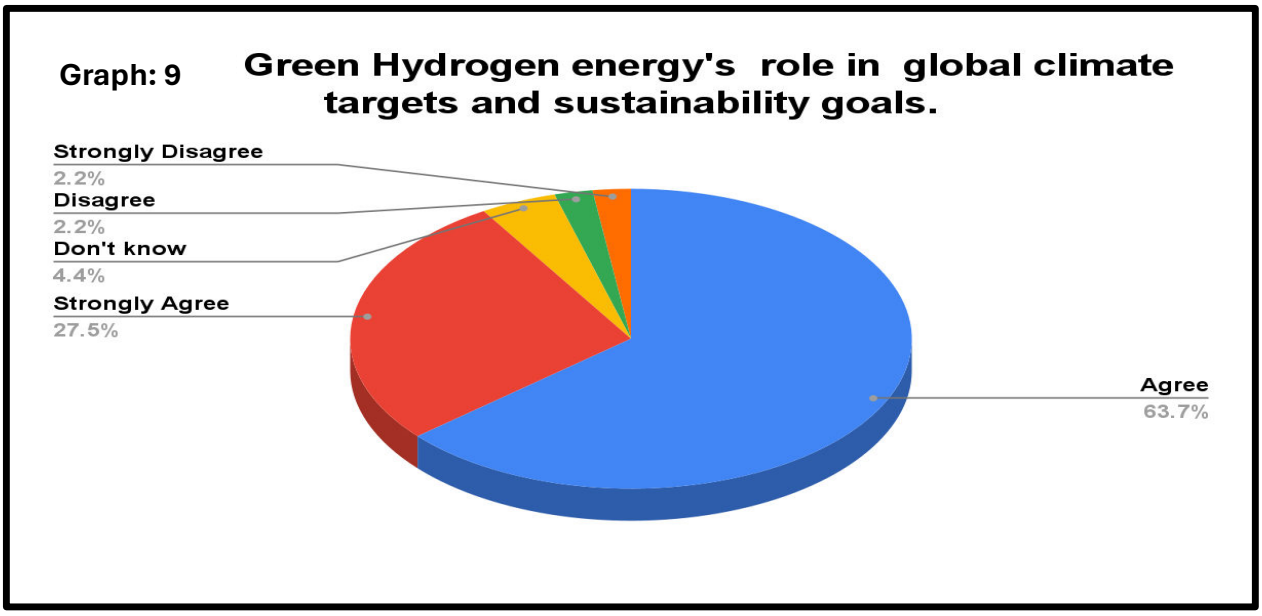
Graph 6: The Graph depicts, that 66.3% agree on the fact that green hydrogen promotes the independence of energy and 15.2% strongly disagree. 12.0% are unaware.



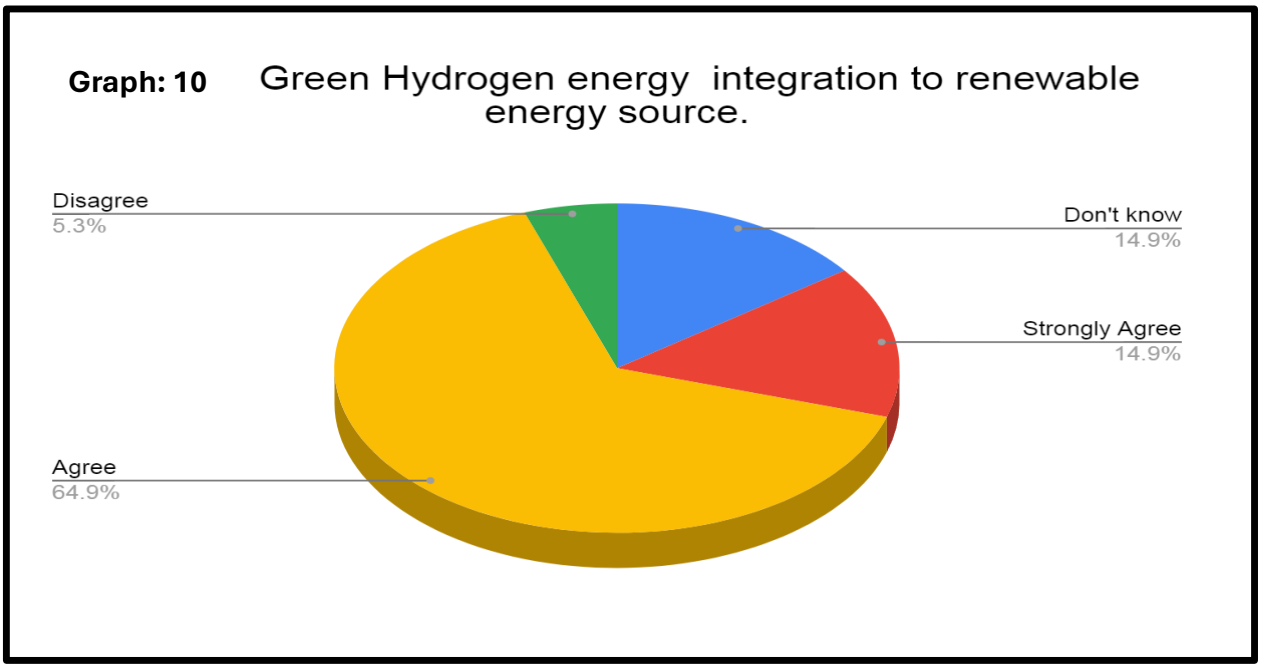
Graph 7: According to the study, 55.3% agree and 31.9% strongly agree that Green hydrogen has the potential to create employment in renewable resources whereas 7.4% don't know, 3.2% disagree and 2.1% strongly disagree.



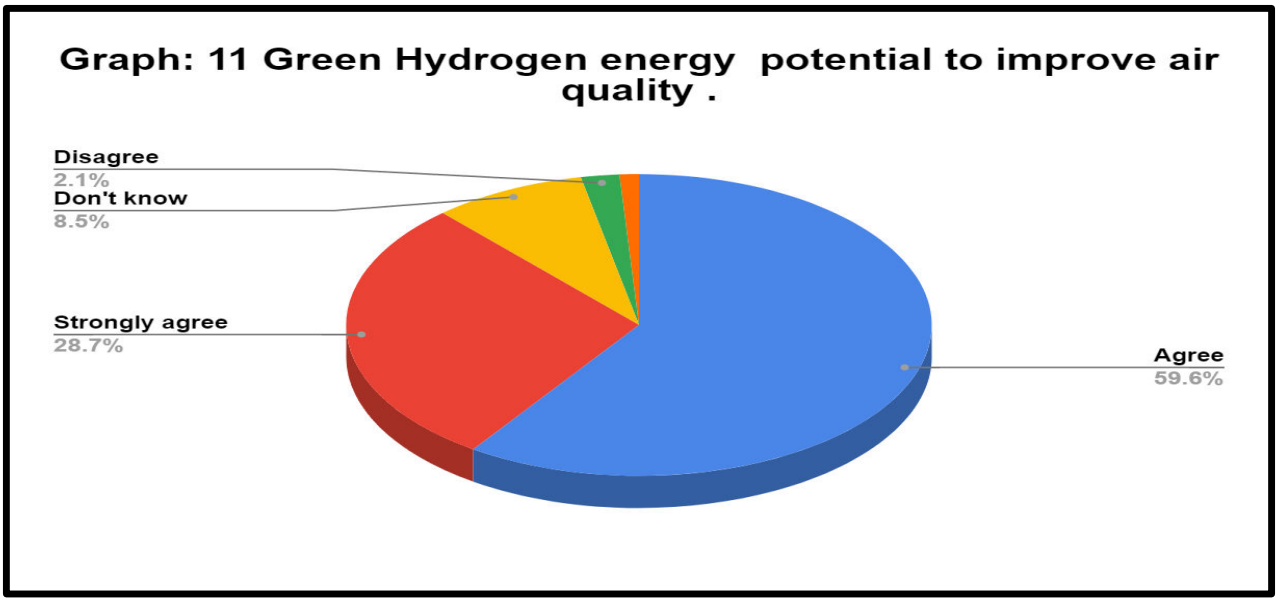
Graph 8: The study says, 61.7% agree, and 28.7% strongly agree that green hydrogen energy helps in reducing green hydrogen gas emissions. 2.1% strongly disagree and 6.4% don't know.



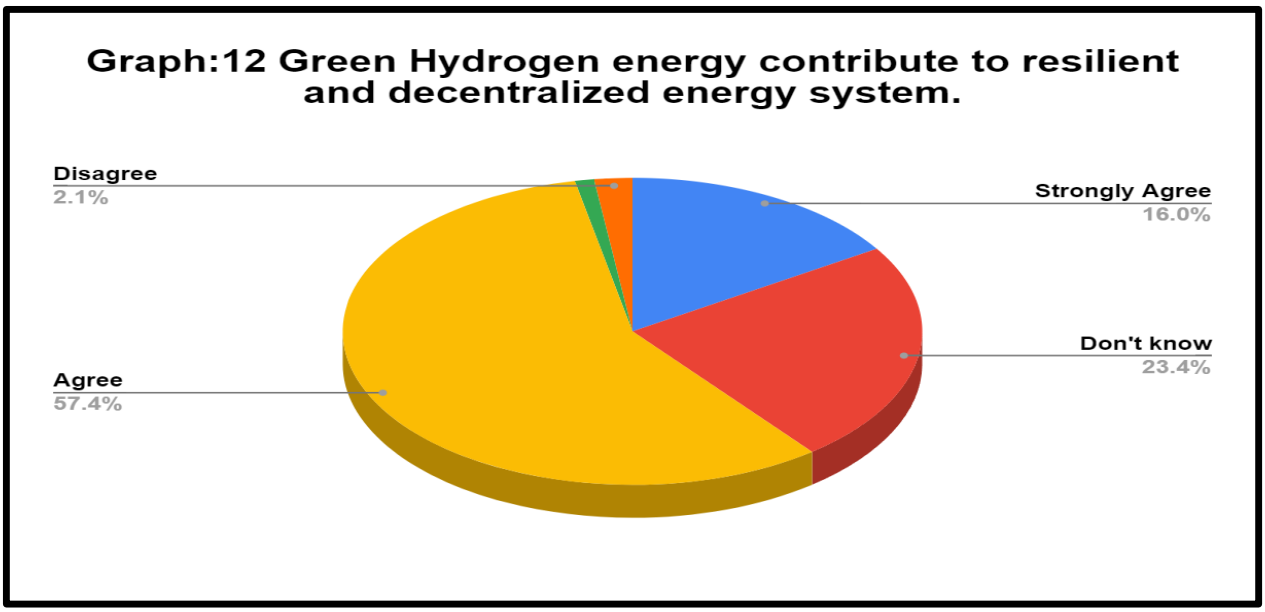
Graph 9: The Graph depicts that 63.7% agree and 27.5% strongly agree whereas 2.2% disagree that hydrogen energy can play a crucial role in achieving global climate targets and sustainability goals.



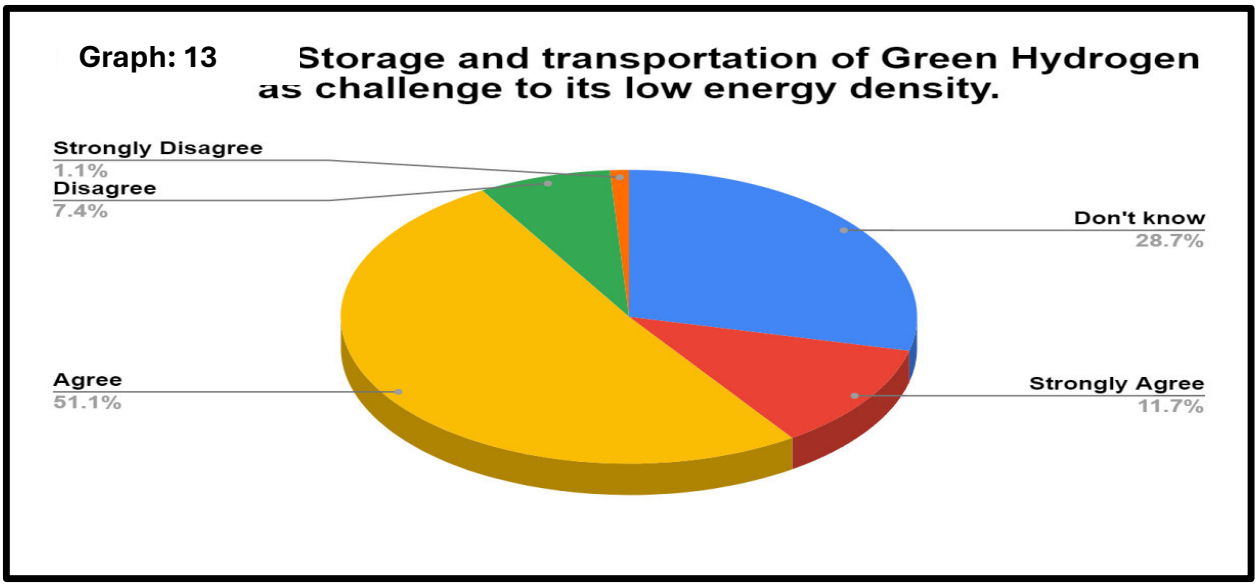
Graph 10: According to the study, 64.9% agree and 14.9% agree that Green Hydrogen energy can support the integration of renewable energy sources into the existing energy system while 5.3% disagree and 14.9% don't know.



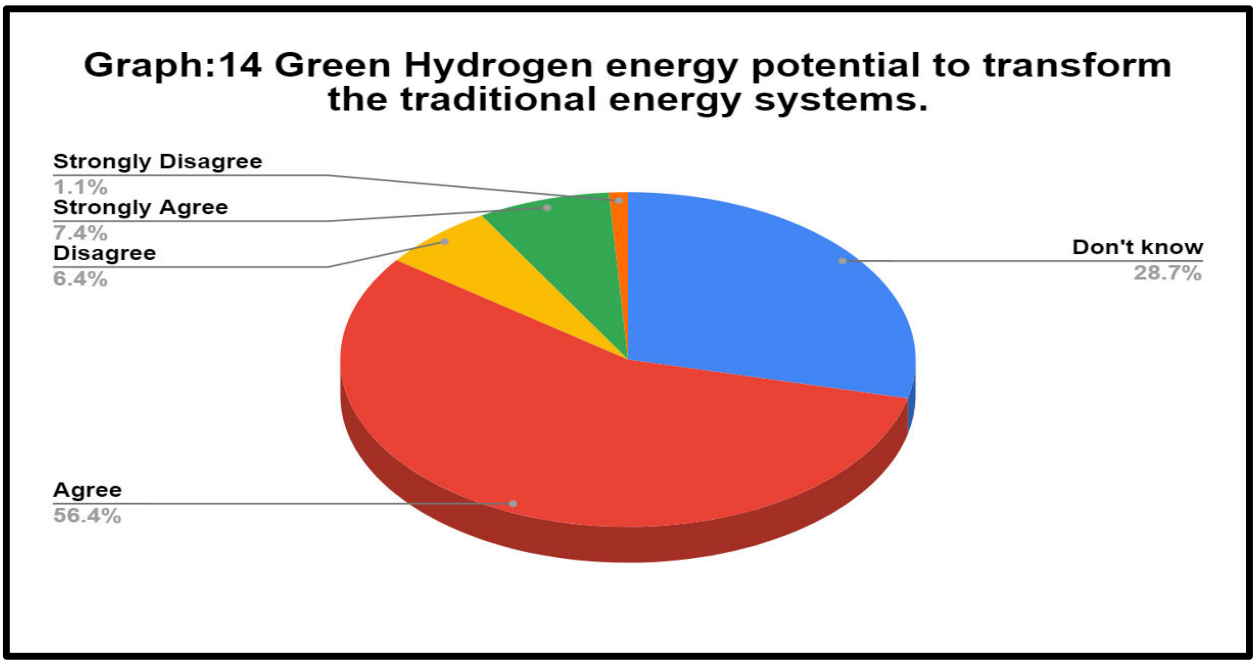
Graph 11: The Graph depicts, that 59.6% agree, and 28.7% strongly agree that Green Hydrogen energy has the potential to improve air quality by reducing emissions from transportation and industrial processes. 1.1% strongly disagree and 2.1% disagree and 8.5% don't know about it.



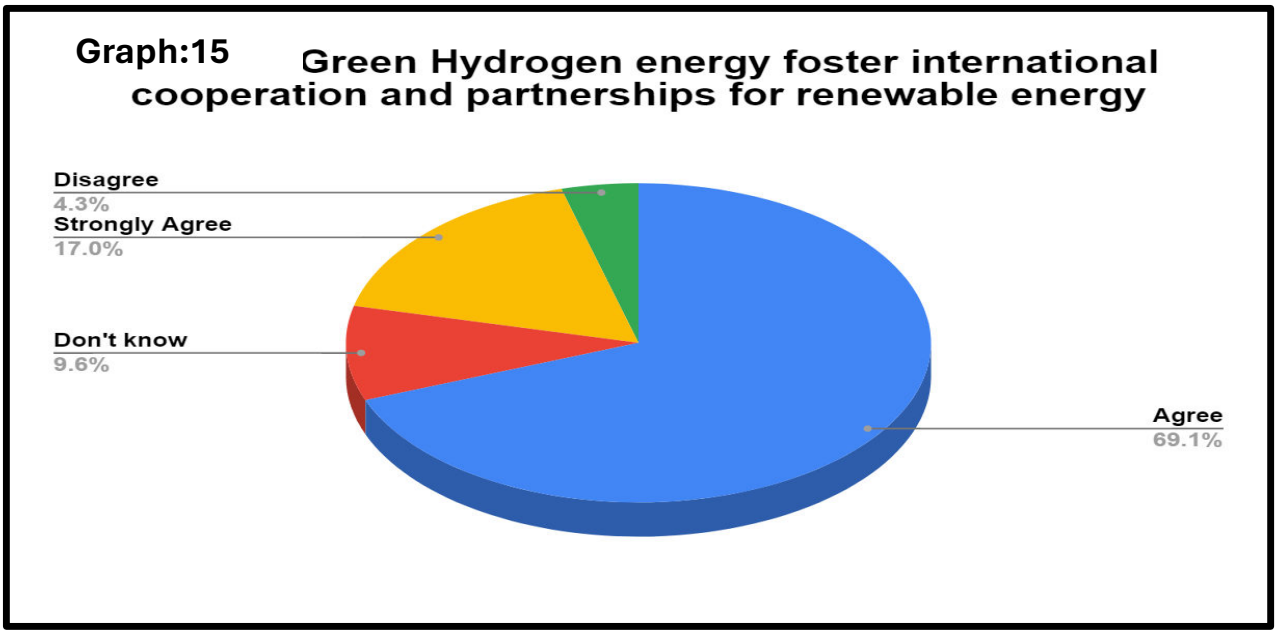
Graph 12: 57.4% agree and 23.4% don't know that Green Hydrogen energy can contribute to the development of a more resilient and decentralized energy system.



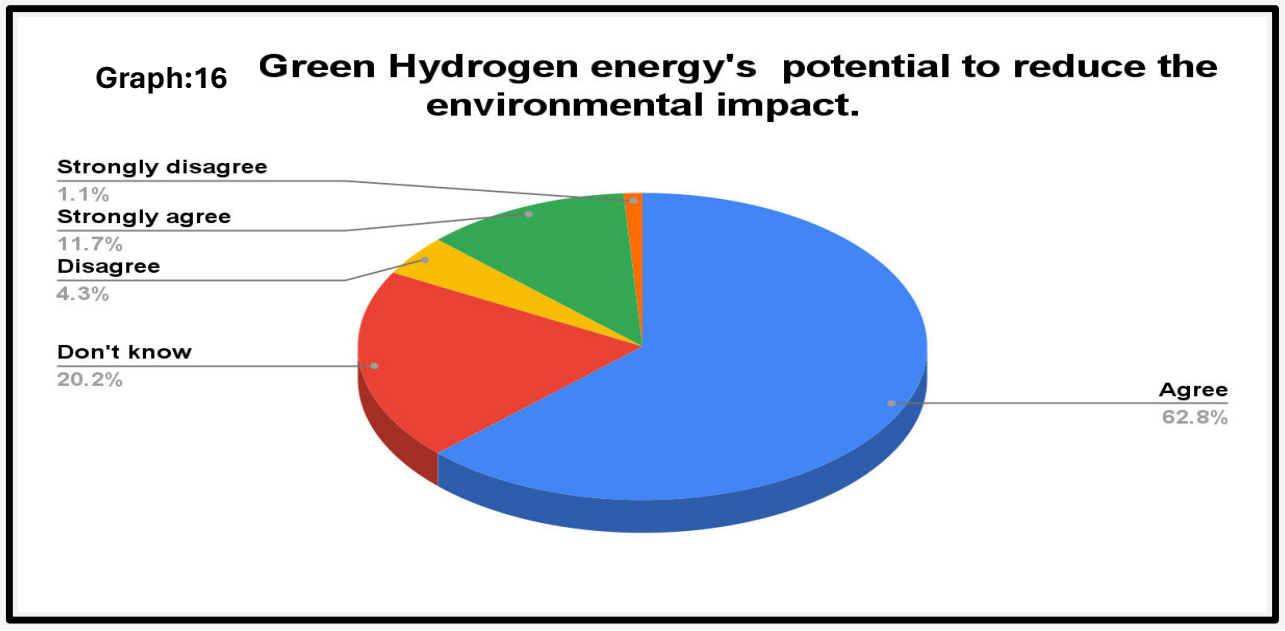
Graph 13: The study says, 51.1% agree that transporting green hydrogen is a challenge in its production because it is highly reactive, and its transportation is also difficult. 28.7% don't know anything about it. 7.4% and 1.1% disagree and strongly disagree respectively.



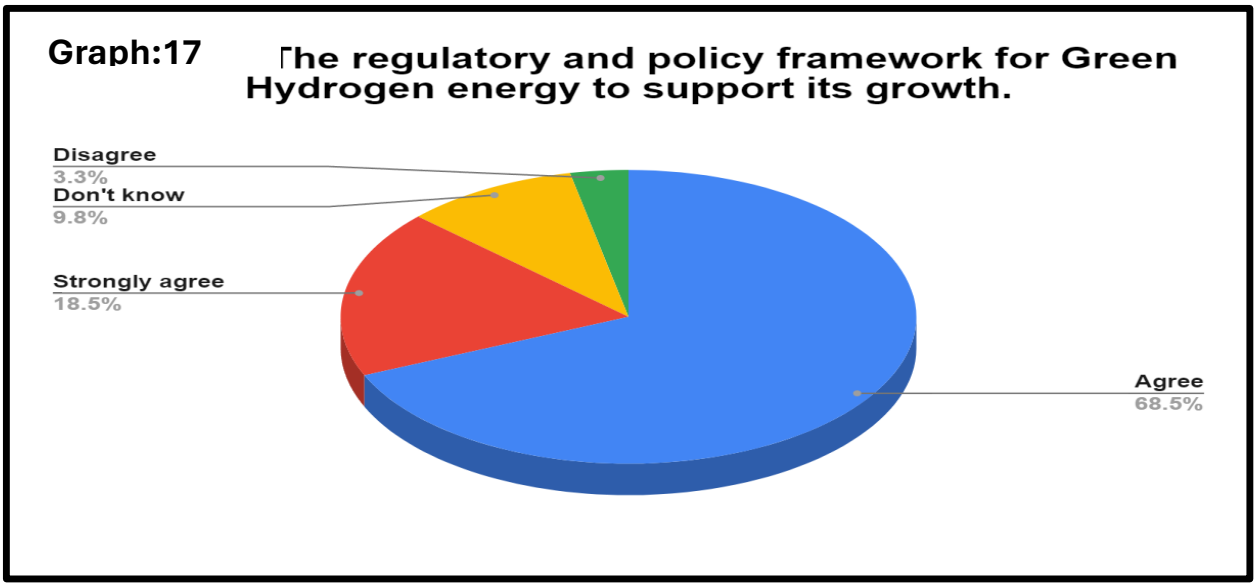
Graph 14: According to the research, 56.4% agree that green hydrogen energy helps transform traditional energy while 26.7% don't know anything about it. 6.4% disagree and 1.1% strongly disagree about it.



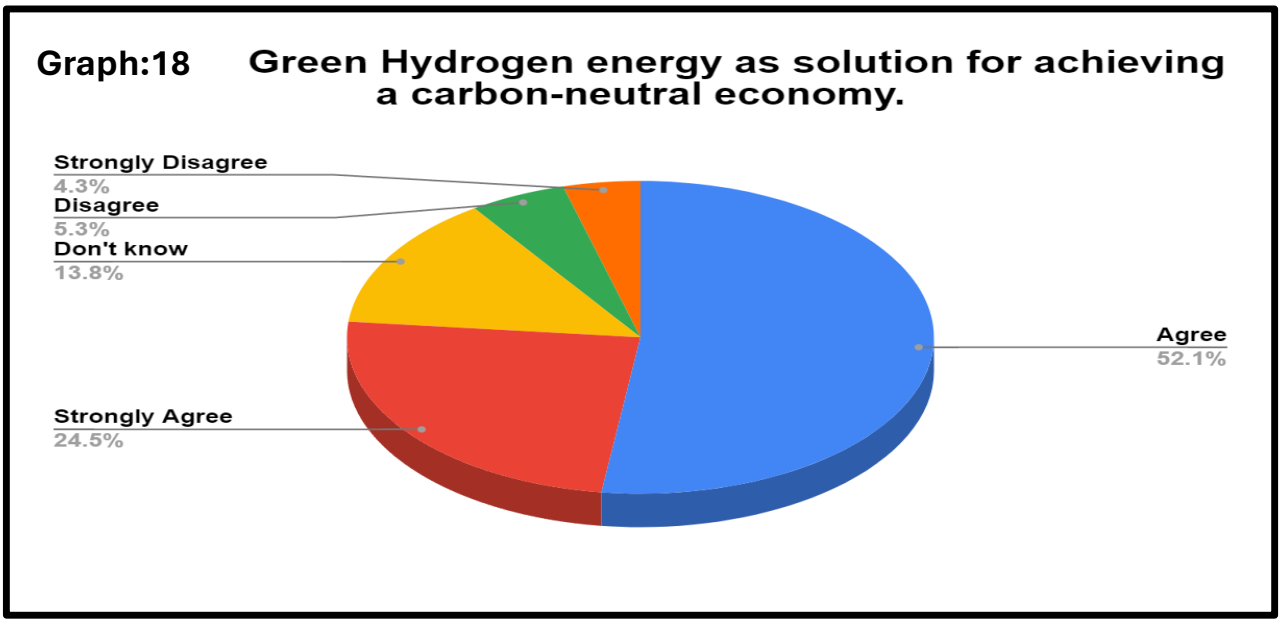
Graph 15: The Graph depicts that 69.1% agree and 17.0% strongly agree that green hydrogen energy can foster international cooperation and partnerships for renewable energy development. Whereas 4.3% disagree and 9.6% don't know.



Graph 16: The research says, 62.9% agree that Green Hydrogen energy has the potential to reduce the environmental impact of hydrogen production compared to other methods. 20.2% don't know, 11.7% strongly agree,1.1% strongly disagree and 4.3% disagree.



Graph 17: According to the study, 68.5% agree, and 18.5% strongly agree that the regulatory and policy framework for Green Hydrogen energy needs to be further developed to support its growth. 3.3% disagree and 9.8% don't know about it



Graph 18: The Graph depicts that 52.1% agree and 24.5% strongly agree that green hydrogen energy helps in achieving a carbon-neutral economy. 5.3% disagree, 4.3% strongly disagree and 13.8% don't know anything about it.

Progress toward Renewable Energy in India

India is one of the world's leading nations in green energy – it is one achievement that the country can be proud of. Indeed, the country is actively promoting the deployment of renewable energy capacities and reducing greenhouse gas emissions. It has set ambitious targets for renewable capacity and green energy and developed several relevant policies and initiatives to achieve them. India is the fourth largest producer of renewable electricity globally. The total installed renewable capacity in India, as of 2021, exceeded 100 GW. The country is using solar, wind, biomass, and hydro to produce renewable electricity. Solar energy was the focus of the country's renewable development, with a capacity target of 280 gigawatts by 2030. India has also set a target of 10% green hydrogen deployment in fertilizers by 2030 and encouraging green hydrogen in other sectors.

Reliance Industries: Reliance Industries has announced an investment of more than ten billion dollars to set up the Dhirubhai Ambani Green Energy Giga Complex in Jamnagar, which will spread over 5,000 acres. In collaboration with REC Solar Holding, Faradion, and Lithium Werks, Reliance Industries' comprehensive Green Digital Ecosystem will help India boost green energy production. Furthermore, Reliance Industries wants to establish a 1 GW green hydrogen plant by 2025, and recently India's 1st hydrogen-fuelled truck as a sign of their dedication to Green Mobility and innovation.

GAIL: GAIL's Proton Exchange Membrane electrolyzer-based facility, to be built in Guna, Madhya Pradesh, India, will be one of India's largest green hydrogen plants. This plant would have a 10 MW capacity and will produce 4.3 tonnes every day. As a result, the production may be mixed in with natural gas and used in fertilizer units and other industrial areas.

NTPC: NTPC, for example, has begun the nation's first hydrogen mixing with natural gas project. A 240-kW solid oxide electrolyzed at the company's floating solar farm will generate pure hydrogen. 'renewables to Rise' is part of NTPC's mission, which promotes NTPC's hydrogen production at inexpensive costs due to other renewables like wind and solar. Their pilot projects go into the full extent of hydrogen-based power-to-mobility or power-to-storage.

IOC: The Indian Oil Corporation is installing a green hydrogen plant in Panipat that will replace a 10% carbon footprint of its fossil fuel use with hydrogen. IOC has set a target of having a renewable power capacity of five gigawatts by 2025, with this facility being one more part of the strategy of decarbonizing the firm.

L&T: L&T setting up a plant in Gujarat's Hazira district. The system will manufacture 45 kg of green hydrogen a day which would be mixed with natural gas. The firm has utilized a 990 kW DC plant and a 500-kW battery storage facility. The Wikimedia Foundation pursues carbon neutrality. They've promised to be completely carbon-neutral by 2023, and all your money will be spent/saved by their commitments to keeping the world safer.

Adani Green Energy: Adani Green Energy invests more than $50 billion in partnership with Total Energies to establish the world's largest green hydrogen ecosystem. By 2030, their Adani New Industries Ltd. Is going to produce 1 million tons per annum of green hydrogen, taking advantage of Total Energies' knowledge of global markets and Adani's understanding of Indian demand. Their cooperation will result in the most cost-effective green hydrogen worldwide.

JSW Steel: It will invest $1.2 billion in green energy projects, including green hydrogen, thanks to a partnership with an Australian company. The business is installing battery storage solutions and combining them with renewable power to become a diversified green energy player. Their unique strategy is in line with the country's sustainable development targets.

Jindal Stainless: In collaboration with Hygenco, they will build a green hydrogen plant to power operations with green hydrogen. This will make them India's first green hydrogen-based stainless-steel manufacturer, resulting in 2,700 metric tons of annual carbon production. It will result in a more sustainable steel production process.

Oil & Natural Gas Corporation: The Greenko ZeroC will enable ONGC to create green ammonia and green hydrogen derivatives. They aim to develop the National Hydrogen Mission and turn India into a top green hydrogen center. They are a prime participant in the energy change with a $6.2 billion investment.

Bharat Petroleum Corporation: In collaboration with BARC, BPCL will introduce the Alkaline Electrolyzer technology to develop a 20 MW green hydrogen plant in Madhya Pradesh. The plant will use green hydrogen for commercial, industrial, and household applications, indicating innovative energy production trends.

Conclusion

Based on the above research and data collection, it can be inferred that although respondents agree on sustainability and environmentally friendly due to reduced carbon emissions by Green Hydrogen, high costs of production and lack of infrastructure are the primary issues. Green Hydrogen also had a wide range of applications and would provide new green job opportunities. It is going to help reduce the negative impact due to climate change and reduce air pollution. A proportion of respondents 28% said they were not sure if hydrogen could contribute to a resilient and decentralized economy. Hence from the above, it can be concluded the respondents are aware of the trends in climate change and regard Green Hydrogen as an energy source due to insufficient policy and frameworks; H2 Energy will be the solution to achieve a carbon-neutral economy.

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