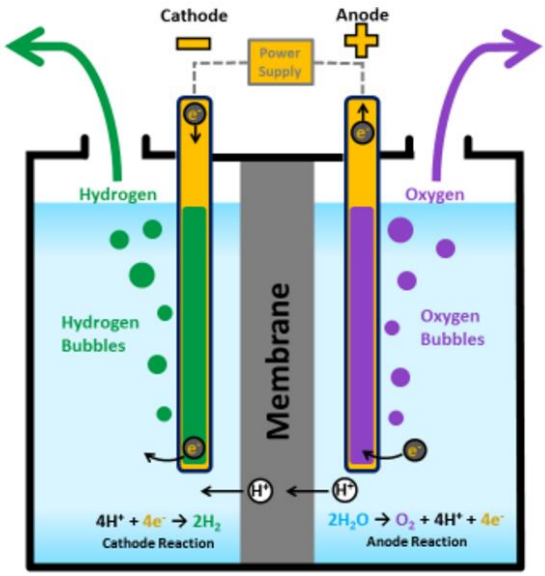


HYDROGEN FUEL CELLS

Green Hydrogen Economy

ABSTRACT

Carbon dioxide emissions are a big issue contributing to the pollution levels of Earth. Sector wise, the power industry is the leading factor with 41.4% followed by transport which is contributing 32.9%. To solve the problem, the green economy is a concept evolving and gaining attention worldwide, the concept focuses on sustainable and environmentally friendly solutions. Hydrogen is such a carbon-free fuel that can help to achieve the targets of the green economy and the best means to store energy for a long time. Hydrogen is a high energy content fuel and has about zero greenhouse gas emissions when used in fuel cells.

Saksham Bansal

Table of Content

1. Introduction

India with a population of approximately 1.3 billion, is the second-most populous country and the third-largest economy in the world. With a significant decrease in poverty level, increased energy access for citizens, availability of cleaner cooking fuel and growing penetration of renewable resources, the country is advancing on a faster growth path.

Global warming is an issue; the whole world is trying to resolve. India and China both represent around 36% of the total world population. India is also one of the largest emitters of greenhouse gases in the world. Considering, the population and pollution, it is the responsibility of India to take important steps to limit global warming. The burning of crude oil is one of the major reasons behind the large emission of greenhouse gases in India. To tackle the issues associated with global warming, many countries are now adopting the concept of a green economy. Hence, to effectively contribute to controlling global warming, along with other countries, India also needs to shift its focus on a green economy. Globally, the automobile sector alone is responsible for 24% of CO_2 emissions, while in India it contributes to 13.5% of total CO_2 emissions. General environmental management by reducing the net carbon emissions from the transport sector is an important consideration in the green economy.

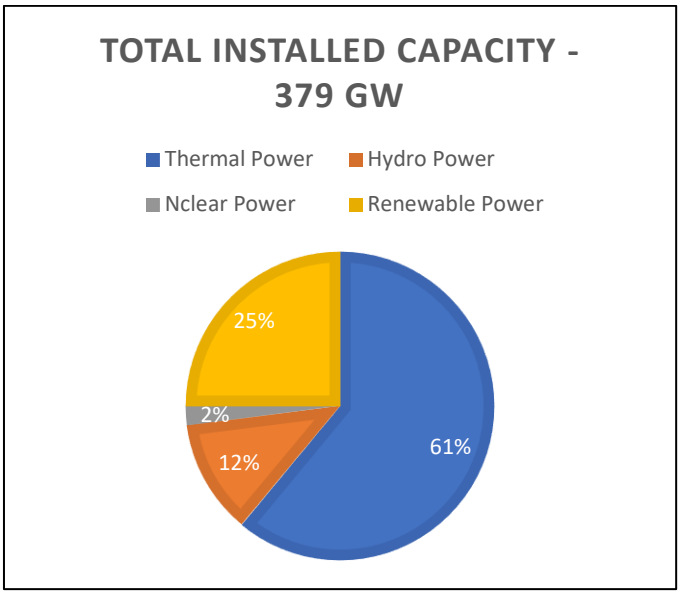


Figure 1. India's Total installed Power Capacity from various renewable and non-renewable sources.

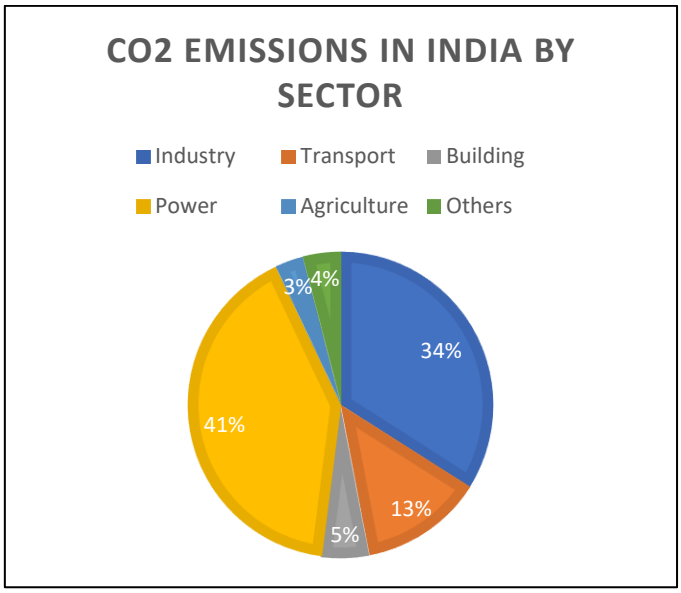


Figure 2. CO_2 Emissions in India by Sector

India's energy system is largely dependent on fossil fuels i.e. coal for power generation, oil for the transport & industrial sector and biomass for residential heating & cooking. Only two-thirds of the Total Primary Energy Supply is met by domestic production and thus the country is largely dependent on oil and gas imports. In the year 2018, the breakup of India's net import was 205.3 Mtoe and its products, 26.3 Mtoe of gas and 141.7 Mtoe of coal accounting for 46.1% of the TPEC. Major consumption is in the Industrial sector (42% of the TFC) followed by residential (29% of TFC), transport (17% of TFC) and services (12% of TFC). The rapid growth in the total final energy consumption and electricity is being met largely by fossil fuels.

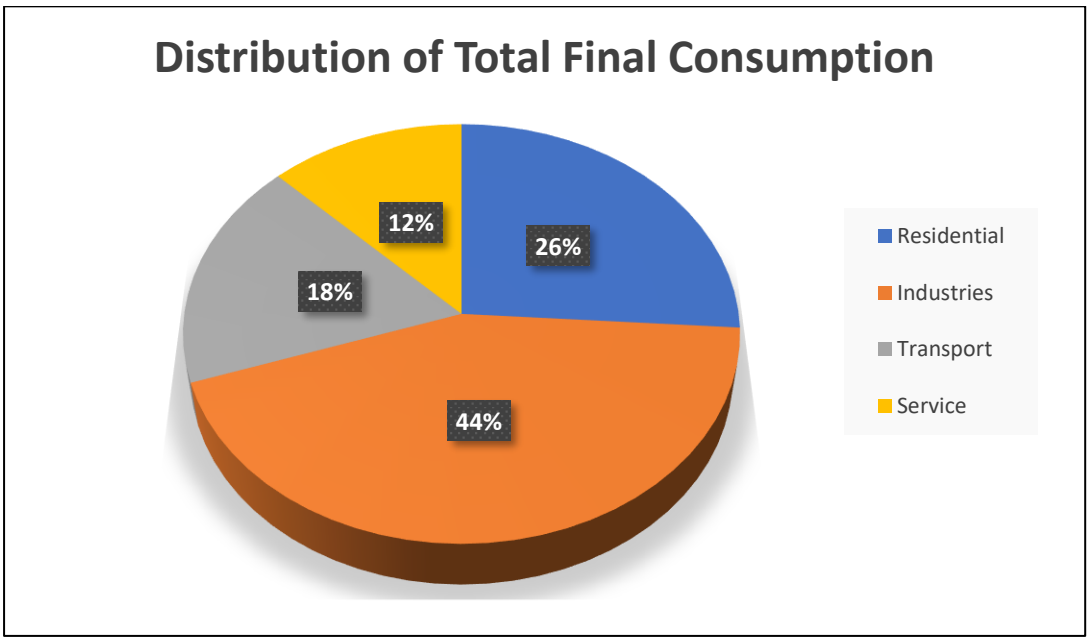


Figure 3. India's Total Final Consumption

Globally massive decarbonization is required if the ambitious emission reduction scenario is to be met and to achieve the 2DS i.e. limit global warming to 2°C above pre-industrial levels. The country is determined to contribute under the Paris agreement towards reducing emissions and increasing the share of non-fossil fuels in the power generation sector.

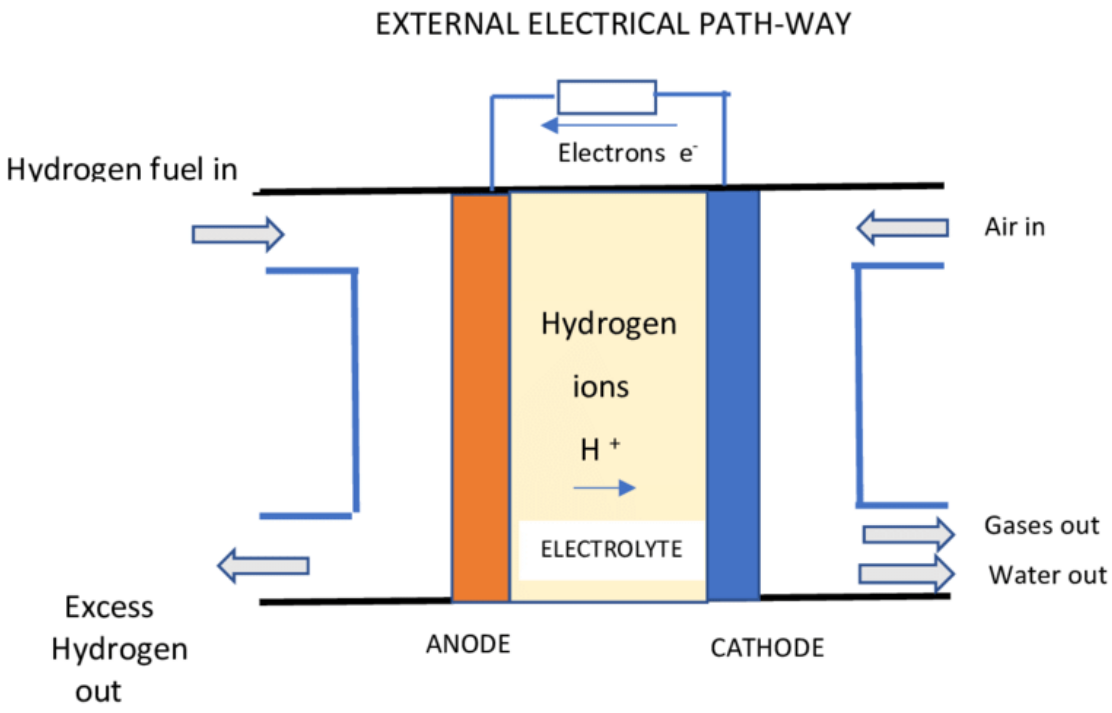
The National Action Plan on Climate Change was launched in 2008 with not only developmental objectives but at the same time addressing the climate change issues effectively. Building on the National Action Plan on Climate Change, the Government of India has initiated several National missions. Other than the deployment targets and incentive mechanisms, these missions are towards RD&D. These National Missions include:

- National Mission for Enhanced Energy Efficiency
- National Solar Mission
- National Electric Mobility Mission
- National Smart Grid Mission
- National Mission on Advanced Ultra Super Critical Technology
- National Mission on Transformative Mobility and Battery Storage

An aggressive renewables-based deployment has been seen in India's energy mix in the past decade, with 84GW of grid-connected renewable electricity capacity in December 2019. The next target is towards achieving 175 GW by the end of 2022 and eventually will have 450 GW of renewable energy capacity.

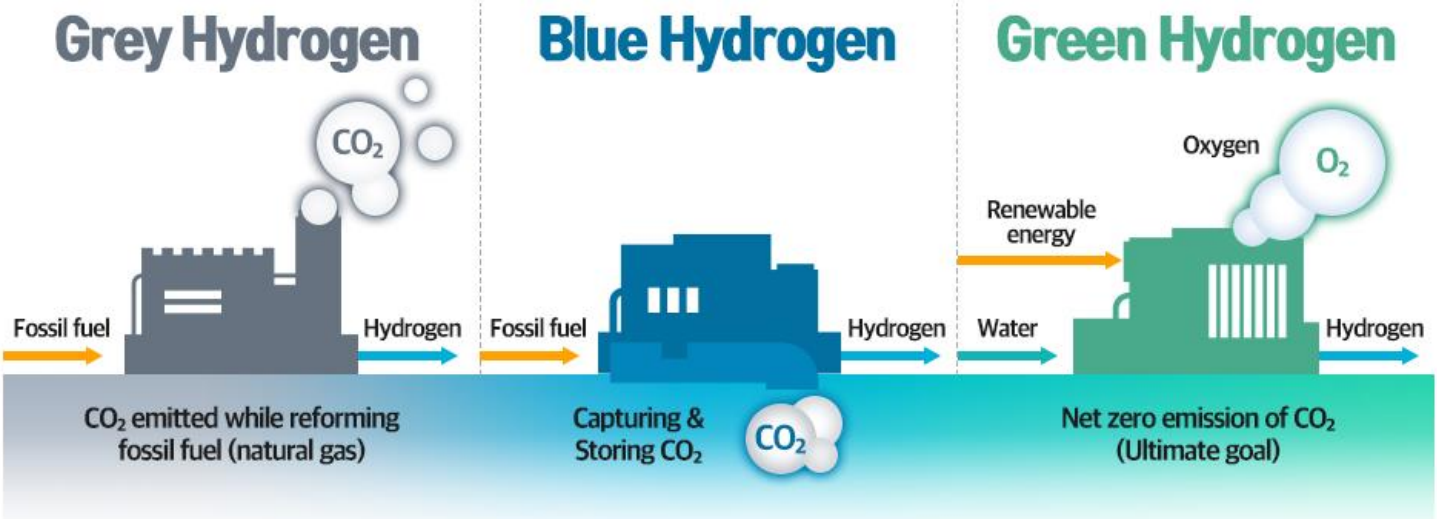
To achieve a Green Economy, the country can look for Hydrogen Fuel Cells as an alternative. A Hydrogen fuel cell is an electrochemical cell that converts the chemical energy of a fuel (hydrogen) and an oxidizing agent into electricity through a pair of redox reactions. Fuel cells are different from most batteries in requiring a continuous source of fuel and oxygen (usually from air) to sustain the chemical reaction, whereas in a battery the chemical energy usually comes from metals and their ions or oxides that are commonly already present in the battery, except in flow batteries. Fuel cells can produce electricity continuously for as long as fuel and oxygen are supplied. In a hydrogen fuel cell, a catalyst at the anode separates hydrogen

molecules into protons and electrons, which take different paths to the cathode. The electrons go through an external circuit, creating a flow of electricity. The protons migrate through the electrolyte to the cathode, where they unite with oxygen and the electrons to produce water and heat.



2. Hydrogen Production

The current global demand for hydrogen is 70 million metric tons per year, in energy terms it's around 330 Mtoe. Most of which is being produced from fossil fuels (76% from natural gas and around 23% from coal, remaining from the electrolysis of water) which consumes 6% of the global natural gas and 2% of the global coal. All this results in CO_2 emissions of around 830Mt/year. Most of this CO_2 produced is not captured, only around 130Mt of this is being captured and used in the fertilizer industry. The situation will change when the hydrogen production from non-fossil fuel-based production will increase and with greater renewables deployment, the shift will be towards green hydrogen production. The production methods are dependent on the feedstock which in turn also depends on the local availability. Depending on which feedstock is used, the different routes for hydrogen production can be reforming, gasification, pyrolysis, fermentation and electrolysis or photolysis. However, the most widely used method for hydrogen production includes steam methane reforming, methanol-reforming, partial oxidation of hydrocarbons, auto thermal reforming, coal gasification, electrolysis of water and thermochemical processes.



	Grey Hydrogen	Blue Hydrogen	Green Hydrogen
Derived From	Natural Gas	Natural Gas	Water Splitting and Renewable Power
Method	Steam Methane Reforming	Advanced Gas Reformation	Electrolysis
GHG Emission	High	Low	Zero
Carbon Capture	CO_2 emitted in the Atmosphere	CO_2 captured and Stored	No CO_2 Emission
Cost Of Production	₹100 – 200/Kg	₹ 300/Kg	₹350 – 400/Kg

Table 1. The classification of hydrogen-based on colour coding and also clarifies the other information that includes the method of production, GHG emissions, carbon capture, and cost of production.

The other methods of production including biomass gasification and photocatalytic or photoelectrochemical are still at the research scale. The cost of hydrogen produced depends on the method of production, separation and purification to achieve the required purity. Hydrogen is an important raw material for the chemical industry, petroleum refining, food processing, metal processing etc. Partial oxidation of oils stands to be one of the important segments which produces large quantities of hydrogen and is also an efficient method (70-80%). The demand of hydrogen in refineries has increased due to stringent emission norms and hydrogen is being used for various hydrotreatment processes like hydrodesulphurization, hydrodenitrogenation and hydrocracking processes.

3. Hydrogen Storage

The major bottleneck in the hydrogen pathway is compact, efficient, conformable, cost effective and safe storage of hydrogen. The requirements from a hydrogen store are different for stationary and vehicular applications. For transportation sector, the weight and size should be low, refuelling should be fast and the hydrogen storage system should have most of the characteristics which current fossil fuel vehicles have like range, passenger space, safety, cost, acceleration/deceleration, start and stop, refuelling time, life and cost etc. Hydrogen can be stored in either compressed, liquified and solid state.

Since the density of hydrogen is very low 0.089 kg/m3 , as such storing in gaseous form requires compression to high pressures. The commercially available Type III and Type IV tank, can store hydrogen at 350 bar or 700 bar. As we go from Type I to Type IV tanks the weight of the tank reduces but the cost increases. Besides this compression of hydrogen requires around 21 MJ/kg H2 to compress from ambient to 700 bars through a five-stage compressor .

The liquefaction of hydrogen is much more energy intensive than compression. Liquid hydrogen temperature is 20K (density is 70.8 kg/m3), as such the container design should involve super insulation to protect any heat inflow into the vessel, but these are not meant to bear high pressures. The liquified hydrogen storage suffer with boil-off losses, which are observed after the pressure build-up and the evaporated hydrogen is released to maintain the tank pressure, thus thereby system acts as an open system. The boil off losses is minimized if the tank is designed to have high volume to surface ratio.

Another method to store hydrogen is in solid state form where either the molecular hydrogen gets adsorbed on the high surface area materials or absorbed to form a hydride. This method of storage has several advantages as against the compressed and liquid state storage methods i.e. it is safe, volumetrically efficient and operating conditions involved like temperature and pressure are optimum unlike the other two methods. Hydrogen is bonded via weak Vander Waals bond in case of adsorption on to high surface area materials like Metal organic frameworks (MOF), zeolites, carbon nanostructure (CNF, GNF, AC, CNT etc.), clathrate hydrides and polymers of intrinsic micro porosity. The enthalpy of formation for such materials is low around 10kJ/mole and thus a low temperature is required to hold the hydrogen, however this method of storage is reversible and kinetics is fast.

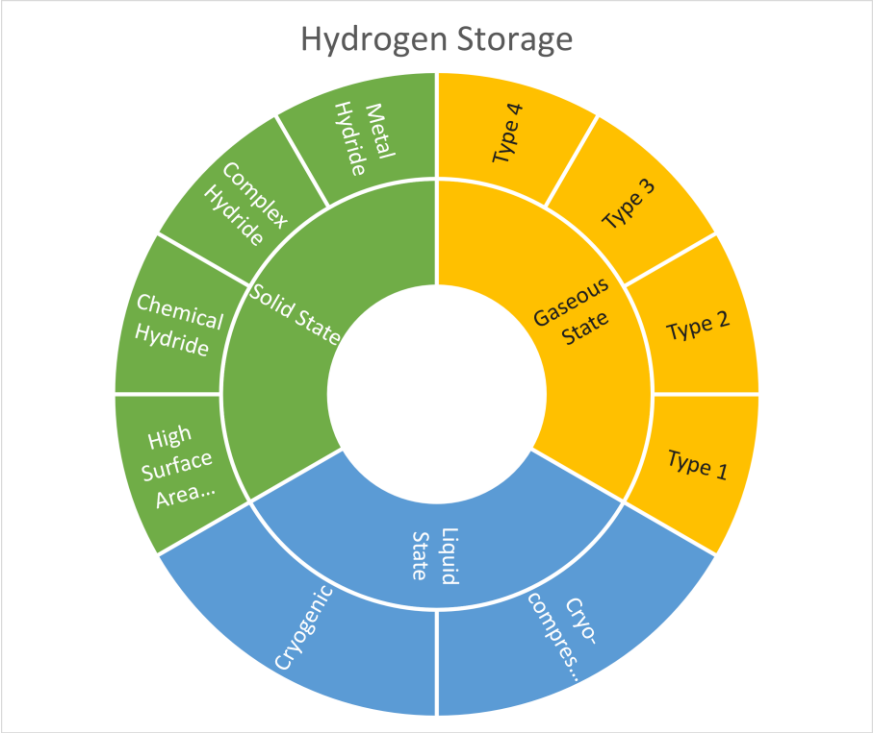


Figure 6. Hydrogen Storage Options

Hydrogen Storage Methods	Compressed Gas Storage	Liquid Hydrogen Storage	Metal Hydride Storage
Hydrogen Transportation by Trailer/Truck	63 – 460 Kg	360 – 4300 Kg	Upto 500Kg
Cost of Storage	₹17.9/Kg	₹48/Kg	₹101.1/Kg
Cost of Transportation	₹35.88/Kg	₹2.16/Kg	₹31.44/Kg
Cost of Fuelling Station	₹30.03/Kg	₹37.95/Kg	-

Table 2. Hydrogen Storage Cost and Options

4. Utilization

Indian Automobile Sector

A total of 11 % of CO_2 emissions in India comes from road transport. This air pollution from vehicular emission can cause various hazardous effects like nausea, breathing difficulties, skin disease, and cancer. Vehicular pollution is also the reason due to which many Indian cities have not succeeded to maintain their air quality index with the safety guidelines of the World Health Organization (WHO). In India, fossil fuel-based vehicles are the major contributor to air pollution followed by industries and thermal power plants. According to the Government of India from the year 1951 to 2012, the number of vehicles has increased from 0.3 million to 159.5 million. Still, the number of vehicles on Indian roads is continuously increasing. The rise in population and economic growth results in the large consumption of fossil fuel-based resources which contribute to the high level of emissions of harmful gases and particulates. Many Indian cities are now witnessing higher Air Quality Index value especially metropolitan areas like Delhi, Mumbai, Kolkata, etc.

Since 1970, Over 90% increase in CO_2 emissions has been recorded as per the United States Environmental Protection Agency. Many nations are now focusing on shifting to electric vehicles by replacing their fleets of ICE vehicles. To overcome the issue associated with PHEV and BEV i.e. Battery recharge time, less availability of charging infrastructure, and low travel range, Fuel cell Electric Vehicle is now a better option.

Fuel Cell Electric Vehicles are equipped with fuel cells that consume hydrogen to supply the necessary power to the vehicle's motor. These fuel cells are more efficient and also more environmentally friendly as compared to many other conventional energy conversion systems. Some automobile manufacturers have already started working on the manufacturing of commercial fuel cell-based vehicles. These vehicles have great potential considering the range and short refuelling time to replace diesel and gasoline-based vehicles. The availability of hydrogen is not an issue as it is abundant in nature, but it is not readily available. Hydrogen can be a better solution for an energy transition. Hydrogen has a huge potential to provide an economical and environmental solution to greenhouse gas emissions.

Features	• Potential - Clean, secure, and affordable future energy source. • Versatile – It can be produced from many resources such as renewable energy, nuclear energy, coal, natural gas, etc. Also, hydrogen is the leading option for energy storage. • Application – Hydrogen can be used in wide applications such as transport, industry, building, and power generation, etc.
Uses	• Industry - Metalworking, Oil refining, Flat glass production, Generator Cooling, etc. Transport – Hydrogen fuel cell-based Passenger cars, Aircraft, Material handling equipment, Buses, Trains, etc. • Building – Hydrogen blending with natural gas in commercial buildings, Heating and Cooling purposes in buildings, etc. • Power Generation – Gas turbines, Backup power, Stationary fuel cells for remote applications, etc.

Opportunities	• Industrial ports, logistic parks – Make industrial ports, logistic parks, etc. hydrogen compatible and encouraging them to shift to a green hydrogen economy. • Building a hydrogen infrastructure – To adopt a hydrogen economy and to take advantage of the future market scenario. • In transport – Using hydrogen in transport for freights, fleets, and corridors. • In trade – International hydrogen trade needs to start soon which can make an impact on the global energy market.
Challenges	• Hydrogen production from renewable energy – The cost of hydrogen production from green energy is not efficient and costly. Mass manufacturing of fuel cells, electrolysers, refuelling equipment is not still implemented which contributes heavily to their price. • Slow development of hydrogen infrastructure – Less number of refuelling stations and other hydrogen infrastructure slows down the wide adoption of hydrogen. • The purity of produced hydrogen for fuel cell applications. • Governmental regulations - for safety in storage and transportation for large volumes of hydrogen.

Table 3. Hydrogen Energy – Features, Uses, Opportunities, and Challenges

5. Conclusion

India has a large growing population and economy, but comparatively has limited availability of fossil fuels to fulfil its energy demands. The consumption of fossil fuels is contributing to the heavy emission of greenhouse gases. A large number of vehicles that are based on petroleum are the major reason for increased petroleum imports in India. To reduce the environmental pollution and petroleum imports in India, there is a need to look for an alternate fuel for the transport sector. Considering the need to search for an alternate fuel, the context focuses on the opportunities offered by Green Hydrogen Economy and related challenges.

The concept of Green hydrogen economy brings many opportunities for India to become energy independent. For the last decade, India is constantly focusing on growing its renewable energy capacity by taking advantage of its geography. Integrating hydrogen production with these renewables can scale up the green hydrogen production in India. India can take the advantage of its renewable energy scenario and can scale up its hydrogen production facilities. The mass production offers India an opportunity to export green hydrogen to other nations. Green Hydrogen when used with fuel cells can help India significantly reduce its petroleum imports and environmental pollution. Renewable energy in India provides the opportunity to produce green hydrogen and to develop hydrogen infrastructure but for adoption, many challenges still need to be solved. These challenges include hydrogen production cost, storage, transportation, policies, regulations, public awareness, etc.

The world is slowly moving towards the adoption of a Hydrogen economy and India is also taking important initiatives. Indian organizations which include both government and public are investing in the research of hydrogen technologies. Many Ongoing research and demonstration projects are very important to develop hydrogen and fuel cell technology economically. The progress in this development will play a key role in the commercialization of the technology. Well-developed fuel cell technology and locally produced green hydrogen will be key players to decarbonize the Indian transport sector by replacing the current petroleum-based vehicle engines.

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8. Abbreviations

- TPES - Total primary energy supply
- Mtoe - mega tonnes of oil equivalent
- TPEC – Total Primary Energy Consumption
- TFC – Total Final Consumption
- RD&D – Research, Design & Development
- GW – Giga Watt
- Mt – Metric Ton
- GHG – Green House Gases

Indo-German International Conference on
Metrology for the Deployment of Green Hydrogen and Renewable Fuels in India

Saksham Bansal

Letter of Recommendation

To whomsoever it may concern

I would be delighted to provide a recommendation for the research paper on *"Hydrogen Fuel Cells – A Way Forward for Green Hydrogen Economy"* by Saksham Bansal, a Class 12 student in Gems Modern Academy, Gurgaon. I am the member of the scientific committee of an "Indo-German International Consortium on Metrology for the Deployment of Green Hydrogen and Renewable Fuels in India" which is funded by the German Federal Ministry for Economic Cooperation & Development.

Under the framework of our first international conference, Mr. Saksham Bansal has submitted his student research paper for my review. I was highly impressed by the maturity and the diligence of the research and analysis put into the paper. His highly informative illustrations and graphs were meticulously drawn with great care for the reader's visual understanding of the content matter. The detailed write up on hydrogen fuel cells, their sustainable yet highly flammable nature and the care and expertise needed to correctly manage these cells is truly commendable and it was an absolute joy to read. His understanding and proposals of their prospective use for a cleaner, pollution free environment is very accurate and aligns perfectly with most of the industry experts, which only goes to show his exceptional calibre and understanding about hydrogen as a new green regenerative fuel as well as his deep concern for environmental conservation.

Saksham is an assiduous and perspicacious young individual who's indefatigable desire to learn has truly impressed me. I am happy and confident to provide this reference, and in case you have any questions or wish to know more about this research paper, please feel free to email me at: bhardwaj@fev.com anytime.

Kind Regards,

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