

GREEN HYDROGEN AS FUTURE ENERGY SOURCE IN INDIA

Abstract

With continuous growth in development, the world energy demand is also increasing at a higher rate year by year. Fossil fuels still fulfil 80% of energy need. The Net Zero Emission scenario by 2050, has forced all nations to adopt clean and renewable energy options. In this context, hydrogen energy has already been assessed as a clean and renewable energy source. Due to its versatile nature and being an energy carrier, hydrogen is even more potent than other renewable energy sources. To meet the global challenge of climate change, India has announced National Hydrogen Mission on 15 August 2021. This mission focuses on producing green hydrogen and green ammonia using electrolysis of water employing renewable electricity and hydrogen production through biomass. Targets of the Indian National Hydrogen Mission, India's Green hydrogen policy, the cost and demand of hydrogen in India and green hydrogen initiatives undertaken by the Government of India have been discussed in detail. In short, National Hydrogen Mission will make India self-sufficient in energy needs. India may become a world leader in energy export, especially in green hydrogen and green ammonia.

Keywords: National hydrogen Mission, Green hydrogen, Green ammonia, Renewable electricity, Net Zero Emission

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I. INTRODUCTION

Due to continuous and increasing development, world energy demand is growing constantly. The world total energy supply in 1973 was 254 Exa Joule (EJ), in 2019 it was 606 EJ, while in 2021 the energy demand was 624 EJ. In 2019 and in 2021, total energy consumption in the world was 418 EJ and 439 EJ respectively, while it was only 194 EJ in 1973 [1, 2]. The share of fossil fuel in consumed energy was still 80% in 2021. Many policies have come forward to cut the emission of greenhouse gases. It is required to meet the goal of limiting global warming to well below 2°C, preferably to 1.5°C compared to pre-industrial levels in Paris agreement on climate change. The Stated Policies Scenario (STEPS) deals with present policy matters. The Announced Pledges Scenario (APS) talks about all the announced policies by governments, including long term goals to achieve the set targets on time. The Net Zero Emissions (NZE) Scenario by 2050 declares a roadmap for stabilizing the global temperature rise to 1.5°C. Along with this, it targets modern energy access by all up to 2030. In 2021, the largest-ever annual increase in CO₂ emission was noticed as 36.6 Giga tonne (Gt). In STEPS, CO₂ emission will fall to a level of 32 Gt in 2050 leading to global average temperatures rise by 2.5°C in 2100. However, before the Paris agreement, rise in global temperature was predicted as 1°C higher than STEPS. Following the APS, in 2050 CO₂ emissions will fall to 12 Gt, predicting average global temperature rise of 1.7 °C in 2100. Whereas, in NZE by 2050, 23 Gt fall in CO₂ emissions will be noticed in 2030 and to zero in 2050. It may increase the temperature to less than 1.5°C in 2100 [3, 4]. The predicted temperature in the different scenarios is presented in Table 1.

Table 1: Predicted Global Temperature and CO₂ emission in various Scenarios

S.N.	Scenario	Predicted temperature in 2100	Amount of CO ₂ emission in 2050
1	Before Paris Agreement	3.5 °C	36.6 Gt in 2021
2	STEPS	2.5 °C	32 Gt
3	APS	1.7 °C	12 Gt
4	NZE	1.5 °C	0

II. WORLD ENERGY SCENARIO

The total consumption of energy in 2021 around the globe was 439 EJ. This energy is derived through electricity, heat, liquid, gaseous and solid fuels. A major portion of energy, around 80% still comes from fossil fuels. The share of different energy sources is shown in Table 2. The major energy consumption sectors are industry, transport, building and others. These sectors globally consume 38, 26, 30 and 6 % of energy respectively (Table 2). In total CO₂ emissions of 36.6 Gt, 39.2, 4.2, 25.4, 21, 8.3 and 1.9 % are emitted from electricity and heat, non-energy sector, industry, transport, building and other sectors, respectively. The emission of CO₂ from the different sectors is given in Table 3. In 2021 total generated electricity was 28334 Tera Watt hour (TWh) around the globe. Among the total electricity generated, 28.4 % was derived from renewable sources and 61.5 % from fossil fuels. 9.8 % share was from nuclear energy. The composition of claims coming from different energy sources for electricity generation is shown in Table 4. Regarding the installed capacity for electricity generation (total installed capacity 8185 GW), 40 % is from renewable energy

installation, and 54.5 % is based on fossil fuel installation. Nuclear energy installation has a share of 5% (Table 5) [1, 2].

Table 2: World energy consumption in 2021 in STEPS

Type of fuel	Energy in EJ				
	Total consumption	Industry	Transport	Buildings	Other
Total consumption	439	167	114	133	25
Electricity	87	37	2	45	
Liquid fuels	170	33	107	14	
Biofuels	4	-	4	-	
Ammonia	-	-	-	-	
Synthetic oil	-	-	-	-	
Oil	166	33	103	14	
Gaseous fuels	72	31	5	31	
Biomethane	-	-	-	-	
Hydrogen	-	-	-	-	
Synthetic methane	-	-	-	-	
Natural gas	72	31	5	31	
Solid fuels	94	59	-	33	
Solid bioenergy	40	11	-	28	
Coal	54	48	-	4	
Heat	13	7	-	7	
Other	3	-	-	3	

Table 3: Sector-wise CO₂ emission in 2021 at global level

Sector	Amount of CO ₂ emission	
	Gt	% of total emission
Total emission	36.639	100
Electricity and heat sector	14.378	39.2
Industry	9.316	25.4
Transport	7.670	21.0
Buildings	3.045	8.3
Others	0.708	1.9
Non energy sector	1.522	4.2

III. INDIAN ENERGY SCENARIO

In India, total energy consumption in 2021 was 27.5 EJ, which is 6.26% of globally consumed energy. The maximum energy in India is consumed by the industry sector, which

is 45.1%. In the transport sector the amount of energy consumed is less (15.3%) in comparison to the global status. Energy consumption in different sectors in India is reflected in Table 6. In 2021 total CO₂ emission in India was 2.472 Gt, showing 6.75 % of world's total CO₂ emission. Among total CO₂ emissions, 1.199 Gt (48.5%) are from the electricity and heat sector, while 1.205 Gt (48.7%) is emitted collectively from the industry, transport and building sectors. Among total electricity generation, India shares 1686 TWh of electricity, which is 5.95 % of total world electricity production. The share of renewable energy in India for electricity corresponds to 337 TWh, which is 20 % of home electricity production and 4.18 % of world renewable electricity production (Table 4) [5].

Table 4: Total electricity generated (TWh) in the world and in India in 2021

Type of technology	In world	In India
Total generation	28334	1686
Renewable	8060	337
Solar PV	1003	73
Wind	1871	77
Hydro	4327	150
Bioenergy	746	37
CSP	15	-
Geothermal	97	-
Marine	1	-
Nuclear	2776	42
Hydrogen and ammonia	-	-
Fossil fuels with CCUS	1	-
Unabated fossil fuels	17436	1304
Coal	10201	1234
Natural gas	6552	70
Oil	683	-
Other	61	3

Table 5: Total installed electricity (GW) in the world in 2021 in STEPS

Total capacity	8185
Renewable	3278
Solar PV	892
Wind	832
Hydro	1357
Bioenergy	173
CSP	7
Geothermal	16
Marine	1
Nuclear	413
Hydrogen and ammonia	-
Fossil fuels with CCUS	0
Unabated fossil fuels	4462
Coal	2185

Natural gas	1850
Oil	427
Battery storage	27
Other	5

Table 6: Sector-wise energy consumption (EJ) in India in 2021

Sector	Energy consumption	
	Amount	%
Total consumption	27.5	100
Industry	12.4	45.1
Transport	4.2	15.3
Buildings	8.5	30.9
Other	2.4	8.7

IV. INDIAN POLICY FOR DIFFERENT SCENARIOS

To meet global clean energy efficiency in production and consumption, India has declared the following overall cross-cutting policy [6]:

- **Steps**
 - Launching of Self-Reliant India Scheme (Atmanirbhar Bharat), focusing on energy-related elements.
 - Government of India targets to increase renewable capacity to 450 GW by 2030. The goal is to install 50% of total capacity with energy sources based on non-fossil fuel sources by 2030.
 - Government has amended Energy Conservation Act in 2022 to enforce energy efficiency policy with higher impact.
 - National Hydrogen Mission has been announced.
- **APS**
 - National Development Council (NDC) has declared the reduction in carbon intensity by 45% by 2030 from 2005 levels across the nation. It targets only 1 Gt CO₂ emission by 2030. To achieve this goal, nation has to increase the non-fossil energy capacity to 500 GW by 2030.
 - India has announced to achieve Net zero emissions by 2070.

1. Electricity Sector:

- **APS**
 - According to updated NDC, the total installed electric power will share 50% energy source coming from non-fossil fuel resources by 2030.

2. Industry Sector

- **Steps**
 - For trading of energy-saving credentials, Perform, Achieve, Trade (PAT) scheme has been launched.

- Through “Make in India” programme, industry sector is boosted to build 11 world-class industrial corridors.
- In national union budget of 2021-2022, provision of USD 26 billion has been made to increase the capabilities of 14 key manufacturing sub-sectors.

3. Building Sector

- **Steps**

- As part of the Energy Conservation (Amendment) Bill, Energy Conservation and Sustainable Building Code is focused on norms of energy efficiency and conservation. It is about conserving renewable energy and adopting other green approaches in buildings.
- Cooling Action Plan together with Standards and labelling for light commercial air conditioners, freezers and light bulbs has been proposed.
- In residential buildings for renters and homeowners Energy efficiency labelling has been launched.

4. Transport Sector

- **Steps**

- Urban and public transit investments.
- Pure gasoline will be replaced partially with a 20% bio-ethanol blending and 5% of biodiesel by 2030.

- **APS**

- FAME program (Faster Adoption and Manufacturing of electric Vehicles) has extended to Phase II to support the target of manufacturing 500000 electric three-wheelers and 1 million electric two-wheelers in India.
- National railways target to achieve net zero emissions by 2030.

V. NEED FOR HYDROGEN ENERGY

Well-known detrimental effect of fossil fuel has forced the world to move towards clean and renewable energy sources. Many countries are moving towards other energy options, including nuclear and renewable energy, to fulfil their energy demand. Hydrogen energy is now established as a potential candidate for a future energy sources. Key parameters for harnessing hydrogen energy at the fullest potential are production, storage, transportation and application. Hydrogen energy has many advantageous characteristics to establish it as a good energy source. Some of them are abundant quantity, renewable nature, environmentally clean, high energy content, storable, economically transportable, conveniently usable, socially compatible and evenly distributed around the globe.

1. Production and Applications of Hydrogen Energy: In 2021 hydrogen demand in the world was 11319 Peta Joule (PJ). The demand in India was 1045 PJ. The major hydrogen productions routes are discussed in the following [7]:

- Steam methane reforming using natural gas
- $\text{CH}_4 + \text{H}_2\text{O} = \text{CO} + 3\text{H}_2$

- Liquefied petroleum gas (LPG) and naphtha cracking
- (In this reaction, a gaseous or liquid hydrocarbon feed like naphtha, LPG or ethane is diluted with steam and briefly heated in a furnace in the absence of oxygen. The products are monomers and hydrogen).
- Gasification of coal
- $\text{CO} + \text{H}_2\text{O} = \text{CO}_2 + \text{H}_2$
- Gasification of biomass
- $\text{C} + \text{H}_2\text{O} = \text{H}_2 + \text{CO}$
- $\text{CO} + \text{H}_2\text{O} = \text{CO}_2 + \text{H}_2$
- Water electrolysis
- $2\text{H}_2\text{O} = \text{H}_2 + \text{O}_2$

Hydrogen produced from different sources is coded with some colour, as mentioned in Table 7.

Table 7: Colour Coding of Hydrogen Production based on the Production Source

Source of hydrogen production	Colour code of hydrogen produced
Coal	Black
Natural gas	Grey
Lignite	Brown
Fossil fuels with CCUS	Blue
Renewable electricity	Green

Hydrogen is an energy carrier with versatile nature. It has wide applications not only as energy to replace fossil fuel, especially in transportation sectors, many more applications in other sectors as well. Some crucial sectors are listed below:

- Refining
- Power
- Transport
- Industry
- Buildings
- In the industry, the categorized significant applications are:
 - Ammonia
 - Other pure chemicals

The above mentioned are specific applications requiring hydrogen with only small additives or contaminants tolerated.

- Methanol
- Steel industry-Direct Reduction of Iron (DRI)
- Other mixed applications

In the above three applications, hydrogen is required as part of a mixture of gases, such as synthesis gas, for fuel or feedstock.

Traditional refining and industry utilizes much hydrogen. Germany initiated operation of hydrogen fuel cell trains. The demands of hydrogen and its derivatives are increasing as fuels. This has been demonstrated in several pilot projects. Hydrogen and ammonia are attractive in the power sector too. It may deliver almost 3.5 GW of potential capacity by 2030.

- 2. Present Scenario of Hydrogen Energy around the Globe:** The share of hydrogen energy in global energy consumption was about 2.5% in 2021 equivalent to 94 million tonnes (Mt). Low-emission hydrogen was produced with an amount less than 1 Mt in 2021. The low-emission hydrogen is produced using fossil fuels with carbon capture, utilisation and storage (CCUS) mechanism. On completing all the current low-emission projects by 2030, the production of low-emission hydrogen could reach 16-24 Mt per year. Among this, 9-14 Mt hydrogen will come from electrolysis and 7-10 Mt from fossil fuels with CCUS. It may require electrolyser capacity of 134-240 GW to be installed by 2030. It will also require enhancing the manufacturing capacity of electrolyser for production of hydrogen. For producing low-emission hydrogen, one requires low-emission electricity in electrolysers. Current electrolyser capacity is nearly 8 GW/yr, which will exceed 60 GW/yr by 2030. In some regions, where fossil fuel price is high, renewable hydrogen price is comparable with it. High jump in manufacturing of electrolyser may reduce its cost by 70% in 2030 compared to today. This may combine with the expected drop in the price of renewable energy to bring the cost of renewable-based hydrogen down to a range of USD 1.3-4.5/kg H₂ (equivalent to USD 39-135/MWh) [8]. Along with the traditional use of hydrogen, some new applications are also seeing accelerated deployment, such as fuel cell electric vehicles (FCEVs). By the end-2021, the global FCEV stock was more than 51000, up from about 33000 in 2020, representing the most significant annual deployment of FCEVs since they became commercially available in 2014. Most FCEVs are passenger cars, but several fuel cell trucks were also in operation in 2021.

Production of hydrogen is always accompanied with the emissions of CO₂. In 2021, 94 million tonnes of hydrogen (Mt H₂) production emitted more than 900 Mt CO₂. In total hydrogen, 62% was produced through natural gas in 2021. 18% of hydrogen was produced as a by-product of naphtha reforming at refineries. At global level, 19% of total hydrogen production in 2021 was from coal. Less than 1% hydrogen was produced through natural oil. Only 1 Mt (0.7%) hydrogen was produced through fossil fuels with CCUS in 2021 and 35 kt H₂ from electricity via water electrolysis under low-emission hydrogen production category. Although the amount of hydrogen production via water electrolysis is very small, the increase in this amount was by almost 20% compared to 2020. It shows that deployment of water electrolysers is increasing [7].

The cost of low-emission hydrogen production is more than the fossil fuels without CCUS route. The hydrogen production cost is USD 1.0-2.5/kg H₂, USD 1.5-3.0/kg H₂, and USD 4.0-9.0/kg H₂ from unabated natural gas, from natural gas with CCUS and from production via electrolysis with renewable electricity respectively. It has been predicted that by 2030, hydrogen from solar PV could fall below USD 1.5/kg H₂ and it may go down to USD 1/kg H₂ by 2050 in regions with good solar conditions. Solar PV electricity costs must fall to USD 14/MWh by 2030 and USD 11/MWh by 2050 to reach these hydrogen production cost levels. The US Hydrogen Earth shot initiative aims to achieve hydrogen costs of USD 1/kg H₂ by 2030. Hydrogen demand in the different

scenarios at the global level and in India is presented in Table 8. Similarly, sector-wise future hydrogen production, demand and consumption in various scenarios at global level is demonstrated in Table 9.

Table 8: Future hydrogen demand (PJ) across the world and in India

Scenario	Present		STEPS		APS	
	2020	2021	2030	2050	2030	2050
World	10730	11319	13438	16822	15064	34575
India	975	1045	1342	2134	1284	3585

Table 9: Sector-wise future hydrogen production, demand and consumption (Mt H₂ equivalent) across the world

Scenario	STEPS			APS		NZE	
	2021	2030	2050	2030	2050	2030	2050
Low-emission hydrogen production	1	6	25	30	225	90	452
Water electrolysis	0	4	17	21	167	58	329
Fossil fuels with CCUS	1	2	8	9	57	31	122
Bioenergy and other	0	0	0	0	1	0	2
Transformation of hydrogen	0	3	10	14	95	50	186
To power generation	0	0	1	4	19	27	60
To hydrogen-based fuels	0	0	3	6	69	18	118
In oil refining	0	2	5	3	6	2	4
To biofuels	0	1	1	1	1	3	3
Hydrogen demand for end-use sectors	0	3	15	16	131	40	266
Low-emission hydrogen-based fuels	0	0	3	3	55	15	96
Total final consumption	0	0	1	3	39	7	68
Power generation	0	0	2	0	16	8	28
Trade	0	1	5	4	44	18	73
Trade as share of demand	0%	10%	22%	13%	19%	20%	16%

VI. NATIONAL HYDROGEN MISSION OF INDIA

The National Hydrogen Mission was announced by Prime Minister Shri Narendra Modi on the 75th Independence Day during his address to the nation. The mission is for making India a hub to produce and export green hydrogen. This mission is a step towards achieving net-zero India by 2070. It will help India to become energy independent before completing 100 years of independence in 2047.

- 1. Targets of the National Hydrogen Mission of India:** India can achieve the following targets under the National hydrogen Mission [9, 10]:

- To build more than 60 GW/5 million tonnes electrolysis capacity to generate green hydrogen by 2030 for domestic consumption. Through this, India may achieve the 500 GW renewable energy target.
 - To produce largest amount of green steel at 15-20 million tonnes by 2030 at global level.
 - To develop annual manufacturing capacity of 25 GW for electrolyser by 2028, representing the world's largest capacity.
 - To become the world's largest producer of green ammonia for exports by 2030 helping India's allies to decarbonise. This may require up to 100 GW of green hydrogen.
 - It requires \$1 billion investment into hydrogen research and development.
- 2. Advantages of the National Hydrogen Mission:** Green hydrogen has power to drastically reduce CO₂ emissions, fight climate change and to achieve net-zero energy imports with proactive collaboration among innovators, entrepreneurs and government. India may export high-value green products and reduce 3.6 Gt of CO₂ emissions cumulatively between now and 2050. It may help India to fulfil announced climate targets and net-zero vision. Thus India has the unique opportunity to invest in this new technology and become a world leader in green hydrogen production and its applications.
- 3. India's Green Hydrogen Policy:** The government of India has announced several policy measures to transform the energy sector from fossil fuel, fossil fuel-based feedstock to Green Hydrogen / Green Ammonia both as energy carriers and as chemical feedstock for different sectors. The green hydrogen policy of Government of India has the following provisions [11]:
- Green Hydrogen / Green Ammonia shall be produced through water electrolyser running with renewable energy and from biomass.
 - To all the projects commissioned before 30th June 2025, discount will be given in inter-state transmission charges for a period of 25 years to the producer of Green Hydrogen and Green Ammonia.
 - For manufacturing Green Hydrogen / Green Ammonia a developer may utilize renewable energy from a co-located renewable energy plant, or sourced from a remotely located renewable energy plant. Renewable energy plant may be of the same developer, or belongs to a third party or procured renewable energy from the Power Exchange.
 - To use renewable energy, 30 days banking shall be permitted to produce Green Hydrogen/ Green Ammonia.
 - The State Commission shall be responsible to fix the banking charges.
 - Connectivity of electricity shall be provided on priority basis at the generation end and the manufacturing end of Green Hydrogen / Green Ammonia under the electricity rule 2021.
 - The manufacturer of Green Hydrogen / Green Ammonia may be allotted land in renewable energy parks.
 - Manufacturing Zones have been proposed by the Government of India to set up Green Hydrogen / Green Ammonia production plants.
 - Bunkers near ports may be set up for Green Hydrogen / Green Ammonia for export/use by shipping.

- Ministry of New and Renewable Energy (MNRE) will be responsible for all statutory clearances and permissions required for the manufacture, transportation, storage and distribution of Green Hydrogen / Green Ammonia through a single portal.
- After collecting demand from different sectors, MNRE may call bids for procurement of Green Hydrogen/Green Ammonia for competitive prices.

4. Cost and Demand of Green Hydrogen in India: In the future cost of Green hydrogen in India will be as follows:

- **2030 Prices:** Green H₂: \$1.7 - \$2.4/kg; Round-the –clock (RTC) Renewable: \$2.1/kg; Grey H₂: \$1.8 - \$2.7/kg
- **2050 Prices:** Green H₂: \$0.6 - \$1.2/kg; RTC Renewable: \$0.9/kg; Grey H₂: \$1.9 - \$2.9/kg

The share of green hydrogen will increase from 16% in 2030 to almost 94% by 2050. It may promote demand of electrolyser capacity from 20 GW by 2030 and 226 GW by 2050, establishing an opportunity for indigenous manufacturing of a global emerging energy technology. The cumulative value of the green hydrogen market in India could be \$8 billion by 2030 and \$340 billion by 2050. The market of electrolyser may reach to \$5 billion by 2030 and \$31 billion by 2050. 3.6 Gt of cumulative CO₂ emissions reductions will be noticed between 2020 and 2050 through adoption of green hydrogen. The saving in energy import due to green hydrogen will correspond to \$246 billion to \$358 billion by 2030 and 2050 respectively.

Hydrogen demand in different sectors for end user is given as under:

- **Fuel: Transport-**Maritime, Trains, Road, Freight, Aviation
- **Power:** Flexibility, Seasonal Storage, Peaking Plants, Power backup
- **Feedstock: Chemicals-**Fertilizer, Plastics, Fuel refining
- **Feedstock: Products -**Metallurgy, Steel, Food, Glass
- **Heat:** Space heating in buildings and industry
- **Industry:** Steel, Paper, Cement, Aluminium, Food

Hydrogen demand in India in 10 years gap is estimated as follows:

- In 2020=7 Mt, the share of green hydrogen =0
- In 2030 =12 Mt, the share of green hydrogen =16 %
- In 2040 = 17 Mt, the share of green hydrogen =70%
- In 2040 = 28 Mt, the share of green hydrogen =94%

VII. CURRENT GREEN HYDROGEN INITIATIVES IN INDIA

- 1. Green Hydrogen Initiatives by The Ministry of Petroleum & Natural Gas (MoPNG):** MoP&NG is funding the projects of the oil industry for the production of hydrogen; H-CNG; and hydrogen production through the decomposition of natural gas through the involvement of academic institutions. The ministry has the following programs:

- Grey hydrogen is blended with compressed natural gas (CNG) to the extent of 18%, for use as a transportation fuel at Rajghat Bus depot. 50 such buses have been launched in Delhi.
- Five projects are planned to produce green hydrogen for transportation fuel as well as an industrial input to refineries. Following projects have been planned for Green Hydrogen production:
 - Two tourist sites (like Delhi-Agra, Gujarat- Statue of Unity) have been selected for fuel cell vehicles, to setting up solar hydrogen refuelling stations.
 - To set up a green hydrogen plant to replace conventional hydrogen in a refinery with green hydrogen.
 - In Rajasthan, produced green hydrogen will be blended with Compressed Natural Gas (CNG) for dispensing at retail outlets.
 - Another project is about green hydrogen infrastructure and pipeline injection of green hydrogen in the City Gas Distribution (CGD) network.

In these ambitious R&D projects of an amount of ₹ 296 crores, addressing all aspects of the value chain of hydrogen-based mobility, one-third each is contributed by the hydrogen corpus fund (HCF), Indian Oil Corporation (IOC) and other participating entities. IOC R&D has procured 15 indigenously manufactured/integrated hydrogen fuel cell buses to conduct a 20,000 km field trial in Delhi NCR. 40 tonnes per day hydrogen production demo units (4 units) will also be set up. Among these, 3 green hydrogen plants will utilize renewable sources (biomass gasification, reforming compressed bio gas (CBG) and solar photo voltaic (PV)-based electrolysis). IOC R&D has collaborated with the Indian Institute of Science, Bengaluru to develop biomass gasification technology, which is the most economical pathway to the hydrogen economy.

VIII. HYDROGEN-BASED TRANSPORT

While Battery Electric Vehicles (BEVs) are dependent on imported raw materials like lithium and cobalt for lithium-ion batteries, the hydrogen fuel cell can be wholly indigenized, making India Aatmanirbhar in the clean energy for transportation sector.

Fuel cell electric vehicles (FCEVs): run on hydrogen fuel and have no harmful emissions. BEVs are suitable for the light passenger vehicle for the shorter driving ranges. For heavy-duty vehicles with longer trip ranges, such as buses, trucks and other commercial vehicles, FCEVs are more cost competitive. Various hydrogen-powered vehicles have been developed and demonstrated under projects supported by the Government of India. These include 6 Cell buses by Tata Motors Ltd., 50 hydrogen-enriched CNG (H-CNG) buses in Delhi by Indian Oil Corporation Ltd. in collaboration with Govt. of NCT of Delhi, 2 hydrogen-fuelled Internal Combustion Engine buses (by IIT Delhi in collaboration with Mahindra & Mahindra).

- 1. Indian Oil Company Initiatives towards Green Hydrogen:** The government-led public sector undertaking (PSU), Indian Oil, is planning to set up India's first green hydrogen unit for the Mathura refinery, which will be used to process crude oil. It will utilize low-cost wind power from Rajasthan (wheeling it to Mathura in Uttar Pradesh) to power this green hydrogen plant. The organization is planning to use hythane (H-CNG), a blend of

compressed natural gas (CNG) and hydrogen in 50 CNG buses to test the feasibility of the H-CNG-powered vehicles and their impact on emissions and fuel economy.

- 2. Green Hydrogen Initiatives by National Thermal Power Corporation:** Another government-run PSU, National Thermal Power Corporation (NTPC), is going to establish a first-of-its-kind hydrogen refuelling station to be powered entirely by renewable in Leh through a stand-alone 1.25 MW solar system.
- 3. Gas Authority of India Limited (GAIL) to set up green hydrogen plant at Guna in MP:** This project will produce around 4.3 metric tonnes of hydrogen per day (approximately 10 MW capacities) with a purity of about 99.999 per cent. It is scheduled to be commissioned by November 2023.
- 4. NTPC in association with Gujarat Gas:** NTPC and Gujarat Gas are planning to blend hydrogen with piped natural gas (PNG). In Surat NTPC plans to reach out 200-home housing colony for supplying blend hydrogen to the extent of 5% for domestic use, to be later ramped up to 20%.
- 5. Green Hydrogen Initiatives by Others:** Few other important industrial units such as Reliance Industries Limited (RIL), GAIL, NTPC, IOC and Larsen and Toubro (L&T) plan to foray into the green hydrogen space. RIL plans to become a net-carbon-zero firm by 2035 and invest nearly INR 750 billion over the next three years in RE. India has declared its ambition to become an exporter of hydrogen to Japan, South Korea, and Europe.

IX. CONCLUSIONS

In conclusion, it can be said that India may emerge as a powerful nation in the energy sector. India may be a leader in Green Hydrogen Technology across the globe. The reason behind this may be low technological cost for setting up renewable electricity plant in India in comparison to other developed countries. India has already shown its potential in the installation of solar and wind power technology across the country. Hence, in the future India will not only become self-dependent in the energy sector, instead, it will be on the front line in exporting energy to other countries, especially green hydrogen and green ammonia.

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