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Challenges in Developing Hydrogen Infrastructure in Emerging Economies: Focus on India

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Abstract: Globally, hydrogen is gaining recognition as a vital component of sustainable energy systems, serving as a versatile and carbon-free energy carrier for industries, transportation, and power generation. Although developed nations have introduced large-scale hydrogen initiatives, emerging economies continue to struggle with unique obstacles related to technology, financing, and policy development.This study examines both the global and Indian hydrogen sectors, emphasizing the essential role of green hydrogen combined with renewable energy sources. It investigates key challenges, including elevated production costs, inadequate infrastructure, water scarcity issues, and policy ambiguities, while providing an in-depth analysis of India's specific hurdles and opportunities.The paper proposes strategic approaches such as expanding domestic electrolyzer production, establishing renewable-hydrogen hubs, enhancing regulatory frameworks, and promoting international partnerships. It further underscores the significance of innovation, workforce training, and raising public awareness to support the development of a strong hydrogen economy. Through focused investments, technological advancements, and coordinated policy efforts, emerging nations like India can establish leadership roles in the global hydrogen transition and move swiftly toward a low-carbon future.

Keywords: Green Hydrogen, Hydrogen Infrastructure, Emerging Economies, Renewable Energy Integration, India Hydrogen Mission, Energy Transition

I. INTRODUCTION

Hydrogen, the most abundant element in the universe, is gaining significant global attention for its role in advancing the clean energy transition. With its high energy density and the emission of only water vapor upon combustion, hydrogen presents a promising substitute for fossil fuels in achieving substantial decarbonization goals. It can serve as a fuel, an energy carrier, or a feedstock across various sectors such as transportation, industry, buildings, and power generation. Unlike conventional battery storage, hydrogen enables long-duration and large-capacity energy storage, making it a critical component of future sustainable energy systems [1][3].

Hydrogen is categorized into different types based on its production method. Grey hydrogen is generated from natural gas or coal through techniques like steam methane reforming, which results in considerable carbon dioxide emissions. Blue hydrogen reduces these emissions by employing carbon capture and storage (CCS) technologies. Green hydrogen, regarded as the cleanest option, is produced through the electrolysis of water using renewable energy sources such as solar and wind power. Emerging variants, like turquoise hydrogen from methane pyrolysis, are also attracting attention. Nevertheless, more than 95% of global hydrogen output still relies on grey hydrogen, highlighting the pressing need for cleaner alternatives [1][6].

Hydrogen's prominence significantly increased after the 2015 Paris Agreement, where countries committed to limiting the rise in global temperatures to well below 2°C compared to pre-industrial levels. As part of their climate strategies, many nations have set "Net Zero Emissions" goals for 2050 or later, identifying hydrogen as a crucial solution for decarbonizing sectors that are difficult to electrify, such as steel production, chemical manufacturing, and heavy transportation. Advanced economies, including Japan, Germany, Australia, South Korea, and the European Union, have introduced national hydrogen strategies backed by major investments, regulatory support, and international collaborations to foster a hydrogen-based economy [4].

Emerging economies encounter a dual challenge: meeting the increasing energy demands driven by rapid industrialization and urbanization, while simultaneously pursuing sustainable development to mitigate climate change impacts. For nations such as India, Brazil, and South Africa, hydrogen offers a transformative opportunity by enhancing energy security, decreasing dependency on imported fossil fuels, fostering technological advancement, and stimulating economic growth through green industries. However, building hydrogen infrastructure in these regions remains challenging due to high production costs, insufficient technological maturity, constrained financing options, policy uncertainties, and the necessity for extensive renewable energy integration [7].

This paper provides a detailed examination of the global and Indian hydrogen sectors, highlights the integration potential between hydrogen and renewable energy sources, investigates the principal challenges faced in establishing hydrogen infrastructure within emerging economies, and proposes strategic solutions to encourage the broader adoption of hydrogen technologies, with a particular focus on the Indian context.

II. CURRENT SCENARIO

A. Global Perspective

The global hydrogen economy is experiencing significant evolution, propelled by the urgent need for deep decarbonization, enhanced energy security, and advancements in industrial innovation. As reported by the International Energy Agency (IEA), global hydrogen demand reached nearly 94 million tonnes in 2021, with major applications in refining and ammonia production. Despite its growing importance, more than 95% of hydrogen continues to be produced from fossil fuels like natural gas and coal, leading to considerable carbon emissions [1].

Acknowledging hydrogen's potential as a clean energy solution, several countries have initiated bold national hydrogen strategies. Japan led this effort by introducing its Basic Hydrogen Strategy in 2017, aiming to establish the world's first hydrogen-based society. Subsequently, Germany and the European Union unveiled expansive plans under the European Green Deal, committing substantial financial resources towards research initiatives, pilot projects, and infrastructure expansion. Australia has also positioned itself as a prominent contender, capitalizing on its abundant renewable energy resources to become a leading green hydrogen exporter [4].

Although optimism surrounding hydrogen development is strong, considerable challenges remain. Green hydrogen—produced via electrolysis using renewable energy—continues to be costlier than grey hydrogen obtained from fossil fuels. Additionally, the infrastructure necessary for hydrogen transport, storage, and distribution is still in its infancy, demanding substantial investments and technological breakthroughs. Furthermore, international standards regarding hydrogen purity, safety, and trade are still under development.

Global investment trends display a mixture of optimism and caution. By 2023, announcements for hydrogen-related projects had surpassed USD 240 billion worldwide; however, most initiatives remain in the planning or feasibility phases. Only a limited number of projects have progressed to final investment decisions, underscoring the prevailing uncertainties and the critical need for robust policy frameworks [6].

The key global hydrogen statistics are summarized in TABLE I.

TABLE II: Global Hydrogen Economy Overview as of 2024

Aspect	Details
Total Hydrogen Demand	~94 million tonnes (IEA, 2021)
Dominant Production Method	>95% Grey Hydrogen (from fossil fuels)
Major Hydrogen Strategies	Japan (2017), Germany (2020), Australia, EU, USA
Total Announced Investments	~USD 240 billion (Global, 2024)
Share of Green Hydrogen Projects	<5% (mostly in early stages)
Key Challenges	High production cost, infrastructure gaps, policy uncertainty

If technological advancements, cost reductions, and regulatory frameworks align, hydrogen could supply up to 10–15% of global energy demand by 2050, playing a critical role in achieving net-zero targets.

B. Indian Perspective

As the world's third-largest energy consumer and a rapidly growing industrial economy, India has acknowledged the strategic role of hydrogen in its energy transition. In August 2021, the Government of India introduced the National Hydrogen Mission with the objective of positioning the country as a global leader in green hydrogen production and exports.

As part of this initiative, India aims to produce 5 million tonnes of green hydrogen annually by 2030, accompanied by a significant expansion of renewable energy capacity. The Mission supports India's broader climate commitments, notably its pledge to achieve net-zero emissions by 2070.

The In February 2022, the Government unveiled the **Green Hydrogen Policy**, introducing several critical measures to accelerate sector growth:

- Exemption from inter-state transmission charges for renewable energy utilized in green hydrogen production,
- Simplified land allocation processes within renewable energy parks for hydrogen projects,
- Open access to the electricity grid for renewable energy procurement,
- Priority grid connectivity for facilities producing green hydrogen and green ammonia,
- Incentives for electrolyzer manufacturing through Production Linked Incentive (PLI) schemes.

India's advantages include its vast renewable energy resources, featuring some of the world's lowest solar and wind energy costs, along with a robust industrial sector capable of integrating hydrogen into refining, fertilizer production, and steel manufacturing.

Nevertheless, several significant challenges persist. High capital costs associated with electrolyzers, inadequate hydrogen-specific infrastructure (such as pipelines and storage facilities), limited technological expertise, and inconsistencies in state-level policies could impede the transition. Additionally, ensuring sufficient water availability for large-scale electrolysis, particularly in water-scarce regions, remains a major concern.

Major Indian corporations such as Reliance Industries, Adani Group, NTPC Limited, and Indian Oil Corporation have already announced investments in green hydrogen initiatives, demonstrating substantial industry interest. Pilot projects, public-private partnerships, and international collaborations are anticipated to be instrumental in shaping India's hydrogen economy over the coming decade.

III. HYDROGEN AND RENEWABLE ENERGY INTEGRATION

Linking hydrogen production with renewable energy sources offers one of the most promising strategies for realizing a sustainable and decarbonized global energy system. Green hydrogen, generated through electrolysis driven by solar, wind, or hydropower, facilitates the storage of intermittent renewable energy, supports deep decarbonization across various sectors, and strengthens overall energy security [8].

Although renewable energy sources play a vital role in reducing carbon emissions, they are naturally intermittent and geographically dependent. Solar photovoltaic (PV) systems can only generate electricity during daylight hours, while wind turbines rely on the availability of wind. This variability presents challenges in maintaining a balance between electricity supply and demand. Converting excess renewable electricity into hydrogen via water electrolysis allows for long-term energy storage and long-distance transport, thereby mitigating the issues related to intermittency [9].

The typical process of producing hydrogen from renewable energy sources follows a series of steps, as outlined in Table II.

TABLE II: Renewable Energy to Hydrogen Production Process

Step	Description
1	Renewable electricity generation (solar, wind, hydro)
2	Electricity supplied to electrolysers
3	Water electrolysis producing hydrogen and oxygen
4	Hydrogen compression and storage
5	Hydrogen usage for transport, power generation, industry

A schematic representation of this process is shown in Fig.1.

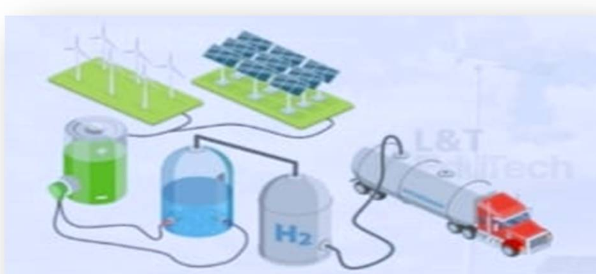

Fig. 1:Renewable Energy-based Hydrogen Production and Transportation Flow

The integration of hydrogen with renewable energy offers several critical advantages:

1) Decarbonization of Difficult-to-Electrify Sectors: Green hydrogen supports significant emissions reductions in industries such as steel production, fertilizer manufacturing, shipping, and aviation, where direct electrification remains difficult.
2) Energy Storage and Grid Reliability: Hydrogen serves as a large-scale, long-duration energy storage option, aiding in grid stabilization by absorbing surplus renewable electricity during periods of low demand.
3) Enhanced Energy Security and Diversification: Domestic hydrogen production using renewable sources decreases dependence on imported fossil fuels and bolsters national energy autonomy.
4) Industrial Growth and Employment Opportunities: The green hydrogen value chain—including the manufacturing of electrolyzers, storage systems, and hydrogen-based applications—generates new economic prospects and promotes job creation, especially in areas abundant with renewable resources.

Advancements in modern electrolyzer technologies are increasingly focused on optimizing the use of excess renewable electricity, thereby enhancing the cost-effectiveness of green hydrogen production. This concept is depicted in Fig. 2.

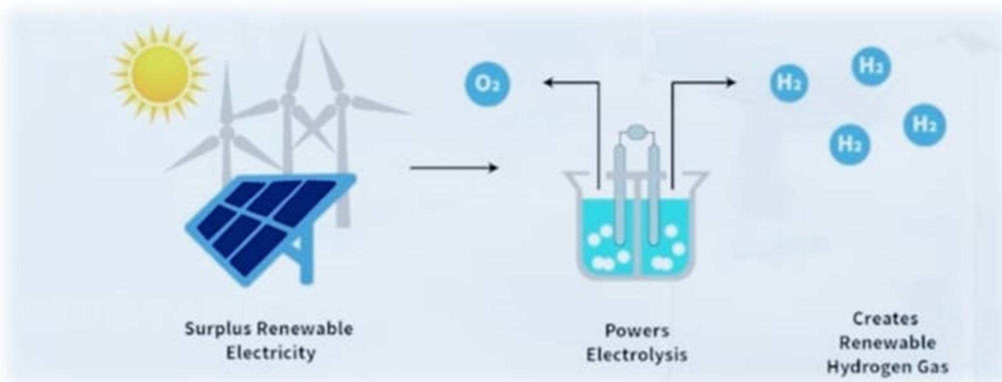

Fig. 2**:**Hydrogen Generation via Renewable-powered Electrolyzers

India possesses a distinct advantage in this area. With access to some of the world's largest solar parks, the development of offshore wind projects, and rapidly falling renewable energy costs, India is well-positioned to produce green hydrogen at competitive prices on a large scale.

Establishing electrolyzer facilities near renewable energy generation sites, such as solar or wind farms, can significantly reduce transmission losses and decrease production costs. Moreover, embedding green hydrogen into industrial hubs and transportation corridors can help build self-sustaining hydrogen ecosystems.

Achieving these opportunities requires meticulous strategic planning, involving investments in advanced electrolyzer technologies, the establishment of hydrogen storage and distribution infrastructure, and the development of comprehensive policies that align renewable energy expansion with hydrogen production goals.

IV. MAJOR CHALLENGES IN DEVELOPING HYDROGEN INFRASTRUCTURE IN EMERGING ECONOMIES

Although hydrogen holds immense potential for facilitating clean energy transitions, emerging economies encounter distinct and significant obstacles in building the required infrastructure. These challenges encompass technological, financial, regulatory, and socio-economic aspects, and must be methodically addressed to fully realize hydrogen’s advantages. The key challenges are outlined below:

A. *High Production Costs*

Green hydrogen production costs are still significantly higher than those of conventional grey hydrogen derived from natural gas. Factors such as the expense of electrolyzer technologies, integration with renewable electricity, water purification systems, and hydrogen compression collectively contribute to the elevated costs. In emerging economies, where financial limitations and affordability are pressing concerns, this cost disparity represents a substantial obstacle to expanding hydrogen infrastructure.

B. Limited Renewable Energy Integration

Despite having substantial solar and wind energy potential, many emerging economies struggle to integrate large-scale renewable projects into their national grids. Issues such as inadequate grid infrastructure, curtailment of renewable generation, and insufficient storage capabilities hinder the cost-effective production of green hydrogen. Enhancing renewable energy capacities and increasing grid flexibility are essential steps toward supporting green hydrogen development.

C. Infrastructure Deficiencies

The lack of specialized hydrogen pipelines, storage systems, refueling stations, and port infrastructure significantly impedes the creation of a robust hydrogen value chain. While adapting existing natural gas infrastructure for hydrogen use is technically feasible, it remains costly. In the absence of a reliable logistics and distribution network, hydrogen production centers are unable to efficiently serve industrial, transportation, and power sectors.

D. Water Resource Constraints

Producing green hydrogen at scale through electrolysis requires substantial amounts of purified water. In regions where water scarcity is already a pressing issue—common across many emerging economies—diverting water resources for hydrogen production could intensify social and environmental conflicts. Advancing water-efficient electrolysis technologies and integrating desalination-based systems will be essential to address this challenge.

E. Lack of Skilled Workforce and Technical Expertise

The deployment of hydrogen technologies—such as electrolyzer manufacturing, system integration, storage solutions, and safety management—demands specialized technical expertise. However, emerging economies frequently experience a shortage of personnel trained in hydrogen-related fields. Substantial investments in education, vocational training, and capacity-building initiatives are necessary to develop a competent domestic hydrogen workforce [5].

F. Policy Uncertainty and Regulatory Gaps

Unstable or incomplete policy frameworks often discourage private investment in hydrogen infrastructure. In several emerging economies, there is a notable absence of clear regulations concerning hydrogen safety standards, certification systems, carbon accounting, and trading mechanisms. Establishing stable and long-term governmental policies is critical to mitigating investor risks and enabling the large-scale development of hydrogen projects [5].

G. Financing and Investment Challenges

Developing comprehensive hydrogen ecosystems requires substantial initial investments across production, storage, transportation, and application sectors. Emerging economies frequently contend with higher financing costs, elevated country risk perceptions, and restricted access to green financing options. Innovative financial models, including public-private partnerships, international funding frameworks, and concessional financing, are vital to mobilizing capital on the required scale [6].

H. Public Awareness and Social Acceptance

Public awareness regarding hydrogen technologies remains limited in many emerging economies. Issues such as concerns over hydrogen's flammability, storage safety, and its environmental impact—particularly water consumption—could impede public acceptance. Conducting extensive awareness campaigns, engaging stakeholders, and ensuring transparent risk communication will be crucial to fostering trust and obtaining social approval for hydrogen initiatives.

V. INDIA'S SPECIFIC CHALLENGES AND OPPORTUNITIES FOR HYDROGEN INFRASTRUCTURE DEVELOPMENT

India, with its ambitious National Hydrogen Mission and abundant renewable energy resources, holds tremendous potential to emerge as a global green hydrogen hub. However, translating this vision into reality involves navigating a unique set of challenges and leveraging strategic opportunities.

Fig.3 provides an overview of the primary objectives outlined in India's National Hydrogen Policy.

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Fig. 3**:**National Hydrogen Policy Objectives in India
(*Boosting green hydrogen production to 5 MTPA by 2030, making India an export hub, and reducing greenhouse gas emissions.*)

The major challenges and opportunities are discussed below:

A. High Electrolyzer and Infrastructure Costs

At present, India relies substantially on imported electrolyzer technologies, driving up the overall cost of hydrogen projects. Expanding domestic manufacturing capabilities through initiatives such as "Make in India" is essential to enhance cost competitiveness. Additionally, the National Hydrogen Policy introduces substantial investment incentives aimed at promoting indigenous electrolyzer production.
Projected investments and capacities are highlighted in Fig.5 later in this section.

B. Water Resource Management

Producing green hydrogen via electrolysis requires considerable water resources, creating challenges in India's water-scarce regions. Potential solutions involve adopting renewable-powered desalination technologies, improving the water-use efficiency of electrolyzers, and implementing systems to recycle industrial wastewater.

C. Infrastructure Deficiencies

Efficient hydrogen transportation poses a major challenge across India's expansive geography. As illustrated in Fig.4, both pipeline and road-based transport methods face limitations in scalability and cost-effectiveness.

Fig. 4**:**Hydrogen Transportation Challenges in India
(India is too large for piped or road-based green hydrogen transport; alternative approaches needed.)

Transportation expenses account for approximately **25–30%** of the total cost of green hydrogen in India. Consequently, innovative alternatives, including ammonia-based hydrogen carriers, liquid organic hydrogen carriers (LOHCs), and the development of localized hydrogen clusters, must be pursued.

D. Policy Implementation and Regulatory Clarity

The National Hydrogen Policy proposes a three-pronged strategy focusing on power transmission enhancements, ease of doing business initiatives, and demand-side measures. Nevertheless, detailed secondary regulations concerning hydrogen blending, safety standards, and trading mechanisms are urgently required to establish a predictable regulatory environment and encourage private sector investment.

E. Financing Mechanisms and Risk Mitigation

Considering the high capital requirements of hydrogen projects, India needs to develop blended financing models. Mechanisms such as sovereign green bonds, viability gap funding programs, and partnerships with international climate finance organizations can help reduce investment risks. The Government of India has outlined plans to support hydrogen infrastructure development with an investment target of approximately **8 lakh crore INR (around USD 100 billion)** [2].

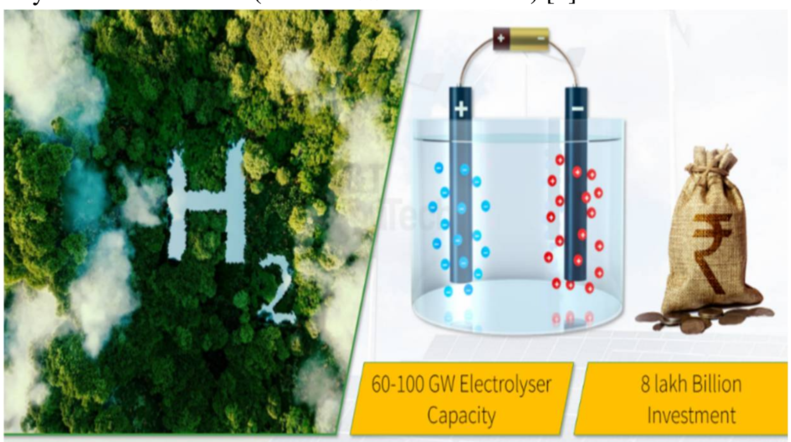

Fig. 5:Projected Electrolyzer Capacity and Investments for Hydrogen Development in India
(60–100 GW electrolyzer capacity and 8 lakh crore investment by 2030.)

F. Development of Hydrogen Ecosystems and Clusters

Establishing integrated hydrogen hubs—including production units, storage facilities, pipelines, and refueling stations—in strategic regions such as Gujarat, Maharashtra, and Tamil Nadu can foster economies of scale. Offering targeted incentives for cluster development would further expedite progress.

G. International Collaborations and Export Markets

With its competitive green hydrogen production costs, India is well-positioned to become a significant exporter to markets such as Europe, Japan, and South Korea. Strategic collaborations with nations like Germany, Australia, and the UAE are already advancing efforts to establish green hydrogen supply chains [7].

H. Public Awareness, Workforce Training, and Innovation Support

India's hydrogen economy is projected to generate **over 600,000 new jobs by 2030**, covering sectors such as manufacturing, research and development, project management, and services. Developing Centres of Excellence for Hydrogen Technologies and implementing technical training programs will be vital for building a skilled workforce [2].

Moreover, successful large-scale hydrogen deployment could result in an annual reduction of approximately 50 million metric tonnes (MMT) of CO_2 emissions, contributing significantly towards India's net-zero commitments.[2]

VI. FUTURE ROADMAP AND RECOMMENDATIONS

Building a sustainable hydrogen infrastructure in emerging economies such as India demands a carefully structured, phased strategy. Successfully advancing this effort requires addressing technical, financial, environmental, and social challenges concurrently. Based on the identified gaps, a detailed roadmap is proposed below.
A graphical representation of the strategic priority areas is shown in Fig.6.

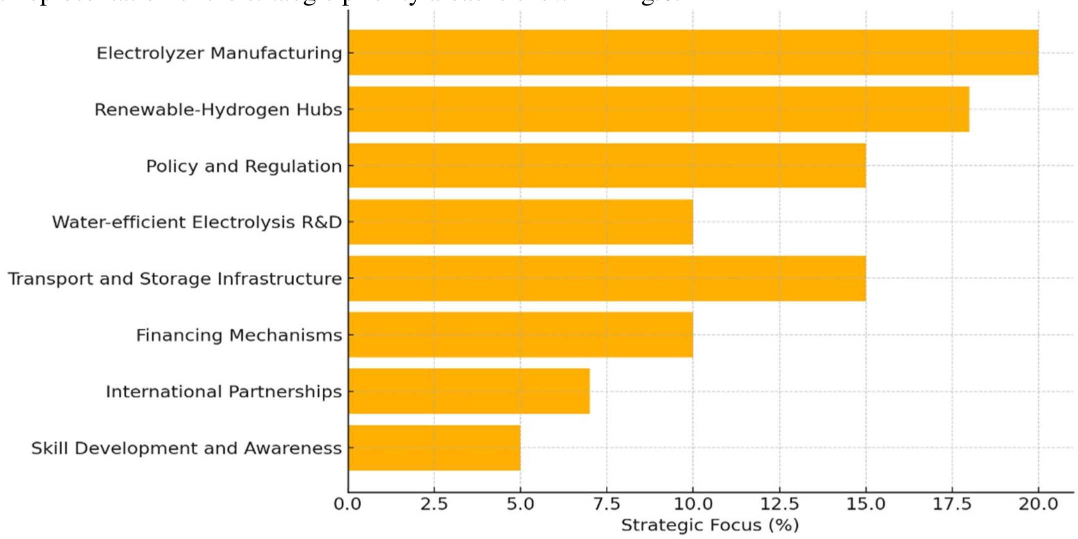

Fig. 6**:**Strategic Priority Areas for Future Hydrogen Infrastructure Development

A. *Establishing Large-Scale Domestic Electrolyzer Manufacturing Ecosystem*

India needs to establish a comprehensive manufacturing ecosystem for high-efficiency electrolyzers, encompassing gigafactories, component suppliers, and research and development facilities. Expanding initiatives like the Production Linked Incentive (PLI) scheme specifically for electrolyzer technologies would support this goal. Developing localized manufacturing capabilities will reduce reliance on imports, lower production costs, and allow technology customization suited to Indian conditions, thereby strengthening the hydrogen value chain.

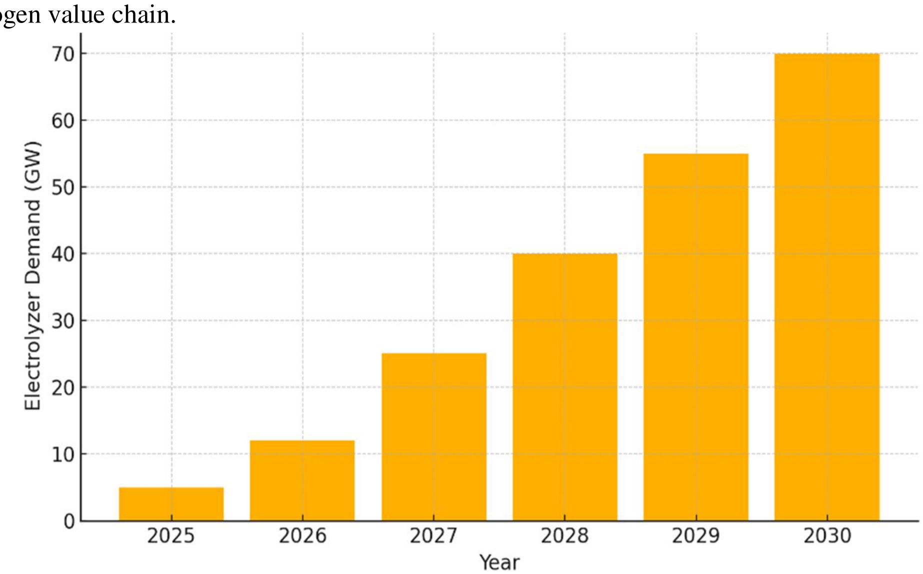

Fig. 7**:**Projected Electrolyzer Demand in India (2025–2030)

B. *Development of Integrated Renewable Energy–Hydrogen Hubs*

Hydrogen hubs should be strategically located near renewable energy generation centers, such as solar parks in Rajasthan and wind corridors in Gujarat and Tamil Nadu.

These hubs should integrate hydrogen production facilities, renewable energy plants, storage infrastructure, refueling stations, and industrial consumers. Developing such hydrogen clusters would optimize energy use, minimize transmission losses, improve cost-efficiency, and facilitate the large-scale adoption of hydrogen technologies.

TABLE III: Potential Hydrogen Hub Locations in India

States in India	Key Advantage
Rajasthan	High solar irradiation; proximity to industrial hubs
Gujarat	Strong solar and wind resources; major ports for export
Tamil Nadu	Leading wind energy producer; industrial cluster presence
Maharashtra	Strong industrial base; policy support for green hydrogen
Karnataka	Renewable energy potential; tech-driven industrial ecosystem
Andhra Pradesh	Emerging renewable investments; coastal advantage

C. Policy Deepening and Standardization

In addition to the National Hydrogen Policy, India should develop comprehensive secondary regulations addressing certification processes for green hydrogen, blending standards for hydrogen-natural gas pipelines, safety protocols, and carbon accounting systems. Establishing standardized frameworks will help reduce investment risks, ease regulatory compliance, and foster innovation and competition throughout the hydrogen sector.

D. Accelerated Research in Water-Efficient Electrolysis Technologies

Considering India's susceptibility to water scarcity, the next generation of electrolysis technologies must emphasize water conservation. Investment should focus on advancing seawater electrolysis, membrane-less electrolyzers, and hybrid systems combining desalination and electrolysis. Deploying renewable-powered desalination alongside hydrogen production in coastal regions could greatly expand green hydrogen output while preserving freshwater resources.

Different electrolysis methods vary significantly in their water consumption patterns, as illustrated in Fig.8.

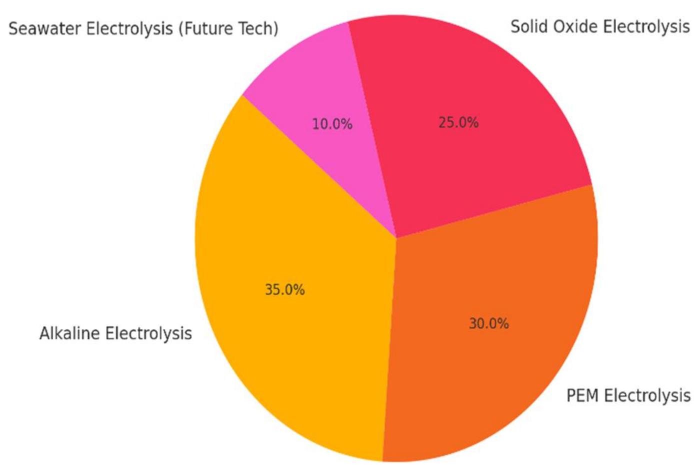

Fig. 8**:**Water Consumption Comparison Across Electrolysis Technologies

1) Alkaline electrolysis uses the most water (~35%),
2) Followed by PEM (~30%), Solid Oxide (~25%),
3) Seawater electrolysis (future technology) promises lowest freshwater consumption (~10%).

By promoting technologies like seawater electrolysis, India can expand hydrogen production sustainably without aggravating freshwater resource challenges.

E. Development of Hydrogen Transportation and Storage Infrastructure

Currently, transportation expenses contribute approximately 25–30% of the overall delivered cost of green hydrogen in India. To address this, it is essential to develop dedicated hydrogen pipelines, compressed gas trailers, ammonia-based transportation systems, and liquid organic hydrogen carriers (LOHCs). Upgrading existing natural gas pipelines to accommodate hydrogen blends and establishing regional storage facilities would significantly enhance hydrogen availability and affordability nationwide.

Table IV: Overview of Hydrogen Transportation Methods

Transport Method	Cost Level	Main Advantage
Pipelines	Medium-High	Low operating cost at scale
Compressed Gas Trucks	High	Flexibility for short distances
Ammonia as Carrier	Medium	Suitable for long-distance export
LOHC (Liquid Organic Hydrogen Carrier)	Medium	Safer handling compared to gas or liquid

A combination of pipelines for regional transport and ammonia-based carriers for international supply could provide India with a flexible, scalable hydrogen distribution network.

F. Financing Innovation and Risk-Sharing Mechanisms

Large-scale hydrogen projects require substantial capital investments and are associated with significant market risks. India must promote innovative financing models such as green bonds, viability gap funding (VGF) programs, blended finance platforms, and risk insurance mechanisms. Reducing the cost of capital through public-private partnerships and concessional lending arrangements will be crucial in encouraging private sector involvement and accelerating project deployment.

G. Strategic International Partnerships

India should proactively seek technology transfer partnerships, joint development programs, and long-term green hydrogen offtake agreements with major hydrogen economies such as Germany, Australia, Japan, and South Korea. Strengthening export competitiveness through bilateral collaborations and active participation in global hydrogen alliances will help position India as a leading supplier in the emerging international hydrogen market.

H. Innovation, Workforce Development, and Public Awareness

Developing a technically proficient workforce is fundamental to the success of India's hydrogen economy. Establishing Centers of Excellence for hydrogen research and implementing skill development initiatives for engineers, technicians, and safety professionals are essential steps. Furthermore, launching nationwide awareness campaigns to educate industries and the general public about hydrogen safety, environmental advantages, and applications will be crucial in fostering widespread acceptance.

According to government estimates, successful hydrogen economy development could create over 600,000 new jobs and reduce 50 million metric tonnes (MMT) of carbon dioxide emissions annually by 2030, contributing significantly to India's sustainable development goals.

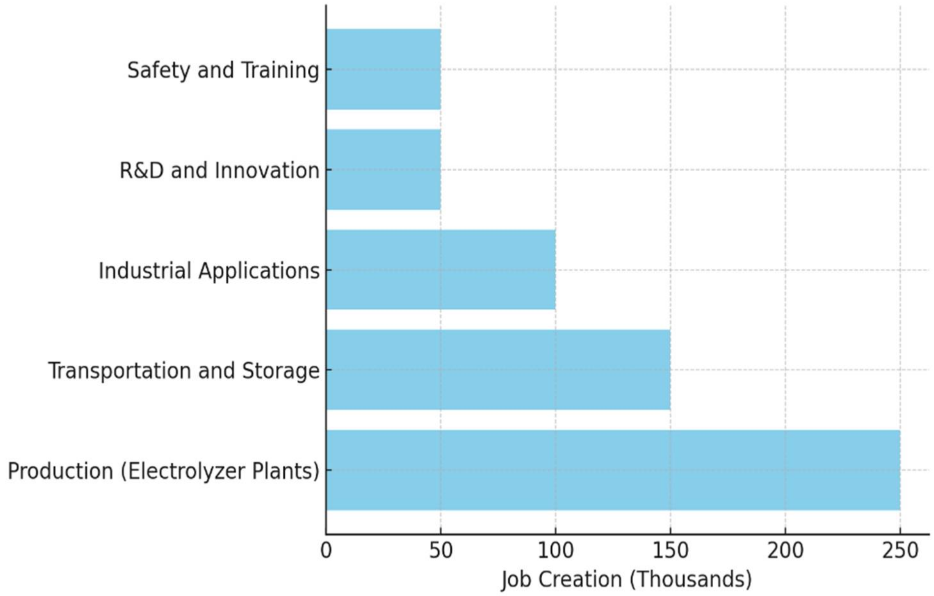

Fig. 9**:**Expected Job Creation by Sector in India's Hydrogen Economy (by 2030)

1) Production (Electrolyzer Plants) will create the most jobs (~250,000)
2) Followed by Transportation and Storage (~150,000),
3) And others like Industrial Applications, R&D, and Safety Training.
4) Focusing on workforce development and public acceptance will ensure a socially inclusive and sustainable hydrogen economy in India.

VII. CONCLUSION

Building a sustainable hydrogen infrastructure is essential for emerging economies striving to achieve deep decarbonization, strengthen energy security, and enhance industrial competitiveness. Green hydrogen, particularly when coupled with abundant renewable energy resources, provides a transformative solution to simultaneously drive economic growth and mitigate climate change impacts.

This study examined the global and Indian hydrogen sectors, emphasized the opportunities for integration with renewable energy sources, and identified key technological, infrastructural, financial, and policy-related challenges confronting emerging economies. It also provided a detailed assessment of India's specific issues, including high electrolyzer costs, water scarcity, infrastructure gaps, and regulatory uncertainties.Alongside these challenges, the paper discussed strategic opportunities such as expanding domestic manufacturing, tapping into hydrogen export markets, and advancing workforce development. The proposed roadmap advocates for a coordinated strategy encompassing the expansion of electrolyzer production, creation of integrated hydrogen hubs, enhancement of regulatory structures, promotion of water-efficient technologies, development of transportation and storage networks, introduction of innovative financing solutions, and strengthening of international partnerships.Additionally, raising public awareness, fostering skill development, and encouraging indigenous innovation will be crucial for maintaining long-term progress. Through decisive action, targeted investments, and collaborative international efforts, India and other emerging economies have the potential to build a resilient hydrogen economy and establish themselves as global leaders in the sustainable energy transition.

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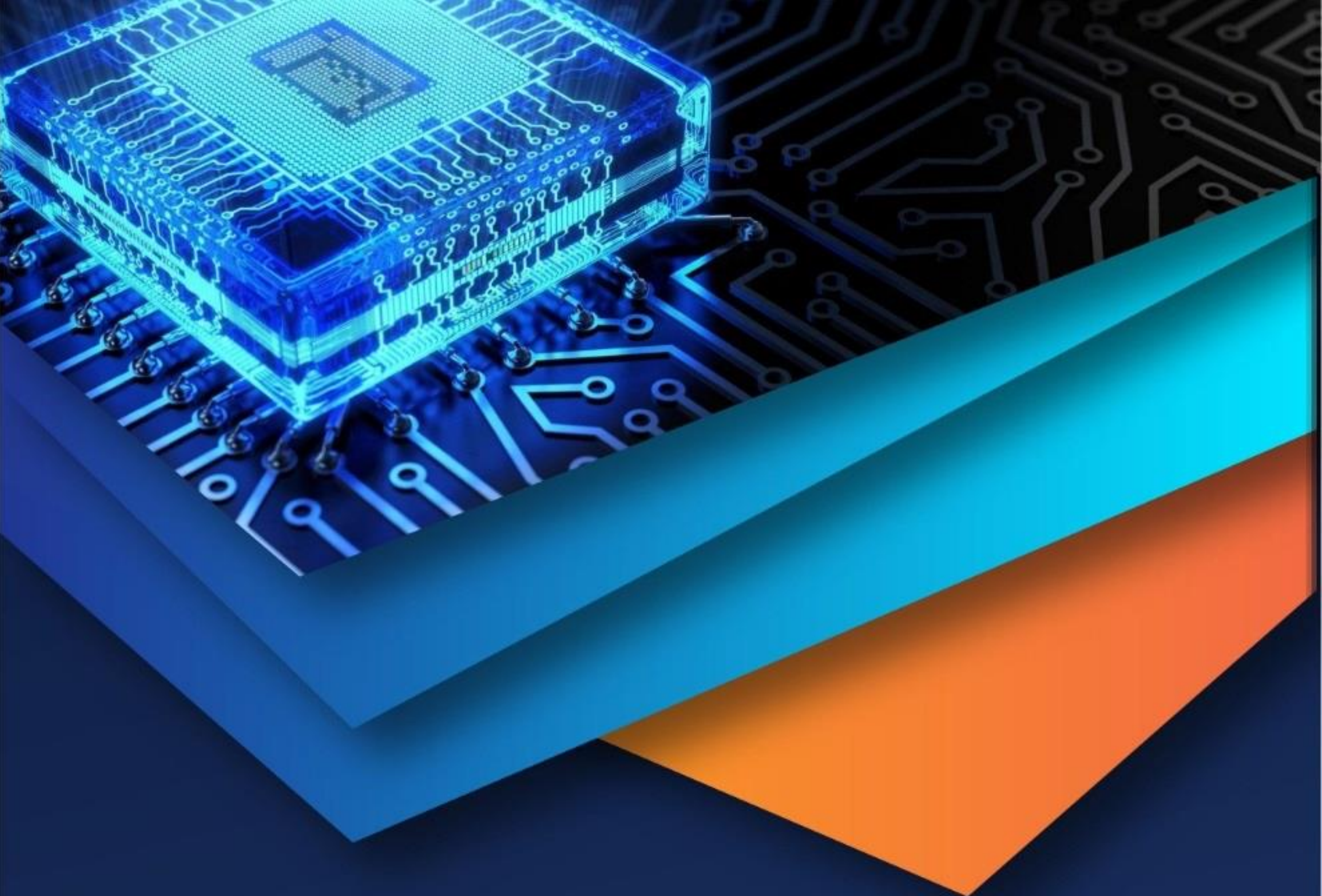

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