Hybrid Renewable Energy System Featuring Pem Green Hydrogen In Regions With High Solar And Wind Density

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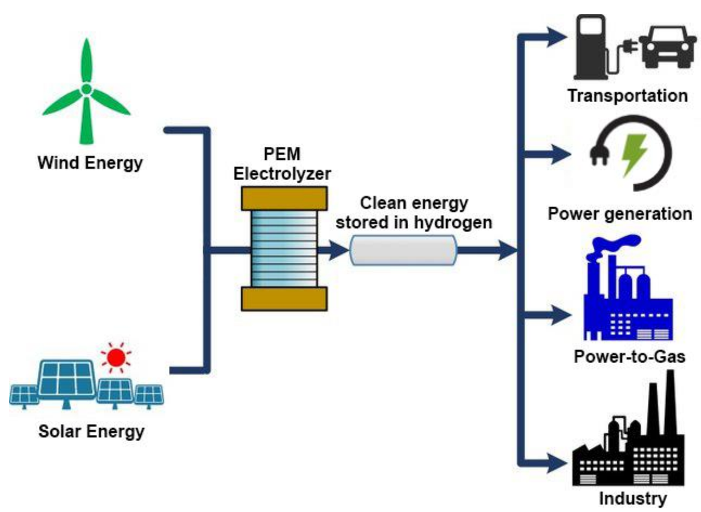
Key Messages

- Green hydrogen enables the imminent future of clean and sustainable energy in developing nations thanks to advances in technologies, expansion in solar and wind power, and its low carbon footprint.
- Cost efficiency plays a crucial role in facilitating the widespread adoption of green hydrogen on large scales.
- The successful implementation of pilot projects would lay the foundation for the production, storage, and utilization of green hydrogen.
- The green hydrogen development path should initiate with the chemical feedstock industry, followed by heavy-duty and long-range transportation, and ultimately in the power sector.
- For developing nations, the roadmap starts with an initial focus on grey (blue) hydrogen, with the goal of evolving into hydrogen export hubs by the late 2030s. This transformation will be supported by a three-phase policy framework aimed at enhancing the competitiveness of green hydrogen. The role of international collaboration, facilitated by the UN and developed countries, is crucial.

Our continued dependence on finite fossil fuels, including coal, oil, and natural gas, not only exhausts these limited natural resources but also emits substantial greenhouse gases (GHG), exacerbating global warming. The relentless progression of climate change, primarily driven by extensive fossil fuel combustion, emphasizes the urgent need for a transition to renewable energy source worldwide, including in developing countries. However, the intermittent nature of renewables, particularly solar and wind energy, presents significant challenges to global power grid stability and reliability, resulting in fluctuations in energy generation. This inconsistency necessitates effective energy storage solutions to ensure a consistent power supply and optimize the seamless integration of renewables into the energy mix. Green hydrogen technology, particularly employing Proton Exchange Membrane (PEM) fuel cells, emerges as a viable solution to address these challenges, even in developing nations.

Green hydrogen, produced using renewable sources, can be efficiently stored and converted back into electricity when needed using PEM fuel cells, which operate in reverse during electrolysis, splitting water into oxygen and hydrogen[2]. This dual functionality offers a solution to the critical challenge of intermittent energy supply. Beyond their primary role in converting hydrogen into electricity for power generation[3], green hydrogen fuel cells provide versatile storage solutions with a wide range of applications[1]. For example, in transportation[4], green hydrogen fuel cells can power buses, trucks, and even trains, offering extended ranges and faster refueling compared to traditional batteries. In the industrial sector, they offer backup or off-grid power solutions[5], and their use in remote or isolated communities[6] highlights their potential in regions facing challenges in energy importation. The purpose of this brief is to outline recommendations for effectively integrating and expanding PEM green hydrogen technology in regions with high potential for solar and wind energy, focusing on sustainable energy development in developing countries.

Figure 1.



Data source: modified from Yodwong et al. (2020)[1]

Opportunities

Green hydrogen is emerging as a promising option in the global energy transition towards achieving net-zero carbon emissions by 2050. The demand for hydrogen worldwide has already seen a 50% increase since 2000[7]. Simultaneously, energy consumption in emerging markets and developing countries is expected to rise by 50% by 2050, with 750 million people lacking access to electricity and 1.5 billion relying on coal and oil for cooking[7], indicating significant potential markets for green hydrogen.

The global expansion of renewable energy capacity and the increasing prevalence of countries adopting high shares of variable renewables in their electricity systems are promising trends. As of 2023, the combined wind and solar energy capacity worldwide exceeds 1,397 MW, distributed across numerous wind farms and solar plants, with a prospective capacity of 3,724 GW[8]. Moreover, essential infrastructure for hydrogen production and storage has been established, including 1.2 million kilometers of pipelines and a total LNG capacity of 4.4 billion tons by 2023. These developments are crucial for enabling the realization of green hydrogen production and utilization[9].

By the end of 2021, nearly all nations worldwide implemented policies to promote renewable energy and hydrogen, with 26 countries having fully developed hydrogen strategies and an additional 22 in various stages of preparation[10,11]. Emerging economies like India and Namibia have set ambitious goals for green hydrogen production, with India targeting 5 million tons by 2030, potentially reaching 10 million tons annually, and Namibia aiming for 1-2 million tons by 2030 and 10-15 million tons by 2050[12]. These policies and goals play a fundamental role in shaping strategies and frameworks for green hydrogen production and utilization.

One of the key advantages of green hydrogen and power conversion systems, which rely on solar and wind energy, is their significantly low carbon footprint[12,13]. Green hydrogen-based gas turbines or fuel cells generate emissions consisting solely of water vapor and warm air[14]. This environmental friendliness positions green hydrogen as a crucial player in the global shift towards sustainable and clean energy sources.

Challenges

Firstly, hydrogen, the central output of this process, presents significant safety concerns due to its high flammability, low ignition energy, and rapid combustion, compounded by its colorless and odorless nature, which have led to incidents involving liquid hydrogen resulting in fires and explosions[15]. To bolster safety in large-scale green hydrogen production, a comprehensive and standardized risk assessment methodology is imperative. This approach should specifically address the hazards associated with the coexistence of oxygen and hydrogen, while considering hydrogen's unique properties, intricate electrolysis systems, modular facility designs, operational variability linked to renewable energy dependence, emerging technologies, and insights from past accidents[16].

Green hydrogen production, additionally, faces significant efficiency hurdles, especially through energy conversion and power storage. The process of converting renewable electricity to hydrogen and then back to electricity for power generation (a round-trip efficiency) ranges only between 18%-46%[17]. Increasing the efficiency of green hydrogen production hinges on technological advancements, notably in developing advanced electrolysis technologies to optimize material use and processes, thereby boosting hydrogen output with less energy[18]. Additionally, enhancing catalyst efficiency to accelerate the electrolysis process, and implementing heat integration and recovery systems are key strategies for reducing energy consumption and improving hydrogen yield[19].

Furthermore, the challenge of preparing a proficient workforce is a significant concern[7]. The hydrogen industry is currently hindered by slow technical learning progress and a shortage of crucial skills, leading to a deficiency in specialized labor required for its growth[20]. In developed nations, the United States and Europe lead in providing extensive higher education programs and industry resources in hydrogen technology, while Australia faces a substantial gap in hydrogen training across educational levels, relying heavily original equipment manufacturers for training and guidance[21,22]. To address these challenges, several initiatives are recommended, including: incorporating hydrogen content into existing training programs, collaborating with industry experts and universities to develop relevant courses, fostering inter-business collaboration, investing in reskilling and certification, providing upskilling opportunities, establishing effective train-the-trainer programs, and encouraging schools to prepare young individuals for diverse roles within the hydrogen supply chain[22].

Finally, the financial aspects associated with green hydrogen production are formidable, primarily due to the intricate nature of scaling up with PEM electrolyzers, which involve high capital costs and reliance on expensive materials such as platinum, iridium oxide, and gold or platinum-coated titanium[23]. Additionally, even in 2050, green hydrogen production still carries a substantial financial burden, with renewable energy sources accounting for 30% to 40% of total costs, electrolyzers adding another 10% to 20%, and financing costs of approximately 30%, thereby intensifying the challenge of achieving competitive levelized costs in the market[24,25]. Currently, green hydrogen production costs are roughly twice as high as those of conventional gray hydrogen. However, it is projected that, due to decreasing costs of renewable energy and the use of more economical materials, the cost of green hydrogen produced through PEM technology is expected to equal that of gray hydrogen by 2030, estimated at around US$1.60 per kilogram, and potentially reduce further to approximately US$1.00 per kilogram by 2050[26].

Successful Case Study

The Orkney Islands, a collection of 20 populated islands with an estimated population of 21,000, are recognized as a renewable energy center with a total capacity of approximately 66 MW. The actual production of renewable energy in the Orkneys falls short of what could potentially be generated, often surpassing the local demand. Consequently, this leads to the exportation of excess electricity to the mainland of Scotland via subsea cables, mainly in summer when the local demand decreases. Since 2013, the Orkneys have consistently exported more electricity than they have used, signifying their role in the field of renewable energy. The BIG HIT project, therefore, was initiated to efficiently utilize the Orkney Islands' abundant renewable energy by converting excess renewable power into green hydrogen.

The BIG HIT project[27], launched in 2016 in Scotland's Orkney Islands, is a groundbreaking five-year initiative to create a model hydrogen economy. Funded by the FCH2JU, it involves 12 partners from six EU countries and aims to generate green hydrogen from wind, tidal, and solar energy. Orkney, with its abundant renewable energy and limited grid capacity, faces energy curtailment issues. BIG HIT seeks to resolve this by producing hydrogen using excess energy from community-owned wind turbines on Shapinsay and Eday, and tidal energy from EMEC sites. A 1.5 MW proton-exchange membrane electrolyzer is used to produce 50 tons of hydrogen annually, which powers local schools' heating systems, a 75-kW fuel cell unit in Kirkwall for harbor and ferries, and a refueling station for fuel cell vans. This initiative has reduced the need to curtail wind turbine operations, which previously lost over 30% of potential annual output[27].

The BIG HIT project has significant environmental, social, and economic impacts. It has created jobs, fostered the transition to renewable energy, and addressed public concerns about hydrogen safety without major negative social impacts[27]. Environmentally, the project substantially reduces GHG, with potential CO_2 emission reductions of 58% in electricity generation, 83% in heating, and 48% in mobility, compared to traditional energy solutions[28]. The project's business model also emphasizes the importance of maximizing electrolyzer operation time and selecting suitable Power Purchase Agreements (PPAs) to make renewable hydrogen economically viable, which are crucial in lowering hydrogen production costs[29].

Figure 2.

Data source: Source: Zhao & Nielsen (2018)[27]

Outlook

The vision for green hydrogen's evolution, considering the increasing rates of solar and wind energy, rising hydrogen demand, technological progress, and developing countries' existing infrastructure status:

Phase 2023-2030: with solar and wind energy already constituting 12% of the world's power and expected to reach one-third of global electricity production by 2030[12], surplus renewable energy will be harnessed for green hydrogen production. This phase sees green hydrogen being increasingly used in feedstock industries like refineries and steel manufacturing[30], sectors crucial for developing economies.

Phase 2030-2040: the phase will witness the complete phasing out of grey hydrogen from the global hydrogen market, along with the continuous growth of green hydrogen. Solar and wind-based hydrogen will extend its reach into the transportation sector, particularly in heavy-duty and long-range vehicles. Developing nations endowed with abundant renewables may emerge as pivotal hydrogen export hubs[31].

Phase 2040-2050: renewable energy, expected to account for 90% of the world's power, will see solar and wind-based hydrogen leading the market[12]. This phase is particularly pertinent for developing countries, as it promises enhanced energy accessibility in remote areas, including off-grid electricity generation, which is vital for regions with limited infrastructure.

Conclusion

PEM green hydrogen technology is key to a low-carbon future and has the unique potential to harness abundant solar and wind resources in developing countries. While currently facing challenges in investment costs, safety, efficiency, and skilled workforce, addressing these issues is crucial for its significant role in various sectors like industry, transportation, and power. PEM green hydrogen technology is especially suited for developing countries, as it can efficiently utilize their often untapped solar and wind potentials. This not only fosters economic growth but also aligns with the UN's SDGs - SDG 7 for affordable and clean energy, SDG 11 for sustainable cities and communities, and SDG 13 for climate action. Importantly, the technology contributes to a 'just' climate transition, ensuring that advancements in green energy do not leave behind developing regions, thus supporting global efforts towards equitable and sustainable development.

Policy Recommendations

1. **Developing a comprehensive hydrogen industry roadmap and strategy aimed at ensuring investment certainty for all involved stakeholders**
   - Establishing a roadmap that begins with grey (or blue) hydrogen and transitions to green hydrogen sources, leveraging existing pipelines for safe and cost-effective blending[31].
   - Formulate a comprehensive strategic plan that delineates specific, attainable objectives for hydrogen production, application, and the advancement of necessary infrastructure, ensuring a cohesive approach for hydrogen deployment across diverse industry sectors.
   - Foster stakeholder collaboration by actively engaging governments, businesses, industry experts, academic institutions, and local communities, to create a comprehensive and inclusive approach to hydrogen development.
2. **Implementing strong policies that directly impact the competitiveness of hydrogen**
   - ***Phase 2023-2030 (policies focus on intiating investments in infrastructure, pilot projects, safety rules)***
     - Craft policies that entice private investment and bolster renewable energy projects through mechanisms like PPAs, tariff systems, and funding that reward energy input, thus fast-tracking the growth of essential infrastructure and the share of solar and wind in the energy sector[32]. In this phase, pilot projects play a crucial role in testing and demonstrating the viability of green hydrogen production.
     - Encourage policies that support green hydrogen production from renewable sources by introducing tax incentives and subsidies[31,33], as well as investment in research and development so as to improve efficiency, cut costs, and foster innovation.
     - Strengthen regulations to ensure safety and environmental sustainability.
   - ***Phase 2030-2040 (policies focus on strengthening sector integration, scaling up projects, exporting hydrogen)***
     - Expand the scope of policies to include broader sectors like transportation, and power generation.
     - Establish regulatory frameworks that favor green hydrogen, mandating its use in certain sectors, setting minimum usage targets, or creating favorable conditions for renewable energy sources that feed into hydrogen production[30] .
     - Enhance public-private partnerships to scale up hydrogen projects.
     - Strategically implement policies that promote the export of hydrogen.
   - ***Phase 2040-2050 (policies focus on maturity and global integration)***

  - Create a mature hydrogen market by introducing competitive pricing in electricity markets and for power grid support services and storage, in order to generate new income sources for hydrogen supply chains, thus promoting their feasibility and sustainability[31,34].
  - Continuously update and refine policies based on technological advancements and market feedback.

3. Boosting green hydrogen production in developing countries through international collaboration

- Enable technology transfer and capacity building, sharing knowledge and expertise in green hydrogen production:
  - The UN, particularly through UNIDO, could support developing countries in the green hydrogen sector by providing policy guidance, developing regulations, codes, and standards to track and define low-carbon hydrogen production, and facilitating international dialogues to align environmental regulations and analyze the impact of carbon pricing[35].
  - Developed countries could contribute to technology transfer by sharing advanced green hydrogen technologies and expertise, helping in identifying appropriate technologies for replication so as to bridge the technological gap with developing nations.
- Facilitate international investment and funding, drawing resources from global partners to support green hydrogen projects in developing regions:
  - The UN could significantly enhance the green hydrogen sector in developing countries by setting up public-private partnerships and utilizing its extensive global networks to attract investors, acting as mediators for technology transfer agreements, ensuring fair and sustainable deals between developed and developing nations.

Developed nations can enhance green hydrogen projects in developing areas by offering direct financial support and establishing bilateral or multilateral funds dedicated to green hydrogen initiatives, encourge private sector investment through risk-sharing mechanisms.

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Annex

Annex 1. List of Experts Consulted

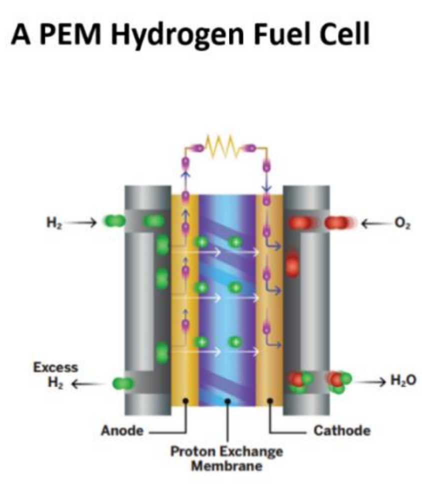
Full name	Title	Affiliation
Nadhilah Shani	ACE Senior Research Analyst	ASEAN Centre for Energy (ACE)
Darius Do	Project Manager	Indefol Solar
Duy Pham	Chief of Credit Acceptance – Corporate Banking	A Bangkok based bank

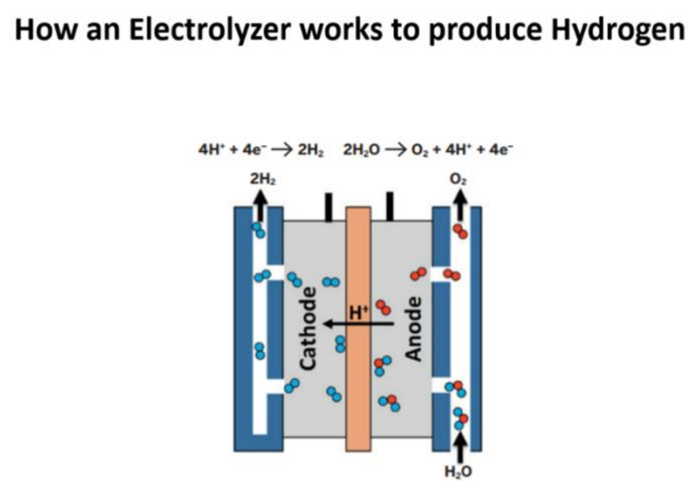
Annex 2. Overview of Hydrogen Production Technologies

Hydrogen production can be categorized into three types, commonly referred to by color codes: gray, blue, and green. *Gray hydrogen*, the most prevalent form, is produced using natural gas or coal as the feedstock. This feedstock undergoes a reaction with steam at high temperatures and pressures, resulting in the formation of synthesis gas, primarily composed of hydrogen and carbon monoxide. In contrast, *blue hydrogen* follows the same production process as gray hydrogen but incorporates carbon-capture technology to trap up to 90% of the GHG, thereby reducing its environmental impact. *Green hydrogen* is distinctively produced using renewable energy sources to power the electrolysis process, which separates water molecules into hydrogen and oxygen. The use of renewable energy sources is what renders this hydrogen production method “green.”

There are three primary electrolysis technologies, each at a different stage of development. *Alkaline water* (ALK) electrolysis is the most basic and established, commanding about 70% of the green hydrogen market share. It is favored for its low cost and long operational life. However, ALK electrolysis requires continuous operation to avoid damaging the equipment, making it unsuitable for power solely by intermittent renewable energy sources. *Proton Exchange Membrane* (PEM) electrolysis, which holds about 30% of the market share, is increasingly preferred by leading electrolyzer manufacturers. PEM electrolysis produces higher-quality hydrogen and can operate intermittently, aligning better with renewable energy sources, though it is costlier and has lower production rates than ALK. Lastly, *solid oxide* electrolyzer cell technology, still in the research and development phase, promises high efficiency at a lower cost but faces challenges like lengthy startup times and shorter component lifespans.

Green hydrogen, produced through renewable-powered electrolysis, emerges as a clean energy source with the advantage of long-term storage and transportability over significant distances. This type of hydrogen is poised to play a significant role in various sectors, including heating, transportation, power generation, chemicals, and primary steel manufacturing.





Data source: modified from Clean Energy Group (2022)[36]