

Going Green: An Evolution, not a Revolution

The quest for sustainable energy and alternative low-carbon fuel sources persists as the global community pushes towards decarbonization, recognizing the pivotal role of energy consumption in greenhouse gas (GHG) emissions worldwide. Nations worldwide are committing to carbon neutrality and achieving net zero emissions, necessitating substantial shifts in our energy consumption patterns. One of the most impactful strategies in this endeavor involves

electrifying various sectors while simultaneously reducing carbon emissions from the power generation process. However, certain industries present unique challenges, making electrification alone insufficient for decarbonization. These hard-to-abate sectors include long-haul transportation (such as trucking, shipping, and aviation) as well as heavy industries like steel and cement production. Additionally, the transition to electrification demands a parallel effort to decarbonize the power sector itself. In this landscape,

hydrogen emerges as a promising solution for decarbonizing these challenging sectors and those resistant to electrification. Renewable energy-driven green hydrogen stands out as a sustainable and eco-friendly alternative. Unlike gray hydrogen derived from fossil fuels, the production of green hydrogen involves water decomposition using renewable electricity, resulting in zero carbon dioxide emissions and negligible pollutants. Embracing green hydrogen technology is imperative for advancing environmental sustainability and curbing carbon emissions, signaling a significant stride towards a cleaner, more sustainable future.





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ONE OF THE MOST IMPACTFUL STRATEGIES IN THIS ENDEAVOR INVOLVES ELECTRIFYING VARIOUS SECTORS WHILE SIMULTANEOUSLY REDUCING CARBON EMISSIONS FROM THE POWER GENERATION PROCESS.



While green hydrogen presents a plethora of benefits, its optimization requires concerted efforts in enhancing production, storage, transportation, and utilization technologies. Additionally, factors such as production costs and infrastructure development warrant careful consideration to fully exploit its potential. Nonetheless, the widespread recognition of green hydrogen as a sustainable and clean energy solution underscores the current emphasis on advancing related technologies.

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Green Hydrogen Production by 2050:

Despite its complexity, various organizations and research institutions have developed models to estimate the production of green hydrogen in major countries worldwide from 2020 to 2050. These models incorporate factors such as policy support, technological advancements, market dynamics, and the accessibility of renewable energy. [1].

- **Europe:** The European Union aims to achieve 40 GW of green hydrogen production by 2030, alongside generating 10 million tonnes of renewable hydrogen within the same timeframe. Projections from the Hydrogen Council suggest Europe could annually produce up to 800 TWh of hydrogen by 2050, potentially constituting a market worth EUR 630 billion annually.
- **China:** With a focus on green hydrogen derived from renewable sources, China targets an annual production of 5 million tonnes by 2025. The International Energy Agency (IEA) forecasts that China

could produce up to 60 million tonnes of hydrogen yearly by 2050, translating to a market size of USD 150 billion per year.

- **United States:** By 2030, the United States aims to achieve 5 GW of hydrogen production, prioritizing green hydrogen from renewable sources. The Hydrogen Council anticipates that by 2050, the U.S. could cater to a quarter of the global hydrogen demand, potentially amounting to a market size of USD 140 billion annually.
- **Japan:** Japan's target for 2030 includes producing 300,000 tonnes of hydrogen annually, with a preference for green hydrogen sourced from renewables. As per the Hydrogen Council, Japan might contribute up to 20% of the world's hydrogen demand by 2050, with a prospective market size of USD 80 billion per year.
- **Australia:** By 2030, Australia aims to produce hydrogen at a cost below AUD 2 per kilogram, primarily focusing on green hydrogen from renewable sources. Projections from the Australian Renewable Energy Agency (ARENA) indicate Australia could account for up to 10% of global hydrogen demand by 2050, potentially comprising an AUD 11 billion per year market.

These estimations and forecasts collectively suggest a significant surge in green hydrogen production across key countries from 2020 to 2050, driven by supportive policies, technological advancements, market dynamics, and the availability of renewable energy sources.

Industries and Applications:

Green hydrogen is poised to revolutionize diverse industries by offering a clean, efficient, and versatile energy solution.

- **Transportation:** The transportation sector is increasingly embracing green hydrogen as a zero-emission fuel option. Automakers like Toyota, Hyundai, and BMW are developing and deploying fuel cell

electric vehicles (FCEVs) powered by hydrogen. Additionally, initiatives are underway to utilize hydrogen for heavy-duty vehicles, buses, and trains.

- **Industrial Applications:** Industries such as steel, chemicals, and refineries are exploring green hydrogen to reduce their carbon footprint. Hydrogen can serve as a feedstock, reducing agent, or source of heat in various industrial processes.
- **Refining and Petrochemicals:** The refining and petrochemical sectors are investigating green hydrogen to lower carbon emissions. Hydrogen can replace fossil fuels in refining processes like desulfurization and hydrocracking, thereby supporting the decarbonization of operations in these industries.
- **Aviation:** The aviation industry is actively researching the use of green hydrogen as a sustainable aviation fuel. Hydrogen-powered aircraft, whether through combustion or fuel cells, have the potential to significantly reduce greenhouse gas emissions compared to traditional jet fuels.
- **Energy Storage and Grid Balancing:** Green hydrogen plays a vital role in energy storage and grid balancing. During periods of low demand, excess renewable energy can be utilized for hydrogen production through electrolysis. The stored hydrogen can then be converted back to electricity through fuel cells or combustion during periods of high demand, thereby stabilizing the grid and ensuring a reliable energy supply.
- **Residential Heating:** Green hydrogen offers a viable alternative for residential heating, displacing natural gas and other carbon-intensive fuels. Hydrogen boilers and fuel cells can provide heat and hot water without emitting carbon.
- **Energy Export:** Countries abundant in renewable energy resources, such as Australia and Canada, are exploring green hydrogen export opportunities. Liquefied hydrogen



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or other derivative green fuels such as ammonia and methanol can be transported as a commodity, enabling nations to share their renewable energy potential with regions lacking such resources.

These examples underscore the global momentum toward green hydrogen adoption, driven by its potential to decarbonize various sectors and foster a sustainable, cleaner energy future.



Innovative Methods of Producing Clean Hydrogen:

Researchers and scientists worldwide are actively investigating and developing new technologies, materials, and processes to enhance the efficiency, scalability, and cost effectiveness of renewable hydrogen production, storage, and usage. By continuously advancing these methods, the aim is to facilitate the widespread adoption of clean hydrogen as a sustainable energy solution [51].

- **Plasma Arc Decomposition:**

Plasma arc decomposition, also known as plasma reforming, utilizes high temperatures generated by an electric arc to break down natural gas (methane) into hydrogen and carbon monoxide. This occurs within a plasma reactor, where the intense heat dissociates methane molecules, liberating hydrogen gas. When electricity for the plasma arc decomposition is sourced from renewables, this method qualifies as a green hydrogen production technique.

- **Thermolysis:** Thermolysis involves the decomposition of a chemical compound, such as water or hydrocarbons, by applying heat.

Subjecting the compound to high temperatures breaks molecular bonds, releasing hydrogen gas. By using heat from renewable energy sources, thermolysis ensures an environmentally friendly production process.

- **Photo Electrochemical (PEC)**

Water Splitting: PEC water splitting utilizes specialized semiconductor materials to directly convert solar energy into hydrogen. These materials can absorb sunlight and initiate the water-splitting reaction within the cell, generating hydrogen and oxygen. PEC technology offers the potential for efficient and direct solar-driven hydrogen production, eliminating the need for external electricity sources.

- **Artificial Photosynthesis:** Artificial photosynthesis is an emerging field that seeks to replicate the process of natural photosynthesis in plants to produce hydrogen. It involves using specialized materials and catalysts to capture sunlight and initiate chemical reactions that produce hydrogen from water. Artificial photosynthesis holds promise for renewable and sustainable hydrogen production, but it is still an area of ongoing research and development.

Green Hydrogen Challenges and Observations:

It is crucial to recognize the transformative potential that green hydrogen holds in the transition to sustainable energy is not without its obstacles. Below, we explore the array of challenges that must be addressed to realize the full promise of green hydrogen as a clean energy solution.

- **Energy Loss:** Around 30% of green hydrogen's energy content is lost during hydrogen liquefaction, meaning each unit produced only retains 70% of its available energy.
- **Liquid Hydrogen Storage:** Storing liquid hydrogen presents challenges due to the extremely low storage temperature required (-253°C) and the necessity for effective isolation systems.
- **Safety Concerns:** Hydrogen's flammability and potential for oxygen dilution pose safety risks.
- **High Energy Density:** Hydrogen's wide combustible range, low boiling point, and high energy density require careful handling to prevent accidents.
- **Technical Hurdles:** Technical challenges, like high temperature

and pressure requirements, complicate hydrogen storage.

- **Cost:** Competitiveness requires reducing hydrogen gas costs to around USD 2 per kilogram or lower.
- **Electricity Demand:** Green hydrogen demands significant electricity, necessitating increased renewable energy production.
- **Offshore Wind Capacity:** Developing offshore wind energy is crucial to meet green hydrogen demand.
- **Infrastructure:** Establishing comprehensive infrastructure for production, storage, and distribution is challenging.
- **Scaling Up:** Meeting demand across sectors requires significant production scale-up.
- **Electrolysis Technology:** Enhancing electrolysis efficiency and cost-effectiveness is key.
- **Renewable Energy Availability:** Reliance on intermittent renewables poses supply challenges.
- **International Collaboration:** Global cooperation is necessary

for successful green hydrogen implementation.

- **Regulatory Framework:** Supportive regulations are vital for green hydrogen deployment.
- **Public Awareness:** Raising public awareness and acceptance is essential.


Currently, the clean hydrogen market struggles to match the economic competitiveness of fossil fuels, largely due to the absence of environmental costs in fossil fuel prices. Nevertheless, as technology advances and production costs for clean hydrogen decrease over time, this disparity is anticipated to diminish. Meeting the rising demand for clean hydrogen necessitates robust infrastructure, efficient production and storage methods, and cost reductions.

Governments and enterprises are poised to invest in research, development, and innovation to bolster the clean hydrogen market's competitiveness [68].

It is through careful consideration and collaboration that the full potential of green hydrogen can be realized, leading to a cleaner and more sustainable energy future.

References

- [1] EIA. Renewable Energy Explained. Available online: <https://www.eia.gov/energyexplained/renewable-sources/>
- [2] Di, L.G.; Olufemi, O.A.; Kumar, A. Blending blue hydrogen with natural gas for direct consumption: Examining the effect of hydrogen concentration on transportation and well-to-combustion greenhouse gas emissions. *Int. J. Hydrogen Energy* 2021, 46, 19202–19216.



CURRENTLY, THE CLEAN HYDROGEN MARKET STRUGGLES TO MATCH THE ECONOMIC COMPETITIVENESS OF FOSSIL FUELS, LARGELY DUE TO THE ABSENCE OF ENVIRONMENTAL COSTS IN FOSSIL FUEL PRICES.