

Improving Green Hydrogen Production in the U.S. by 2050

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ABSTRACT

This paper explores how the United States can improve its green hydrogen production by 2050 to help fight climate change and meet global temperature goals. Green hydrogen is a clean energy source and is made using renewable energy. By prioritizing green hydrogen over traditional fossil fuels, it can help reduce pollution, especially in tough areas where fossil fuels is heavily used like in the industry and long-distance transportation sectors. Currently, the U.S. is facing challenges like high costs and insufficient infrastructure to support large-scale green hydrogen production. In comparison to the U.S., other countries like Germany and Japan have been able to successfully implement better solutions to combat the 1.5°C Scenario. Our research paper displays how the U.S. is lacking in fundamental ways to overcome environmental challenges like carbon dioxide emissions, rising sea levels, and climate change. We can tackle these challenges through using more renewable energy sources, improving upon green technology, and creating supportive policies for environmental impact. These recommendations aim to help the U.S. increase its green hydrogen production and contribute to a cleaner energy future.

Introduction

The world is currently grappling with a critical challenge: climate change. Scientists and policymakers are united in their call to limit the global temperature rise to 1.5°C above pre-industrial levels, a target known as the 1.5°C Scenario (IPCC, 2018). This goal is crucial for preventing severe consequences such as catastrophic weather events, rising sea levels, and irreversible damage to ecosystems, as illustrated in Figure 1 below. However, the World Energy Transition Outlook Report indicates that a clear path to achieving this scenario is still elusive over the next 30 years (IRENA, 2023). This situation underscores the urgent need for transformative changes in our energy production and consumption systems to address climate change effectively. Among the various solutions being considered, green hydrogen emerges as a particularly promising option in the quest to combat climate change (DOE, n.d.).

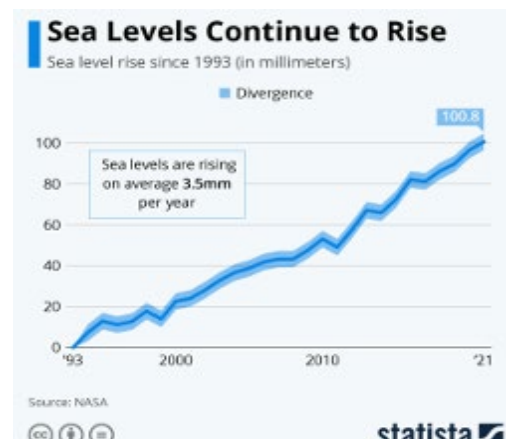


Figure 1. This graph highlights the rising sea levels, a pressing consequence of climate change that justifies the urgency of achieving the 1.5°C Scenario. This increase in sea levels illustrates the severe impacts of climate change, reinforcing the need for transformative energy solutions like green hydrogen to reduce global temperatures. Addressing these challenges through enhanced green hydrogen production in the U.S. is crucial for mitigating these effects and moving closer to climate goals by 2050.

Unlike conventional hydrogen produced from fossil fuels, green hydrogen is generated using renewable energy sources like wind and solar power through a method called electrolysis, resulting in zero carbon emissions. This makes green hydrogen a clean fuel with a wide range of applications and a vital feedstock for producing other clean fuels. Given green hydrogen's potential to transform the energy landscape, it is essential to explore strategies for scaling up its production and supply chain. This research aims to investigate how the United States can significantly enhance its green hydrogen production by 2050. By analyzing current production methods, technological advancements, and policy frameworks, this study seeks to identify the most effective strategies to increase the U.S.'s capacity for green hydrogen production. We will do this by evaluating the feasibility of various production technologies, understanding economic and regulatory challenges, and proposing actionable recommendations to accelerate the transition to a green hydrogen economy. Lastly, our goal is to contribute to the broader conversation on sustainable energy solutions and provide a clear roadmap for the U.S. to strengthen its global efforts to achieve the 1.5°C Scenario.

Current Status of Green Hydrogen Production

The World Energy Transition Outlook Report presents a concerning reality: the absence of a clear and definitive trajectory for achieving the 1.5°C Scenario over the next 30 years (IRENA, 2023). This revelation highlights the pressing need for profound and transformative changes within our energy systems by the year 2050. Among the various strategies being considered, green hydrogen emerges as a pivotal and promising solution to this pressing challenge (DNV, 2024). Unlike traditional hydrogen, which is derived from fossil fuels and contributes to carbon emissions, green hydrogen is produced through the utilization of renewable energy sources such as wind and solar power via the process of electrolysis (IEA, 2023). This process offers a zero-emission alternative, positioning green hydrogen as a critical player in the quest to reduce our carbon footprint and transition towards a more sustainable energy future. Despite the potential for future green hydrogen development, the current landscape of green hydrogen production in the United States reveals a number of significant challenges and limitations that must be addressed to fully realize its potential.

The U.S. has made commendable progress in green hydrogen production by capitalizing on its rich and diverse renewable energy resources. One of these primary technology for producing green hydrogen is through Electrolysis which operates by splitting water into hydrogen and oxygen using electricity generated from renewable sources. This process is inherently clean, as it does not produce carbon emissions. However, there are considerable concerns regarding the efficiency and scalability of electrolysis technology. Optimizing the integration of renewable energy sources into the hydrogen production process is essential to ensuring a steady and reliable supply of green hydrogen. This optimization necessitates advancements in energy storage solutions and improvements in grid management systems to handle the intermittency and variability of renewable energy sources (Johnson & Lee, 2024). In addition to these technical advances, there still pose challenges in the high production costs associated with electrolysis represent a significant barrier to the widespread adoption of green hydrogen. This involves not only technological innovations but also scaling up production capacities to achieve economies of scale (IRENA, n.d.). Developing a more cost-effective and efficient electrolyzers is crucial to making green hydrogen a viable and competitive alternative to traditional hydrogen production methods and other fossil fuels.

Infrastructure limitations also pose a substantial obstacle to the growth of green hydrogen production in the U.S. The existing infrastructure for hydrogen production, storage, and distribution is currently inadequate to support the large-scale deployment of green hydrogen. Significant investments are required to develop and expand

infrastructure, including the construction of dedicated hydrogen pipelines, storage facilities, and refueling stations. These investments are critical for enabling the widespread use and integration of green hydrogen into the energy system (McKinsey & Company, 2023). This includes implementing incentives to encourage the use of renewable energy in hydrogen production, providing research and development subsidies, and creating regulations that promote the adoption of green hydrogen across various sectors (German Federal Government, 2023). The establishment of supportive regulatory and policy frameworks is essential for fostering the growth of the green hydrogen industry.

To advance green hydrogen production in the U.S. by 2050, it is imperative to address these challenges through a comprehensive and multifaceted approach. This approach will not only involve advancing electrolysis technology and optimizing the integration of renewable energy sources but also reducing production costs and developing robust infrastructure. Furthermore, the implementation of supportive policy measures and increased investments in research and development are crucial to accelerating the transition to a green hydrogen economy. By effectively overcoming these hurdles, the U.S. can enhance its green hydrogen production capabilities and play a leading role in the global effort to achieve the 1.5°C Scenario, thereby contributing to a more sustainable, resilient, and environmentally friendly future (Liebreich, 2024).

Improving Green Hydrogen Production in the U.S.

Improving green hydrogen production in the United States requires a meticulously crafted strategy that addresses several crucial areas to ensure substantial progress. At the forefront of this strategy is the urgency for increasing our renewable energy capacity. The strategy will involve scaling up the deployment of wind, solar, and hydroelectric power sources. With this advancement, we can build a consistent and reliable supply of electricity is fundamental for producing hydrogen. Integrating these renewable energy sources into hydrogen production processes effectively will help establish a continuous and sustainable supply of green hydrogen. This task necessitates overcoming the challenges associated with the variability of renewable energy sources, which will require the development and implementation of advanced grid management techniques and cutting-edge energy storage solutions to maintain balance between supply and demand (Renewable Energy Institute, 2022). To illustrate the potential impact of these efforts, Figure 2 provides a graphical representation of the projected reduction in CO₂ emissions by 2050 if the goals for green hydrogen production are met. Advancing green hydrogen production in the U.S. depends on expanding renewable energy capacity and improving grid management and storage solutions, setting the stage for a sustainable and effective green hydrogen industry.

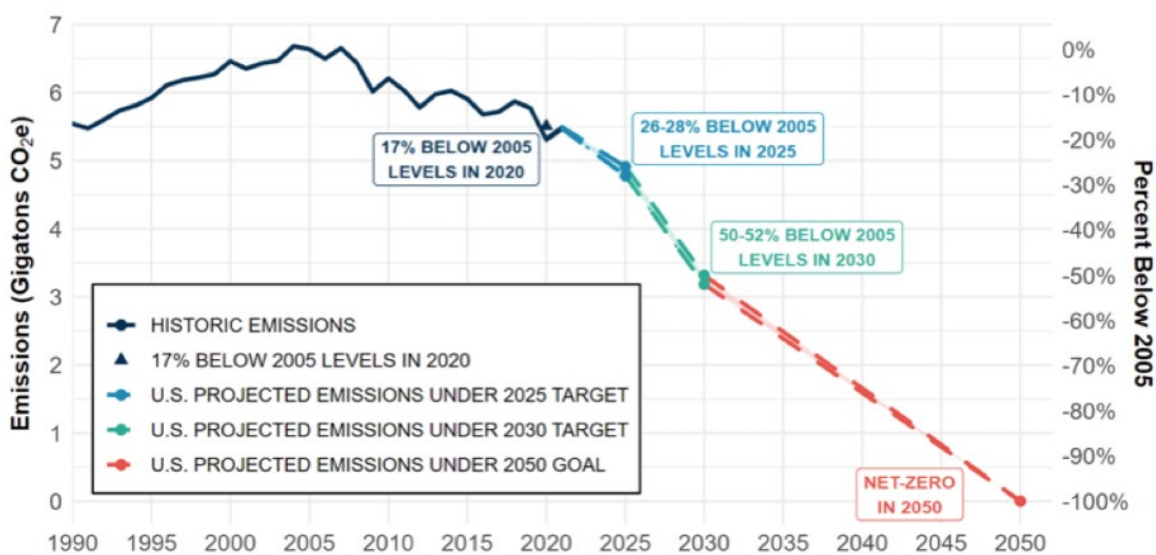


Figure 2. This graph shows how CO₂ emissions in the U.S. could decrease if we use more green hydrogen by 2050. The y-axis represents CO₂ emissions in millions of metric tons, while the x-axis shows the years from 2025 to 2050. The line slopes downward, indicating that as green hydrogen use goes up, pollution levels go down.

Equally important is the development of the necessary infrastructure to support green hydrogen production. This will include constructing new hydrogen production facilities and creating an extensive distribution network composed of refueling stations and pipelines. Currently, the infrastructure for hydrogen production, storage, and distribution in the U.S. is insufficient to handle large-scale deployment. Therefore, substantial investments for new infrastructure are required to build and upgrade the infrastructure needed to accommodate increased hydrogen production and ensure its efficient distribution throughout the country. These investments will be crucial for establishing a robust and effective hydrogen infrastructure network capable of supporting the anticipated growth in green hydrogen production (DOE, n.d.). By overcoming the initial costs for building new infrastructure, we can then take a step closer to our green hydrogen production.

In addition to physical infrastructure, we also want to advocate for government support through thoughtful policies and regulations for the green hydrogen sector. This support growth and development in green hydrogen should include financial incentives and subsidies designed to make green hydrogen production more economically viable and competitive. Establishing a clear and supportive regulatory framework and setting industry standards will also help create a stable and predictable environment that attracts investment and fosters innovation within the hydrogen industry. Such measures are necessary to encourage businesses and investors to commit to the green hydrogen sector, thereby driving forward the development of new technologies and infrastructure (German Federal Government, 2023). Government support through financial incentives, clear regulations, and industry standards is essential for advancing the green hydrogen sector, fostering investment, and driving technological innovation.

Technological advancements represent another critical element in improving green hydrogen production. Innovations in electrolyzer technology, which is the primary method for producing hydrogen through electrolysis, are essential for enhancing efficiency and reducing production costs. The development of new materials and designs for electrolyzers can lead to improvements in their performance and longevity, thereby lowering the overall cost of hydrogen production. Additionally, advancements in hydrogen storage and transport technologies are crucial for enhancing the efficiency and cost-effectiveness of green hydrogen production. Effective storage solutions are particularly important due to the intermittent nature of renewable energy sources, which necessitates the ability to store and manage hydrogen supplies effectively (IRENA, n.d.). Technological advancements in electrolyzer efficiency, storage, and transport are crucial for reducing costs and enhancing the effectiveness of green hydrogen production.

To comprehensively address the challenges of improving green hydrogen production in the U.S. by 2050, it is necessary to take a multifaceted approach. This approach should include advancing electrolysis technology, optimizing the integration of renewable energy sources, reducing production costs, and developing a robust infrastructure. Additionally, supportive policy measures and increased investments in research and development are critical to accelerating the transition to a green hydrogen economy. By making progress in these areas, the U.S. can significantly enhance its green hydrogen production capabilities and play a leading role in the global effort to achieve the 1.5°C Scenario. Successfully overcoming these challenges will not only improve the country's green hydrogen production capacity but also contribute to a more sustainable and resilient future.

Economic and Environmental Impacts

To harness the full potential of green hydrogen, it is essential to conduct a thorough and detailed analysis of both its economic and environmental impacts. This comprehensive evaluation begins with a clear understanding of the costs associated with green hydrogen production, which are pivotal in assessing its viability and scalability. One of the primary costs involves sourcing renewable energy sources, such as wind, solar, or hydroelectric power, which are

critical for the production of green hydrogen through the electrolysis process (IEA, 2023). Electrolysis itself is a process where water is split into hydrogen and oxygen by applying electricity. This process necessitates the use of electrolyzers, which are sophisticated and specialized pieces of equipment designed for this purpose. The procurement, installation, and maintenance of these electrolyzers require a significant financial investment, which can be substantial to green hydrogen production.

In addition to the costs associated with electrolyzers, there are considerable expenditures related to the development and maintenance of infrastructure required for hydrogen production, storage, and transportation. This includes the construction of hydrogen production facilities, as well as the establishment of storage tanks, pipelines, and refueling stations. Building and maintaining such infrastructure is a complex and expensive undertaking. These costs must be factored into the overall investment required for scaling up green hydrogen production. Despite these initial financial outlays, it is important to recognize that the long-term economic benefits of green hydrogen are significant and potentially transformative, making it a worthwhile area of investment and exploration.

Investing in green hydrogen technology can stimulate significant job creation across various sectors. As the green hydrogen industry expands, it will create numerous opportunities in fields such as manufacturing, engineering, and technology development. This growth will likely lead to the emergence of new business ventures and the expansion of existing ones within the clean energy sector. Furthermore, the development of green hydrogen infrastructure and technology can drive innovation and foster growth in related industries. This dynamic economic environment can contribute to a more robust and diverse economic landscape. Reducing reliance on imported fossil fuels through the adoption of green hydrogen can enhance national energy security and stability, providing further economic benefits and strengthening the resilience of the energy sector (Liebreich, 2024). Investing in green hydrogen technology boosts job creation, innovation, and energy security, leading to a more resilient and sustainable economy.

On the environmental front, green hydrogen offers substantial benefits. The shift away from fossil fuels to green hydrogen significantly lowers greenhouse gas emissions, which is crucial for mitigating the impacts of climate change (DNV, 2024). This reduction in emissions contributes to a decrease in global warming, which is essential for stabilizing the climate and improving overall air quality. Improved air quality has direct benefits for public health, resulting in better health outcomes and a cleaner environment. Furthermore, green hydrogen can help diversify energy sources, which enhances the sustainability of energy production and reduces its environmental impact. As the production of green hydrogen scales up, it can help lower the carbon footprint of energy-intensive industries, supporting the development of a more sustainable and resilient energy system.

It is of critical importance to acknowledge that the environmental benefits of green hydrogen are contingent upon the availability and use of renewable energy sources. If the electricity used for the electrolysis process is generated from fossil fuels, the environmental advantages of green hydrogen could be significantly diminished. Therefore, it is critical to ensure that the production process is powered entirely by renewable energy sources to fully realize the environmental benefits of green hydrogen. Additionally, the large-scale deployment of green hydrogen must be managed with care to avoid potential ecological disruptions. For instance, water scarcity in regions where water resources are already limited could be a concern. Addressing these challenges requires a strategic and coordinated approach that maximizes the benefits of green hydrogen while mitigating potential risks. Such a multifaceted approach will be essential for advancing towards a more sustainable and resilient energy future, ensuring that the full potential of green hydrogen is realized and its impact on both the economy and the environment is optimized.

Case Studies and Global Comparisons

Examining successful green hydrogen initiatives in other countries provides valuable insights and guidance for advancing this technology. Many nations have made significant strides in green hydrogen development, offering lessons that can help shape future efforts. For instance, countries like Germany and Japan have been at the forefront of green hydrogen projects. Germany's ambitious plans include integrating hydrogen into their industrial processes and public transport systems, while Japan has focused on developing hydrogen fuel cells for vehicles and creating a

comprehensive hydrogen supply chain. These initiatives highlight several best practices that can be applied elsewhere. One key lesson learned is the importance of government support and strategic planning. In both Germany and Japan, strong government policies and financial incentives have played a crucial role in accelerating green hydrogen adoption. These policies include subsidies for research and development, tax incentives for companies investing in hydrogen technology, and funding for infrastructure projects. Another important practice is fostering international collaboration.

By partnering with other countries and businesses, these nations have been able to share knowledge, reduce costs, and scale up their hydrogen technologies more effectively. These successful initiatives demonstrate the value of creating a robust hydrogen infrastructure. Investing in the development of production facilities, storage solutions, and distribution networks is essential for scaling up hydrogen use. Implementing pilot projects and scaling them gradually has also proven effective in addressing technical challenges and refining technologies. By studying these international examples, other countries can learn from the experiences of leaders in the green hydrogen sector. Applying these best practices, such as strong policy support, international cooperation, and strategic infrastructure development, can help accelerate the growth of green hydrogen technologies and drive their successful implementation on a global scale. Understanding these successful models will be crucial in shaping effective strategies for green hydrogen initiatives and achieving a sustainable energy future.

Discussion and Conclusion

Improving green hydrogen production in the U.S. by 2050 requires a multifaceted approach that draws from successful international examples and addresses the current challenges. Our exploration reveals that green hydrogen has immense potential to contribute to a cleaner and more sustainable energy system, but realizing this potential demands significant advancements and investments (IEA, 2023). Key findings highlight the importance of expanding renewable energy sources, developing efficient electrolyzer technology, and building robust infrastructure for hydrogen production, storage, and distribution (IRENA, 2023). Recommendations for policymakers include implementing supportive regulations and financial incentives to accelerate green hydrogen adoption (German Federal Government, 2023). Industry stakeholders should focus on innovation and international collaboration to reduce costs and scale up technologies (Liebreich, 2024). In conclusion, technological advancements in electrolyzer efficiency, storage, and transport are crucial for reducing costs and enhancing the effectiveness of green hydrogen production.

Researchers are encouraged to pursue advancements in hydrogen production methods and storage solutions to enhance efficiency and affordability (DNV, 2024). Looking ahead, the future of green hydrogen is promising but requires ongoing commitment to research and development. Addressing technical challenges, improving integration with renewable energy, and building comprehensive infrastructure is essential for advancing green hydrogen (McKinsey & Company, 2023). By applying lessons from successful global initiatives and adopting a strategic, well-supported approach, the U.S. can enhance its green hydrogen production capabilities and play a pivotal role in the worldwide effort to achieve the 1.5°C Scenario, contributing to a more sustainable and resilient energy future (Johnson & Lee, 2024). By focusing on advancing hydrogen production and storage technologies to improve efficiency and reduce costs, this commitment to ongoing R&D, the U.S. can enhance its green hydrogen capabilities and significantly contribute to global climate goals.

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References

- Det Norske Veritas: DNV. (2023) *Energy Transition Outlook*, Retrieved from <https://www.dnv.com/energy-transition-outlook/key-highlights/#:~:text=The%20transition%20is%20still%20in,fuel%20use%20is%20still%20growing>
- The Federal Government. (n.d.). *Energy from climate-friendly gas* Retrieved from <https://www.bundesregierung.de/breg-en/news/hydrogen-technology-2204238>
- Gulli, C., Heid, B., Noffsinger, J., Waardenburg, M., & Wilthaner, M. (2024a). *Global Energy Perspective 2023: Hydrogen Outlook*. Retrieved from <http://www.mckinsey.com/industries/oil-and-gas/our-insights/global-energy-perspective-2023-hydrogen-outlook>
- IRENA. (2023). *World Energy Transitions Outlook 2023: 1.5°C Pathway*, International Renewable Energy Agency. Retrieved from <https://www.irena.org/Publications/2023/Jun/World-Energy-Transitions-Outlook-2023>
- IRENA. (2024, May 29). *Hydrogen*. Retrieved from <https://www.irena.org/Energy-Transition/Technology/Hydrogen>
- Intergovernmental Panel on Climate Change (IPCC). (2022). Framing and Context. In *Global Warming of 1.5°C: IPCC Special Report on Impacts of Global Warming of 1.5°C above Pre-industrial Levels in Context of Strengthening Response to Climate Change, Sustainable Development, and Efforts to Eradicate Poverty* (pp. 49–92). chapter, Cambridge: Cambridge University Press.
- International Energy Agency: IEA. (2023), *Global Hydrogen Review 2023*, Retrieved from <https://www.iea.org/reports/global-hydrogen-review-2023>
- Liebreich, M. (2023, December 12). *Liebreich: Clean Hydrogen's Missing Trillions*. Retrieved from <https://about.bnef.com/blog/liebreich-clean-hydrogens-missing-trillions/#:~:text=BloombergNEF%27s%20Hydrogen%20Strategy%20Tracker%20shows,and%20South%20Korea%204%20million>
- Maka, A. O., & Mehmood, M. (2024). Green hydrogen energy production: Current status and potential. *Clean Energy*, 8(2), 1–7. doi:10.1093/ce/zkae012
- Marouani, I., Guesmi, T., Alshammari, B. M., Alqunun, K., Alzamil, A., Alturki, M., & Hadj Abdallah, H. (2023a). Integration of renewable-energy-based green hydrogen into the energy future. *Processes*, 11(9), 2685. doi:10.3390/pr11092685
- New Zealand Foreign Affairs & Trade. (2023). *Japan: Hydrogen Strategy* Retrieved from <https://www.mfat.govt.nz/en/trade/mfat-market-reports/japan-hydrogen-strategy-november-2023/#:~:text=a%20new%20mid%2Dterm%20volume,of%20the%20global%20electrolyser%20market>
- Ohno, T., Nishida, Y., Ishihara, T., & Hirose, A. (2022). *Re-Examining Japan's Hydrogen Strategy Moving Beyond the "Hydrogen Society" Fantasy*. Retrieved from <https://www.renewable-ei.org/en/activities/reports/20220922.php>
- Statista. (n.d.). *Rate of rising sea levels*. Statista. Retrieved from <https://www.statista.com/chart/27581/rate-of-rising-sea-levels/>

World Economic Forum. (n.d.). *[Image of a world map with data visualizations]*. Retrieved August 28, 2024, from <https://assets.weforum.org/editor/jFwSn53i4su7uFbJtFZQjF9LWdUkRxQ5TmyfnnsTRD4.png>