THE HYDROGEN CIRCULAR ECONOMY: ESTABLISHMENT OF AN ADVANCED HYDROGEN INDUSTRY TOWARD VIETNAM NET ZERO 2050

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GENERAL INFORMATION

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ABSTRACT

In recent years, the development of hydrogen as a new reliable energy source has become a trend and caught lots of attention from all over the world. Hydrogen is a fundamental element that can be produced via different processes, which can be classified into three main groups: green processes (electrolysis), carbon-treated processes (thermoconversion processes), and traditional processes (reforming processes). Hydrogen products were identified using their specific color such as green, blue, and brown hydrogen… Clean hydrogen (blue and green hydrogen) possesses strong energy density, is a renewable energy source, is produced without emissions, and possesses high economic value. However, the sufficient solution to produce hydrogen on a large-scale level must be done based on a well-prepared hydrogen economy; this hydrogen economy must be directed towards the goal of a circular economy model, using green energy, and following the route of carbon-neutral industries or other production activities. In that manner, the hydrogen industry development roadmap must combine the advantages of geographical conditions, appropriate technologies, and compliance with the support policies of each country and region. Building a hydrogen economy is specific to its intended use, needs to be built on a scale from small to large, and deployed based on an economic model that can promote the advantages in the production process, create a flexible mechanism in the product storage and distribution process, and finally create convenience in replicating the production model that may easily bring products to end users. Recognizing all those concerns, the concept of the *circular hydrogen economy* was born and is predicted to be the dominant model in the hydrogen industry worldwide. Clarifying the role of the *circular economy* in the establishment of a *circular hydrogen economy* model plays a key role in this research; Accordingly, the advantages and disadvantages of the *circular economy* are also analyzed and presented, through the comparison and conclusion obtained from case studies conducted in other countries.

1. INTRODUCTION

Energy plays an important role in the development of countries, especially in industrial production, optimally serving the process of industrialization and modernization. However, humanity's excessive abuse of resources such as gas, coal, and fossil-related materials... creates many negative impacts on the environment which is also accompanied by the phenomenon of climate change, natural disasters, and thus creating many harmful effects on the world of men. These effects also endanger the world's ecological structures and creatures' behavior; not only that, it also negatively crashes the social development, and economic systems from regional to international. Accordingly, the need for a useful energy solution toward a more sustainable future has become a very trending and important task. Therefore, indicating a new and viable energy source will play a crucial role in the mentioned energy solution (UN General Assembly et al., 2015; Nick et al., 2019). In the current context, hydrogen is emerging as a very promising candidate that can replace traditional resources in creating a new energy industry that is renewable, cleaner, more efficient, and safer (Dominique et al., 2021; Nguyen et al., 2020). Hydrogen possesses excellent physical and chemical properties and can be applied very flexibly in many modern industries, such as the automobile manufacturing industry, energy industry, food industry, transportation industries... However, the development of a reliable hydrogen industry can only be accomplished on a solid foundation of a hydrogen economy system.

However, to enable the establishment of a hydrogen economy and thereby successfully create a hydrogen society, the problem of resource supply and the specifics of products need to be resolved. While the natural source of hydrogen is too small, traditional hydrogen production has failed to create a positive impact and would not be able to serve humanity's requirements for the new era (Fran et al., 2022). The development of hydrogen energy is expected to make a difference and bring new values to the global energy plan, which is interdisciplinary and possesses very different characteristics depending on the energy policy, infrastructure, and plans of each country. Currently, there are about 75 operating hydrogen production factories and 150 facilities in the planning stages of development worldwide (*mainly in the US and China*), the number of projects and underdeveloped plants for hydrogen industries is assumed to be twice those that were reported (Zoback, Smit et al., 2023). Although the cost of hydrogen production is still very high compared to other types of renewable energy, researchers predict that future production costs will gradually decrease thanks to the development and application of advanced technologies (Environmental et al., 2022; Zun, McLellan et al., 2023).

In the early 2020s, hydrogen consumption is estimated to be around 87-90 million tons per year, of which the demand for hydrogen is expected to increase exponentially depending on each industry group in the period of 2030 to 2050 (Global Hydrogen Review et al., 2022). The global demand for hydrogen is growing, which means opportunities to invest and develop this industry are constantly appearing and promising to create more than 30 million new jobs, along with a source of income of up to 2.5 trillion USD/year by 2050 (Marouani et al, 2023; Tarvydas e al., 2022). According to predictions, to achieve zero emissions by 2050, the hydrogen market must be able to provide the source (*mainly supplying the transportation sector and key industries*) with a capacity of up to 170 million tons by the end of 2030.

In this work, the authors indicate the importance of building a circular hydrogen economy and explain the great possibilities of this model in building a sustainable hydrogen industry worldwide, especially in the case of Vietnam. The concept of a circular hydrogen economy is new and was determined based on the idea of circular economy and the supply chain of hydrogen products. Accordingly, the circular hydrogen economy possesses distinct production, specific storage and distribution, and safer, cleaner consumption processes. This work also addresses the development and advancement of technologies related to the circular hydrogen economy that is considered a key factor in improving the efficiency of energy production, while also being effective in reducing related costs. Not only that, there are many suggestions on hydrogen energy development policy in Vietnam that are also mentioned and analyzed, thereby explaining the prediction related to the ability to supply 600 million tons by 2050 to maintain energy security, form a hydrogen ecosystem, and establish a net zero emission society in Vietnam and at many places worldwide.

2. METHODOLOGY

This work was conducted using the method that concerns the relationship between the theory of circular economy and broad data acquired from questions and inquiries from the field of energy industries. The mentioned field of energy industries relates to policies from many sources and especially from Vietnam, and other scientific reports. This work also involves creating recent developments of theories that were described as hydrogen circular economy. All data were evaluated and explained with references with the use of plots and diagrams.

3. RESULTS AND DISCUSSIONS

3.1. The demand for hydrogen as a new reliable energy

The developing strategy for hydrogen has been oriented in many countries, especially in European countries since very early of 2015 and still growing strong, even though the affection of the COVID pandemic during the period of 2019-2021. According to Marouani and his colleagues, the demand for hydrogen in industrial production and transportation will grow rapidly over time in the period 2035-2045 (Megia et al., 2021). Currently, energy consumption is heavily dependent on fossil fuels which equal to more than 85% of global electricity consumption (22,850 TWh) (*produced from traditional processes and fuels*) (Le & Nguyen, 2023). This current situation, on the contrary, does not hinder the development of the hydrogen industry but also creates a driving force to promote the development of hydrogen technology (*production, storage and distribution technology, hydrogen consumption technology*) thereby creating a solid foundation for reducing investment, establishment and operation costs for hydrogen projects, moving closer to realizing a hydrogen society.

The International Energy Agency (IEA) indicates that the period of 2022-2025 will see the hydrogen move to the global climate and energy policy center stage. The IEA's World Energy Outlook report shows that the cost advantages of clean energy technologies are gradually maturing, creating promising premises for clean hydrogen production technologies that require high investment costs and interdisciplinary nature (Ballo et al., 2022).

Accordingly, by the end of 2022, there would be more than 30 countries will have hydrogen development strategies including import and export plans, and the suggestion of cross-border trade will grow significantly.

Therefore, countries that do not have a tradition of energy exchanges are establishing bilateral relations focused on hydrogen-related technologies; Depending on the differences

between countries, the solutions to develop a hydrogen economy would greatly benefit the energy transition, and thus so are invested with appropriate mechanisms and policies. suitable (Razmi et al., 2023).

(*The briefing on the advantages of hydrogen energy can be found in figure S1 in the supplementary materials*)

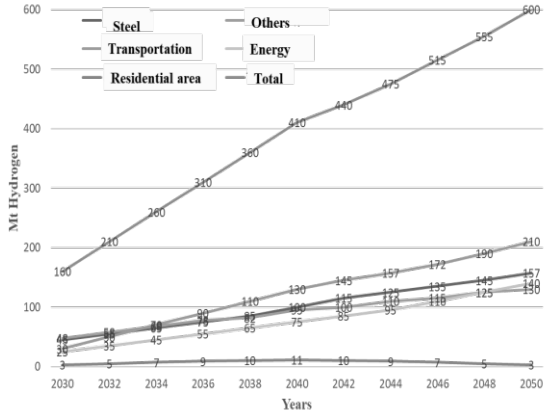

Figure 1. The suggestion for hydrogen demand/consumption in the period of 2030-2050 (Marouani et al., 2023).

3.2. The establishment of the circular hydrogen economy – from philosophy to end-users

The establishment of the hydrogen economy is expected to be a prerequisite step to developing the hydrogen industry toward the building of a modern society using clean energy, reducing carbon emissions, and achieving the social status of carbon neutral. In that spirit, building a hydrogen economy is expected to not only create a foundation for developing the hydrogen industry and producing hydrogen products but also to accomplish those tasks sustainably and effectively in both production and environmental protection aspects.

The hydrogen economy is established based on the construction of three prerequisites: the hydrogen production process is considered the *upstream* source - creating hydrogen products (1), the distribution network and the hydrogen storage system are considered the *midstream* transition factor – transporting the product to the consumer (2), and the hydrogen consumption process is considered the final process of the *downstream* supply chain of all types of hydrogen products (3). However, the circular hydrogen economy conducts a new step in completing the hydrogen supply chain – the addition of the waste-utilizing process and turning these waste products into a resource that can serve as feedstocks of the hydrogen production processes. In that manner, the characteristics of the hydrogen economy must be determined through four interrelated factors: hydrogen production technologies, hydrogen transportation and storage processes, hydrogen consumption, and finally the processes that utilize wastes and apply them as input materials for the initial production process. The circular hydrogen economy model is explained in Figure 2.

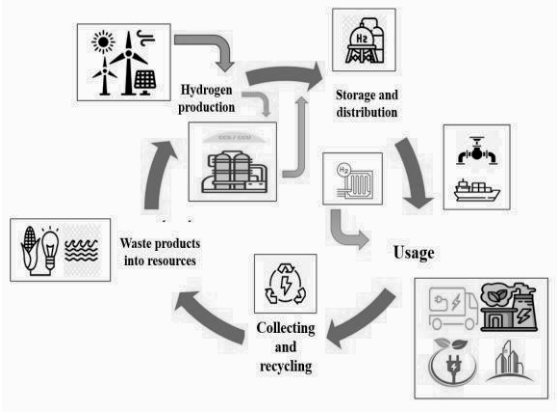

Figure 2. The description of modern circular hydrogen economy

Accordingly, this model creates a bridge between production processes and related ecosystems by continuously and effectively addressing generated waste sources. The circular economy focuses on solving the flow of resources (*both input materials and wastes*) rather than solving problems from the perspective of increasing energy input and enhancing waste treatment efficiency at the end of these processes.

Therefore, the circular economy can be applied and recognized via the process of intelligently reducing input resources (reduce) for production processes, making the most of waste sources (*reuse*), and regenerating (*recycle*) components suitable parts and materials. From the perspective of establishing a circular hydrogen economy, the authors acknowledge that the story of building a hydrogen industry is not new content, but the circular hydrogen economy is a new approach that creates added economic value and contributes to reducing pressure on related industries such as energy and emissions treatment.

3.3. Circular hydrogen economy products and technologies

The products of the circular hydrogen economy are parts of the hydrogen industry products, not all those products can be recognized as hydrogen economy products, except for those that fulfill the requirements below:

- Produced from input materials that are output waste from another industry (industrial wastewater, food industry waste products...) or a renewable material source or originate from nature (biomass, seawater, rainwater...).

- The hydrogen production process is accompanied by effective carbon capture and storage techniques, minimizing emissions during the production process. Hydrogen production technologies themselves are designed with effective emission treatment processes and emission limitations.

- The energy source for this hydrogen production process is usually electricity and heat generated from renewable energy sources. In addition to using environmentally friendly technology and taking advantage of waste sources from other industries, using clean energy to limit emissions to produce hydrogen also plays an important role.

Thus, it is reasonable to classify the hydrogen product group into two main categories: the traditional hydrogen product group is the result of the traditional hydrogen economy, and the hydrogen product group is the result of the circular hydrogen economy. Regarding the hydrogen product group of the circular hydrogen economy, the products are also classified into two main groups: the pure hydrogen product group, and the hydrogen product group that integrates carbon emission treatment techniques. Below, the study will clarify the product groups that result from the circular hydrogen economy along with their achievements, as well as information on the optimal technology to create these products.

Green hydrogen products: Green hydrogen possesses the best economic value that the circular hydrogen economy can create. Green hydrogen has high energy density, and high purity, and is produced in a complete water-splitting (*electrolysis*) process without the participation of other impurities (Kang et al., 2022; Dos Santos et al., 2023). The characteristics of the electrolysis process that splits water and produces green hydrogen are depicted in Figure 3.

There are lots of reviews on green hydrogen production centered on the electrolysis of water, and most of those works discussed how to reduce the cost of the electrochemical system or improve the quality of the electrode pairs; However, this view is not enough, the water source issue deserves more attention. Accorded to many studies (Maeda et al., 2016; Tran et al., 2023), including an in-depth study by these authors published in the prestigious journal Applied Energy Materials, under the American Chemical Society publisher in 2023(Ajanovic et al., 2022), the understanding of water resources plays a

prerequisite role and needs to be given priority. So on, the customization of the electrochemical system can then be operated to suit the properties of the input aqueous sources.

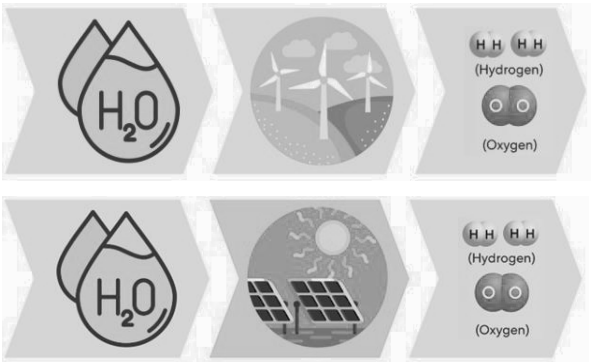

Figure 3. The production of green hydrogen via the electrolysis processes using renewable energy from wind/solar energy.

Pink hydrogen product: pink hydrogen belongs to the group of pure hydrogen products and is the result of a production process oriented towards a circular hydrogen economy. Compared to the group of hydrogen products that came before it: *gray hydrogen, brown hydrogen, blue hydrogen, and blue hydrogen,* pink hydrogen belongs to the second-generation group. The industrial-scale production of pink hydrogen is still in progress. development, this type of hydrogen product is sometimes referred to in some documents as purple hydrogen or red hydrogen. The pathway to produce pink hydrogen is presented in Figure 4.

Figure 4. The production of pink hydrogen via electrolysis of water using nuclear energy.

The production of pink hydrogen also depends on an electrolysis that splits water and produces a high-purity emission-limited hydrogen product. The energy source for this production process comes from nuclear energy. Utilizing nuclear energy to produce hydrogen is an important and key idea that can help stabilize energy plans in many countries with advanced nuclear energy industries. The specific characteristics of the pink hydrogen production process are different from the conventional electrolysis process; because of the dependence on high-temperature electrochemical process (*HTE – high-temperature electrolysis*) (Shrizadeh et al., 2023; Boardman et al., 2022).

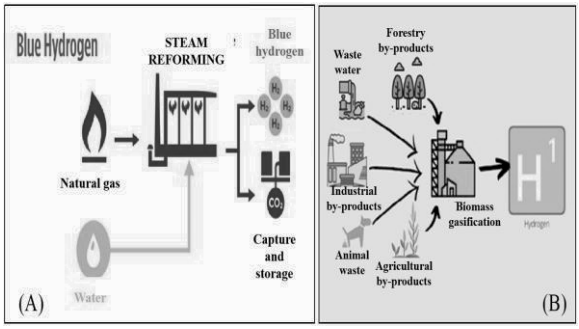

Figure 5. The production of hydrogen blue from natural gases (A) and the source of biomass or wastes (B). These processes can only be recognized as circular hydrogen products if they are accompanied by carbon treatment solutions

Blue hydrogen products and other products: In the processes explained in Figure 5, the technical elements of these processes are inherited from traditional processes. Hydrogen products are produced through traditional techniques such as reforming (steam/methane gas reforming) or gasification (gasification), the process raw materials used are flexible and the technical requirements during the process are flexible. The hydrogen production operation process is familiar to the production situation of many industries (Ucler et al., 2014; Zhao et al., 2022). However, close integration with carbon capture and storage techniques, as well as other emission treatment processes during operations, makes a vital contribution to creating blue hydrogen products instead of Products that are not suitable for the circular hydrogen economic model such as brown, gray hydrogen, etc.

The classification and evaluation of hydrogen products are still going strong and are constantly updated worldwide. However, the classification of hydrogen products can be viewed more simply from the following perspective:

- Group 1 – products are directly produced high-purity hydrogen products.
- Group 2 – hydrogen produced with the support of carbon capture and storage technologies;
- Group 3 – new hydrogen products in the testing phase.

In this article, the author does not mention hydrogen products that are considered potential and may be not yet suitable for a circular hydrogen economy; Accordingly, there are several new products such as yellow hydrogen (hydrogen is produced through the electrochemical process of splitting water, but using excess power on the grid to operate the electrochemical system), or turquoise hydrogen (produced from the methane pyrolysis process, applying emission treatment techniques during the production process).

3.4. The roadmap for circular hydrogen energy development in Vietnam: towards Vietnam Net-zero 2050

The strategy for developing a circular hydrogen economy shares many similarities with pioneering countries in this field such as China, Germany, and other European countries (Montag, 2023; European Commission, 2020, and Hassan et al., 2023). Accordingly, the development direction of the hydrogen economy in these countries is implemented based on four key issues with technology development and supportive policies as the focal points:

- The issue of investment in research and development of technology and scientific solutions (R&D).
- The issue of hydrogen project development (projects are diversified and categorized into human resource development projects, feedstock development projects, common operation management projects, and hydrogen product supply chain development projects).
- The issue of building supportive policies.
- The issue of applying hydrogen energy content into industries with a roadmap.

The most significant and effective implementation of energy transition and the application of hydrogen energy content is determined to be in industrial sectors (*such as the food industry, green fertilizers, oil refining, iron, steel, etc.*) and transportation sectors (Arvagani et al., 2022; Nakano et al., 2022).

Therefore, the process of developing a circular hydrogen economy should be approached with the following orientations:

- Utilizing hydrogen energy to effectively contribute to the mission of carbon emission reduction, aiming towards Vietnam's Net-zero target.
- The construction of a hydrogen economy must be based on a circular economic foundation: focusing on resource management and utilizing appropriate waste as inputs for the hydrogen production process.
- The circular hydrogen economy is intimately related to the carbon economy, and carbon certification issues, and has deep intersectoral connections (flexible in utilizing various raw materials, and different energy sources, and applicable to many production processes).

The R&D development directions for clean hydrogen products (*produced through carbon* emission *reduction processes*) of pioneering countries are shown in Table 1. According to the information provided in Table 1 *(compiled from the National Development and Reform Commission (China)*, *the Federal Ministry for Economic Affairs and Climate Action (Germany), and the European Commission*), all three sources of information are from developed countries with strong economies and significant resources for scientific and technological investments in the field of hydrogen energy (Ajanovic et al., 2023; Yuki et al., 2020). Among them, blue and green hydrogen products are considered focal points, while the role of gray/brown hydrogen in China is restricted and must be combined with carbon reduction processes.

The development of clean hydrogen projects is closely related and plays a crucial role in realizing the circular hydrogen economy. Benefiting from the achievements of efficiently implemented R&D activities, clean hydrogen development projects (*low-carbon hydrogen*) are led by reputable research institutes and universities in collaboration with companies and enterprises (*preferably those in the same region as the research unit*) and receive co-management and investment from the state budget (*as in the case of the National Key Research and Development Program of China (NKPs)*) (Ministry of Science and Technology of the People's Republic of China, 2018), or investment from international corporations, multinational agencies (*as in the case the H21 Leeds City Gate Project of the UK*) (Park et al., 2023).

Table 1. Investment orientation for hydrogen production technology development in the period from 2020 to 2035 in some pioneering countries

National strategy	*Medium and long-term plans for hydrogen energy industry development (2021-2035)*	*National hydrogen strategy (2020-2030)*	*Hydrogen strategy towards European neutrality (2020-2035)*
Key hydrogen products	*Gray, Green*	*Green*	*Blue, Green*
Expected hydrogen production	*100-200 thousand tons of clean hydrogen by 2025*	*5 GW by 2030*	*6 GW and 1 million tons by 2024* *40 GW and 10 million tons by 2030*
Estimated investment limit	-	*9 billion euros*	*Investment in electrolysis system development: 24-42 billion euros.* *Total investment value by 2050: 180-470 billion euros.*

In Vietnam, the Project Development Program (PDP) also emphasizes the focal role of green hydrogen development tasks, although specific information and projects have not yet been implemented. In addition to the open-ended points in the recent National Power Development Plan VIII, Vietnam also updates the progress of the hydrogen industry through Decision No. 893/QD-TTg and Decision No. 165/QD-TTg. These decisions outline plans to prepare energy sources and feedstock for future hydrogen production processes, as well as establish a roadmap and implementation plan to develop the hydrogen industry sustainably and feasibly, in line with the direction of building a circular hydrogen economy (*Appendix 1 provides information related to the roadmap for the development of the hydrogen industry in*

Vietnam). Accordingly, the orientations and analysis of key project groups in the development of the circular hydrogen economy are summarized in Table 2

Table 2. Summary and analysis of the roles of project groups in building a circular hydrogen economy

	**Workforce development projects for the hydrogen industry:** These are projects that need to be emphasized and developed in the period from 2020 to 2030. These projects not only focus on building a workforce for the hydrogen industry but also create a team of pioneering experts in the field of circular economy. For developing countries or countries with nascent hydrogen industries, absorbing lessons learned, scientific and technical research, and technology transfer activities heavily rely on the expertise and skills of the workforce in this sector.
	**Clean hydrogen production project group**: This project group is prioritized for implementation in countries such as China, Germany, the European Union, and other resource-rich nations. The determination of the desired hydrogen product plays a dominant role in the implementation of projects within this group (*scientific and technological, investment capital, infrastructure, specific advantages of each country, etc*.). Electrolysis is playing a central role in the story of hydrogen production technology in many countries such as the US, China (*currently leading the world in patent numbers and advanced hydrogen production facilities*), Germany, Japan, and the UK.
	**Hydrogen energy development project group in the transportation sector**: Hydrogen-based products have been developed earliest and most effectively in the transportation sector. There are numerous projects involving fuel cell electric vehicles (FCEVs) that use hydrogen fuel cells (*Toyota Mirai and Hyundai Nexo*). There are also projects involving hydrogen buses (*Hydrogen Bus Hyundai*) and hydrogen-powered trains like the Alstom Coradia iLint (*Germany*), which is the first and only one in the world and has been in operation since 2019. These FCEVs serve as a solution to address energy shortages and air pollution, as their emissions consist solely of water vapor.
	**Hydrogen energy application project group in industrial production**: The main objective of applying hydrogen in heavy industries is to reduce carbon emissions. Pilot projects applying hydrogen in sectors such as iron and steel production, food technology, and oil refineries… have been implemented and are ongoing in many developed countries around the world. For developing countries, the transition to hydrogen energy in industries should be implemented alongside hydrogen production projects, with priority given to the transportation sector.
	**Hydrogen storage and transportation project group**: The storage and transportation of hydrogen play a crucial role as a bridge between the upstream hydrogen production group and the downstream hydrogen consumption infrastructure group, ensuring the integrity of the hydrogen supply chain. In this regard, hydrogen storage and transportation are seen as valuable solutions for the group of developing countries participating in the construction and expansion of a global hydrogen economy. Establishing the necessary infrastructure and interconnecting cross-border hydrogen transportation networks is an effective strategy that does not require comprehensive changes in scientific and technical aspects (*hydrogen pipelines can be integrated into existing gas pipelines across countries*), and it generates sufficient economic value for a country to develop a comprehensive hydrogen plan.

As mentioned in the previous sections, the policies for developing the hydrogen industry in developing countries, including Vietnam, have several differences compared to countries with stronger capabilities, as mentioned earlier. The countries in the Southeast Asian region are typical examples of deploying blue hydrogen products and prioritizing infrastructure development for hydrogen transportation. It is challenging to propose a development roadmap for countries in this group due to the diverse orientations of the relevant countries, the lack of necessary connectivity, and the absence of a clear desired trajectory. However, the development roadmap for a circular hydrogen economy can be summarized as follows:

The period of 2024-2030: This phase strongly focuses on activities to develop human resources and establish policies that support the commercialization of hydrogen products. Policies that encourage investment and create conditions for foreign organizations and experts to conduct training activities and enhance awareness of hydrogen energy are considered prerequisites during this phase. Although recent implementation decisions in Vietnam do not specifically mention the task of developing human resources for the hydrogen industry, it is considered a prerequisite and will play an important role in the future endeavor of building a circular hydrogen economy in Vietnam.

The period of 2030-2035: This phase focuses on developing resource management policies for blue hydrogen production and considering this product as the focus of domestic production. Expanding capital support policies and mechanisms for R&D projects in hydrogen storage and distribution are also proposed. This phase also suggests policies to support the adoption of technology transfers in hydrogen production, gradually improving hydrogen transportation pipeline infrastructure.

The period of 2035-2040: This phase involves the localization of hydrogen production technologies, implementing policies to support the construction of microgrids & smart energy networks and electrification solutions.

Additionally, the deployment of fuel cell electric vehicles (FCEVs) contributes to driving national hydrogen consumption, prompting further support policies from relevant vehicle manufacturers. During this phase, the application of hydrogen in industrial operations should be nearing completion, while carbon emission regulations and carbon credits have already had certain impacts.

The period of 2040-2045: This phase focuses on achieving significant carbon emission reduction with comprehensive support policies, regulations, and relevant sanctions. The hydrogen production sector has achieved certain accomplishments after the issuance of policies promoting technology localization, while hydrogen has been incorporated into industrial production processes. At this stage, the pathway toward Net Zero is confirmed as feasible by 2050 or may require additional time for implementation.

The period of 2045-2050: This phase marks the initial achievement of a carbon-neutral Net Zero society. The support policies are fundamentally complete, entering a phase of maintaining Net Zero or addressing issues that arise after the first period of the Net Zero plan. Hydrogen emissions become a topic of discussion, which was initially mentioned in research during the 2020-2022 period and now likely becomes a significant concern in this phase. Thus, with clear development pathways, directions, and an analysis of the correlations

among the factors influencing the construction of a circular hydrogen economy, the development of the hydrogen industry in Vietnam and many places worldwide can choose a preliminary outline. However, the path to achieving a hydrogen society with zero emissions and a carbon-neutral society is not easy.

4. CONCLUSION

In recent years, hydrogen has emerged as a star in the field of new energy and has attracted a lot of attention. The development of hydrogen energy has become essential and has been strongly promoted with continuous updates on new technologies and products. Developed countries with superior economic and technological strength have laid a solid foundation for the development of the hydrogen industry. However, developing countries also desire to participate in the promising and innovative hydrogen economy. Nevertheless, limitations in scientific and technological capabilities and investment have posed challenges to this story. There are many developing countries, including Vietnam and neighboring Southeast Asian countries, that possess significant advantages in developing the hydrogen industry. Utilizing geographical advantages to develop hydrogen production industries holds the promise of bringing these Southeast Asian countries into a new era of energy, with carbon-neutral societies and numerous opportunities to attract investment and support from developed countries.

In this manner, this research outlines an overall picture describing the methods and proposed roadmap for developing a circular hydrogen economy, where developed countries could invest in and support their allies while developing countries have the chance to transition safely and efficiently into a new era. This research combines two intriguing concepts: building a hydrogen economy and developing a circular economy, aiming to create an effective, equitable, and promising solution for the hydrogen era. In terms of development models, the products of the circular hydrogen economy are formed through the coordination of superior scientific and technological solutions, clever support policies, and the process of managing waste as input for hydrogen production technologies. Accordingly, hydrogen products produced in the circular economy are considered clean, safe, low-emission, and can be flexibly applied and integrated with various other industries or production processes. Modern technologies such as fuel cells and carbon capture and storage (CCS)/carbon capture, utilization, and storage (CCUS) techniques are applied in the hydrogen production process to create products that meet the criteria set by the circular hydrogen economy.

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NỀN KINH TẾ HYDROGEN TUẦN HOÀN: THIẾT LẬP NGÀNH CÔNG NGHIỆP HYDROGEN HIỆN ĐẠI HƯỚNG TỚI MỤC TIÊU VIỆT NAM NETZERO 2050

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ABSTRACT

Trong những năm gần đây, việc phát triển hydrogen như một nguồn năng lượng đáng tin cậy mới đã trở thành xu hướng và thu hút được nhiều sự chú ý từ khắp nơi trên thế giới. Hydrogen là một nguyên tố cơ bản có thể được sản xuất thông qua nhiều quy trình khác nhau, nhìn chung các quy trình này có thể được phân loại thành ba nhóm chính: *quy trình xanh (điện phân), quy trình xử lý carbon (quy trình chuyển đổi nhiệt) và quy trình truyền thống (quy trình cải cách)*. Trong khi đó, các sản phẩm hydro được xác định bằng màu sắc cụ thể như hydro xanh lá cây, xanh lam và nâu… Giữa các sản phẩm này, Hydrogen sạch (xanh lam và xanh lục) có mật độ năng lượng mạnh, là nguồn năng lượng tái tạo, được sản xuất không phát thải và có giá trị kinh tế cao. Tuy nhiên, để có thể sản xuất được sản phẩm hydrogen ở quy mô lớn, quá trình sản xuất đó phải được thiết kế trên nền tảng nền kinh tế hydrogen tuần hoàn, sử dụng năng lượng xanh trong quá trình sản xuất, và tuân thủ các quy định về hạn chế phát thải carbon trong công nghiệp. Để làm được như vậy, lộ trình phát triển ngành công nghiệp hydrogen phải kết hợp được các lợi thế về điều kiện địa lý khu vực sản xuất, ứng dụng các công nghệ phù hợp, và tận dụng sự hỗ trợ của các chính sách đặc thù. Nền kinh tế hydrogen khỏe mạnh là một mô hình được xây dựng trên quy mô từ nhỏ đến lớn, cụ thể theo từng loại sản phẩm, xác định rõ được nhu cầu tiêu thụ. Từ đó, mô hình sản xuất này được triển khai cùng với những giải pháp lưu trữ linh hoạt, và quá trình vận chuyển sản phẩm hydrogen đến nơi tiêu thụ một cách an toàn và nhanh chóng. Nhận thức được tất cả những mối quan tâm đó, khái niệm nền kinh tế hydrogen tuần hoàn đã ra đời và được dự đoán sẽ là mô hình thống trị trong ngành công nghiệp hydro trên toàn thế giới. Làm rõ vai trò của nền kinh tế tuần hoàn trong việc thiết lập mô hình kinh tế hydrogen tuần hoàn đóng vai trò then chốt trong nghiên cứu này; Theo đó, những ưu điểm và nhược điểm của nền kinh tế tuần hoàn cũng được phân tích và trình bày, thông qua việc so sánh và kết luận thu được từ các nghiên cứu điển hình được thực hiện ở các quốc gia khác.