Chapter

Introductory Chapter: Hydrogen Energy

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1. Introduction

The purpose of this book is to provide abundant and substantial information about recent development in the production, storage, and application of hydrogen in the energy sector. Since hydrogen energy has benefits in use cases and, unlike synthetic carbon-based fuels, can be truly carbon neutral or even negative throughout its life cycle, hydrogen is emerging as a new energy vector outside of its traditional role and garnering more recognition globally as a viable fuel pathway. This book aims to cover the recent development in the use of hydrogen, storage, transportation, distribution, and the main difficulties and opportunities in the commercial deployment of such systems. It also discusses various methods for producing hydrogen using conventional and renewable energy sources.

2. An overview on energy demand

Because of the ongoing difficulties caused by diminishing fossil fuel supply and deteriorating environmental circumstances, the international community views sustainable development as a long-term issue. Rising energy demands, erratic fossil fuel prices, and significant greenhouse gas (GHG) emissions from fossil fuel-powered vehicles and businesses are the primary causes of this fundamental transition [1–3].

By 2030, the population of the world is expected to reach eight billion, and an increase in energy demand is predicted. In recent decades, renewable energy sources including wind, solar, hydro, and geothermal have drawn a lot of interest. These forms of energy do not produce liquid or gaseous fuels for transportation. Their applicability is constrained by their unpredictable and sporadic existence [4]. Invasive plants and food waste (especially tree trimmings and agricultural crop waste) are additionally low-cost and accessible resources for conversion to clean energy production [5]. Food scraps [6], municipal waste residue, agrochemicals, pharmaceuticals, animal waste, mixed polymers, and lignocellulosic feedstocks are all readily available and inexpensive [7].

Human life, social culture, and economic development all depend on energy. Conventional fossil fuels have been exploited for over two decades, including coal, gasoline, and natural gas, lead to unsustainable oil use, unrestrained exploitation, and major pollution [8]. These non-renewable resources are therefore rapidly approaching degradation and exhaustion [9]. Particularly, the rapid economic transformation and escalating worldwide population increase are driving up energy demand and escalating the energy issue [10]. Furthermore, there is enormous environmental

contamination because of the overuse and consumption of fossil fuels. The majority of nations are therefore eager to create a different source of renewable energy [11].

3. Hydrogen energy

Hydrogen is an excellent choice as an energy source for heat and power, among many other uses, due to its many positive qualities, including its overall storage capacity, efficiency, renewability, cleanliness, massive distribution, high conversion, zero emissions, sources, versatility, and quick recovery [12]. It is, therefore, recognized as the most promising and environmentally beneficial energy source of the twenty-first century. It is essential to industrial processes like the generation of ammonia, oil refinement, and water-gas switch reactions [13].

The demand for hydrogen has recently increased dramatically in industrialization's classic oil upgrading industries, including hydro-desulfurization, hydrogenation, and ammonia processing. Due to its affordability and easy access to hydrogen, the majority of the liquid-compressed hydrogen gas used in industrial processing is created commercially using the compression method [14]. Solar power can also be used to produce hydrogen from renewable sources like lignocellulosic biomass or water purification.

3.1 Hydrogen production

Numerous methods exist for obtaining hydrogen from various sources, including electrolysis of water, biofuels, petroleum-based liquids, microbes, and biofuels [14]. Hydrogen production methods and classifications are briefly schematized in **Figure 1**. As seen in the Figure, classification of hydrogen according to the production

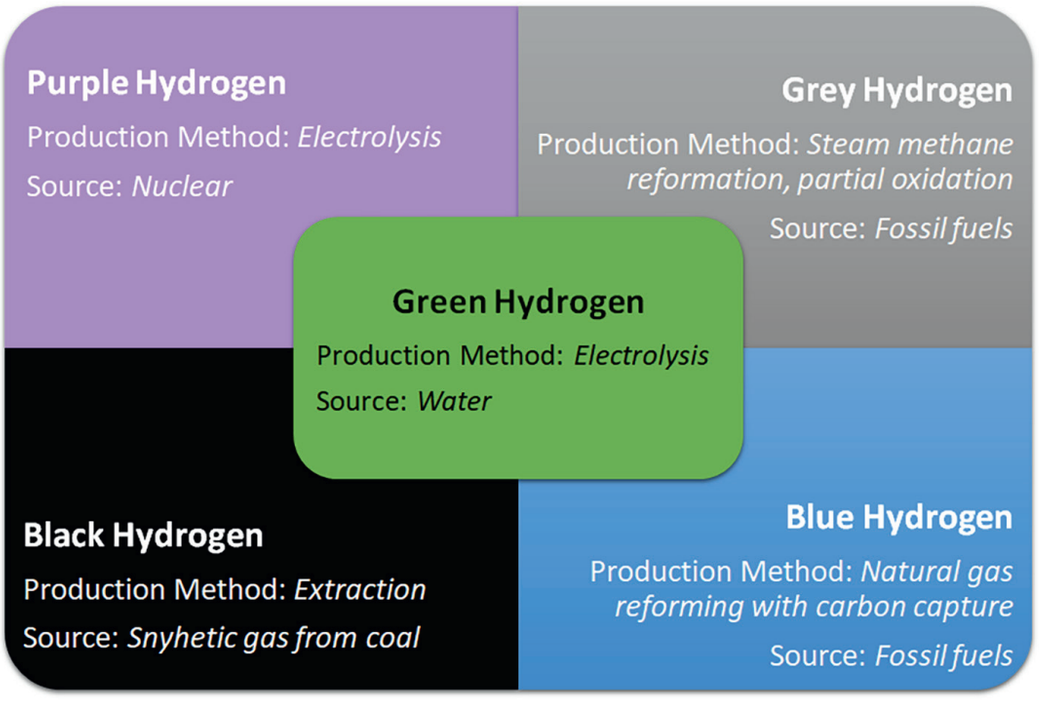

Figure 1.
Hydrogen production methods and hydrogen classification.

method is made with color codes. Greenhouse gas emissions that may occur during the production process are also considered in color coding. For example, hydrogen produced through the electrolysis of water using electricity from renewable sources is coded green and produces near-zero greenhouse gas emissions. Hydrogen, coded in blue, is produced through carbon capture and storage and steam methane reforming. Greenhouse gas emissions from the production of blue hydrogen are characterized as low. Greenhouse gas emissions are high in the gray hydrogen production, produced through steam methane reforming using natural gas [15].

3.2 Hydrogen storage and transportation

There are various methods for storing and transporting hydrogen after its production. The transportation process is done by compressing the hydrogen in gas form or converting it into liquid form in a pressurized environment and then loading it into tankers. However, due to the increasing need for hydrogen in the coming years, it is possible to transport hydrogen through existing natural gas pipelines. For storage, the priority is concentrated on methods that allow transportation. Methods that prioritize transportation for the storage of hydrogen, liquid hydrogen, gaseous hydrogen, metal hydride, and chemical storage. The storage methods of hydrogen are presented in **Figure 2**.

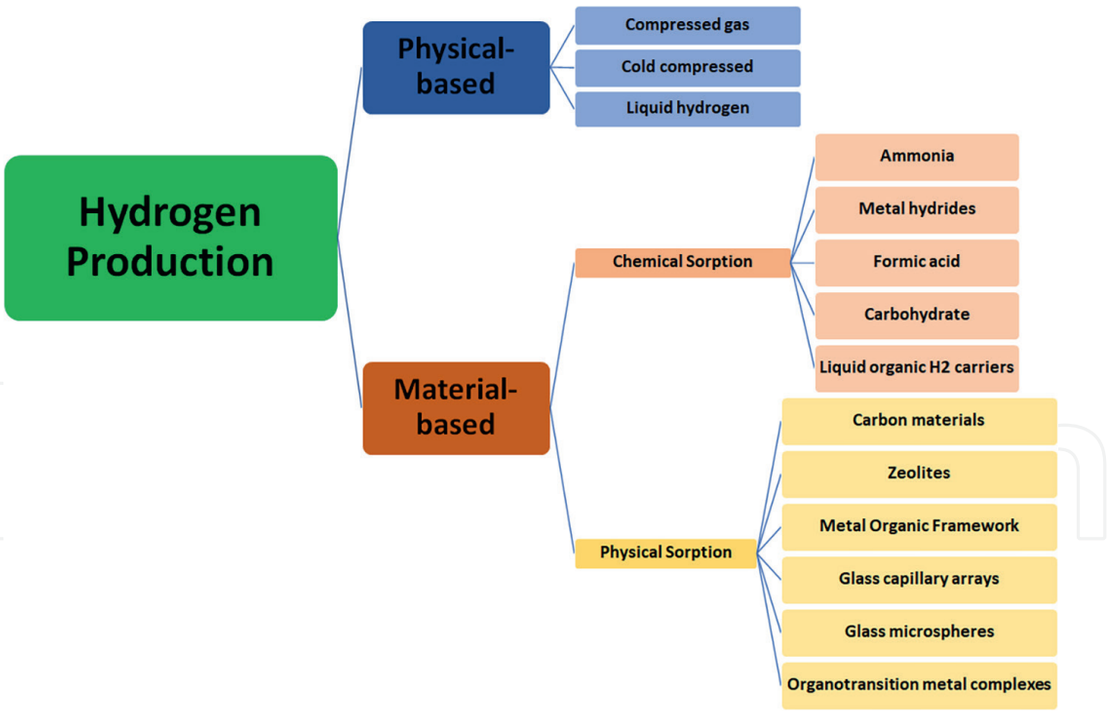

Figure 2.
Hydrogen storage methods (adopted from [16]).

3.3 Hydrogen applications

Hydrogen is an energy storage medium, as well as an energy carrier. It has multiple fuels uses—hydrogen vehicles, stationary power sources, building heating, industrial feedstock, and industrial energy [17] (**Figure 3**). Thus, hydrogen is attracting the

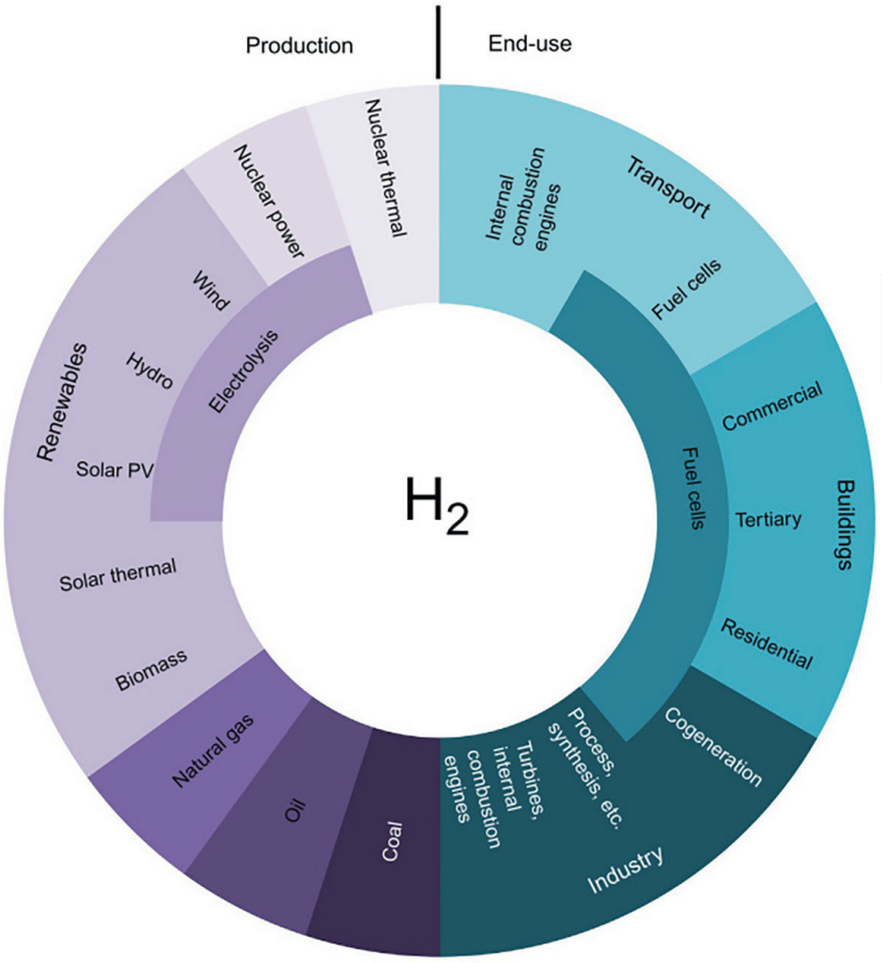

Figure 3.
Production and applications of hydrogen [18].

keen interest of several groups from governments to companies as it offers ways to decarbonize a lot of sectors, especially those that have been proven to be difficult to reduce emissions meaningfully. Moreover, in the industry, hydrogen has had an increasingly important role along the production chain in the last few years [19].

4. Conclusions

Hydrogen energy technologies cannot be used in the industry due to the high production cost, storage difficulties, and transportation costs in today's conditions. However, the fact that hydrogen can be used directly without air pollutants or greenhouse gas emissions and can be produced from low-carbon energy sources are the main reasons for the widespread preference for hydrogen. Clean energy is used to limit air pollution and global warming, especially where the climate crisis has come to the fore in global markets. Various countries and companies see hydrogen as an important clean energy resource that is likely to play a role in the future of the energy sector.

Hydrogen: is a resource that proposes methods that can provide decarbonization in sectors where it is difficult to reduce emissions such as transportation, petrochemistry, and iron and steel. In addition, hydrogen can help improve air quality and

increase energy security. Thanks to hydrogen, some technologies can produce, store, transport, and use energy in different routines. Hydrogen, which can be transported in liquid form by pipelines, tankers, and ships, can be converted into electricity and methane, used as energy for households or manufacturing sectors, or as fuel for cars, trucks, ships, and airplanes.

Hydrogen is increasingly forming the basis of mainstream energy debates all over the world. In recent years, many experts have been investigating the potential of using this source to produce, transport, and store hydrogen from various sources and to provide an emission-free final energy supply.

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References

[1] Javaid R, Kawanami H, Chatterjee M, Ishizaka T, Suzuki A, Suzuki TM. Fabrication of microtubular reactors coated with thin catalytic layer (M=Pd, Pd–Cu, Pt, Rh, Au). Catalysis Communications. 2010;**11**:1160-1164. DOI: 10.1016/J.CATCOM.2010.05.018

[2] Rana R, Nanda S, Reddy SN, Dalai AK, Kozinski JA, Gökalp I. Catalytic gasification of light and heavy gas oils in supercritical water. Journal of the Energy Institute. 2020;**93**:2025-2032. DOI: 10.1016/J.JOEI.2020.04.018

[3] Staples MD, Malina R, Barrett SRH. The limits of bioenergy for mitigating global life-cycle greenhouse gas emissions from fossil fuels. Nature Energy. 2017;**22**(2):1-8. DOI: 10.1038/nenergy.2016.202

[4] Nanda S, Azargohar R, Dalai AK, Kozinski JA. An assessment on the sustainability of lignocellulosic biomass for biorefining. Renewable and Sustainable Energy Reviews. 2015;**50**:925-941. DOI: 10.1016/J.RSER.2015.05.058

[5] Okolie JA, Nanda S, Dalai AK, Berruti F, Kozinski JA. A review on subcritical and supercritical water gasification of biogenic, polymeric and petroleum wastes to hydrogen-rich synthesis gas. Renewable and Sustainable Energy Reviews. 2020;**119**:109546. DOI: 10.1016/J.RSER.2019.109546

[6] Yukesh Kannah R, Merrylin J, Poornima Devi T, Kavitha S, Sivashanmugam P, Kumar G, et al. Food waste valorization: Biofuels and value added product recovery. Bioresource Technology Reports. 2020;**11**:100524. DOI: 10.1016/J.BITEB.2020.100524

[7] Nanda S, Berruti F. A technical review of bioenergy and resource recovery from municipal solid waste. Journal of Hazardous Materials. 2021a;**403**:123970. DOI: 10.1016/J.JHAZMAT.2020.123970

[8] Santana KVR, Apolônio FCSO, Wisniewski A. Valorization of cattle manure by thermoconversion process in a rotary kiln reactor to produce environmentally friendly products. Bioenergy Research. 2020;**13**:605-617. DOI: 10.1007/S12155-019-10047-0/TABLES/6

[9] Nanda S, Berruti F. Thermochemical conversion of plastic waste to fuels: A review. Environmental Chemistry Letters. 2021b;**19**:123-148. DOI: 10.1007/S10311-020-01094-7/TABLES/2

[10] Mohr SH, Wang J, Ellem G, Ward J, Giurco D. Projection of world fossil fuels by country. Fuel. 2015;**141**:120-135. DOI: 10.1016/J.FUEL.2014.10.030

[11] Ouyang X, Lin B. Impacts of increasing renewable energy subsidies and phasing out fossil fuel subsidies in China. Renewable and Sustainable Energy Reviews. 2014;**37**:933-942. DOI: 10.1016/J.RSER.2014.05.013

[12] Javaid R. Catalytic hydrogen production, storage and application. Catal. 2021;**11**:836. DOI: 10.3390/CATAL11070836

[13] Sánchez JM, Barreiro MM, Maroño M. Bench-scale study of separation of hydrogen from gasification gases using a palladium-based membrane reactor. Fuel. 2014;**116**:894-903. DOI: 10.1016/J.FUEL.2013.02.051

[14] Singh S, Kumar R, Setiabudi HD, Nanda S, Vo DVN. Advanced synthesis

strategies of mesoporous SBA-15 supported catalysts for catalytic reforming applications: A state-of-the-art review. Applied Catalysis A: General. 2018;**559**:57-74. DOI: 10.1016/J.APCATA.2018.04.015

[15] Scita R, Raimondi PP, Noussan M. Barriers to the Implementation of a Clean Hydrogen Economy; Green Hydrogen: Kolding, Denmark; Milan, MI, USA: Fondazione Eni Enrico Mattei (FEEM); 2020. pp. 8-15

[16] Montenegro AR, Sanjuan M, Carmona M. Energy storage development using hydrogen and its potential application in Colombia. International Journal of Energy Economics and Policy. 2019;**9**:254-268. DOI: 10.32479/ijeep.8294

[17] Sakthivel S. Hydrogen economy offers low-emissions fuel to combat air pollution. Available from: http://gasprocessingnews.com/features/202008/hydrogen-economy-offers-low-emissions-fuel-to-combat-air-pollution.aspx [Accessed: 04 November, 2022]

[18] Mansilla C, Bourasseau C, Cany C, Guinot B, Le Duigou A, Lucchese P. Hydrogen Applications: Overview of the Key Economic Issues and Perspectives. In:Azzaro-Pantel C, editor. Hydrogen Supply Chains (Chapter 7 in Hydrogen Supply Chains: Design, Deployment and Operation). Academic Press-Elsevier; 2018. pp. 271-292. DOI: 10.1016/b978-0-12-811197-0.00007-5

[19] Von Zuben T, Moreira D, Germscheidt R, Yoshimura R, Dorretto D, de Araujo A, et al. Is hydrogen indispensable for a sustainable world? A review of H2 applications and perspectives for the next years. Journal of the Brazilian Chemical Society. 2022;**33**:824-843. DOI: 10.21577/0103-5053.20220026