catalysts

Editorial

Catalysts for Sustainable Hydrogen Production: Preparation, Applications and Process Integration

Concetta Ruocco * and Marco Martino *

Department of Industrial Engineering, University of Salerno, Via Giovanni Paolo II 132, 84084 Fisciano, SA, Italy
* Correspondence: cruocco@unisa.it (C.R.); mamartino@unisa.it (M.M.)

check for updates

Citation: Ruocco, C.; Martino, M. Catalysts for Sustainable Hydrogen Production: Preparation, Applications and Process Integration. *Catalysts* **2022**, *12*, 322. https://doi.org/10.3390/catal12030322

Received: 9 March 2022
Accepted: 10 March 2022
Published: 11 March 2022

The earth is experiencing a series of epochal emergencies, directly related to the overexploitation of natural resources. Climate change, economic and health conditions of poor countries as well as geopolitical tensions affect the availability of raw materials and, above all, the environmental and economic costs of energy. Researchers around the world have raised the alarm about the effect of excessive greenhouse gas emissions on the environment and on humans, advocating for the reduction of greenhouse gas emissions by at least 45% by 2030 [1] and carbon neutrality by 2050 to ensure a containment of global warming to +1.5 °C [2]. The world is hungry for cheap, clean energy; however, these two requirements seem difficult to reconcile. The current most practicable route involves the use of clean energy vectors, and, in this context, hydrogen appears to be extremely promising in supporting the electrification of processes, which requires long-term energy storage [1]. In this Special Issue, a series of articles tackle the issues associated with the production, storage, and purification of hydrogen.

Hydrogen production can be centralized or on-site, depending on the intended use. In both cases, different production processes are used; moreover, in the case of centralized production, the additional steps involved in the storage and distribution of hydrogen may present critical issues [3].

Hydrogen can be produced from a large variety of processes and raw materials; however, only hydrogen obtained from a renewable feedstock (by using renewable energy sources) can be defined as "green" [4] and hence clean. Most hydrogen is produced via the natural gas reforming processes; however, the biomass gasification and pyrolysis [5] to obtain bio-oil and followed by reforming is growing as a green alternative [6]. Model organic molecules derived from biomass, such as methanol, ethanol [7] or acetic acid [8] have been extensively studied in the last decades as hydrogen sources by pointing out the required improvement of the stability and selectivity of the involved catalytic systems. Water splitting is considered an ideal hydrogen production process as it can potentially substitute conventional fossil fuel-based processes with zero-carbon dioxide emissions [9]. However, the high cost of the most used Pt-based catalysts for the hydrogen evolution reaction is a major limitation to large-scale diffusion. Alternative catalytic systems, such as nickel sulfides on stainless steel, obtained by using electrodeposition and sulfurization techniques, may represent an effective solution [9]. Biological and photonic methods, such as fermentation, are extremely attractive but, despite meeting the demand for obtaining green hydrogen, are affected by the variability of the composition and high process costs, which represent a serious limitation to their diffusion [10].

Hydrogen storage materials, such as chemical hydride, are strategic hydrogen reserves that reconcile production with storage needs. An excellent example is the ammonia borane, which, with a high hydrogen capacity (19.6 wt%), low molecular mass, high solubility and stability in atmospheric pressure and ambient temperature, can be considered a candidate for the controlled storage and release of hydrogen [3]. On the other hand, on-site production allows the overcoming of issues related to distribution and storage, although applicable only to small scale productions. In the latter case, the size of the production plants plays a fundamental role.

When hydrogen is produced by reforming processes, further purification steps are required to obtain high purity hydrogen; in this regard, a critical issue is related to the reduction of the CO percentage [11]. To meet the specifications for fuel cell applications (ISO 14687:2019) the CO content must be less than 10 ppm, while for road vehicles and stationary appliances it must be less than 0.2 ppm [12]. CO water–gas shift is often used to reduce the amount of carbon monoxide and increase the amount of hydrogen in the reformate gas stream. Structured catalysts have been proposed as the best choice for the design of a single-stage process for small reactors [13]. However, the water–gas shift alone is not sufficient to reduce the CO content to levels of a few ppm; therefore, an integration with membranes is required. Pressure swing adsorption can be used to remove most of the contaminants, not only CO; however, single purification methods are limited. Therefore, in view of meeting the most stringent standards [14], the integration between two or even more purification technologies should be adopted.

The hydrogen economy is still a long way off, as a number of limitations and problems have not yet been resolved and massive investments in research are needed. A new generation of membranes could be the flywheel for integration with electrified hydrogen production processes. The articles presented in this Special Issue provide a comprehensive picture of what has already been done in this regard and what still needs to be done.

Author Contributions: Conceptualization, C.R. and M.M.; methodology, C.R. and M.M.; software, C.R. and M.M.; validation, C.R. and M.M.; formal analysis, C.R. and M.M.; investigation, C.R. and M.M.; resources, C.R. and M.M.; data curation, C.R. and M.M.; writing—original draft preparation, C.R. and M.M.; writing—review and editing, C.R. and M.M.; visualization, C.R. and M.M.; supervision, C.R. and M.M.; project administration, C.R. and M.M.; funding acquisition, C.R. and M.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: The Guest Editors would like to thank everyone who contributed to the success of this Special Issue. The Authors of the published articles for the quality of the submitted papers, and the Catalysts Editorial staff for the commitment and constant support.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Marnellos, G.E.; Klassen, T. Welcome to Hydrogen—A New International and Interdisciplinary Open Access Journal of Growing Interest in Our Society. *Hydrogen* **2020**, *1*, 6. [CrossRef]
2. What Is Carbon Neutrality and How can It Be Achieved by 2050? Available online: https://www.europarl.europa.eu/news/en/headlines/society/20190926STO62270/what-is-carbon-neutrality-and-how-can-it-be-achieved-by-2050 (accessed on 5 March 2022).
3. Liu, M.; Zhou, L.; Luo, X.; Wan, C.; Xu, L. Recent Advances in Noble Metal Catalysts for Hydrogen Production from Ammonia Borane. *Catalysts* **2020**, *10*, 788. [CrossRef]
4. Atilhan, S.; Park, S.; El-Halwagi, M.M.; Atilhan, M.; Moore, M.; Nielsen, R.B. Green hydrogen as an alternative fuel for the shipping industry. *Curr. Opin. Chem. Eng.* **2021**, *31*, 100668. [CrossRef]
5. Quiroga, E.; Moltó, J.; Conesa, J.A.; Valero, M.F.; Cobo, M. Kinetics of the Catalytic Thermal Degradation of Sugarcane Residual Biomass Over Rh-Pt/CeO_2-SiO_2 for Syngas Production. *Catalysts* **2020**, *10*, 508. [CrossRef]
6. Martino, M.; Ruocco, C.; Meloni, E.; Pullumbi, P.; Palma, V. Main Hydrogen Production Processes: An Overview. *Catalysts* **2021**, *11*, 547. [CrossRef]
7. Palma, V.; Ruocco, C.; Cortese, M.; Martino, M. Bioalcohol Reforming: An Overview of the Recent Advances for the Enhancement of Catalyst Stability. *Catalysts* **2020**, *10*, 665. [CrossRef]
8. Megía, P.J.; Carrero, A.; Calles, J.A.; Vizcaíno, A.J. Hydrogen Production from Steam Reforming of Acetic Acid as a Model Compound of the Aqueous Fraction of Microalgae HTL Using Co-M/SBA-15 (M: Cu, Ag, Ce, Cr) Catalysts. *Catalysts* **2019**, *9*, 1013. [CrossRef]
9. Youn, J.-S.; Jeong, S.; Oh, I.; Park, S.; Mai, H.D.; Jeon, K.-J. Enhanced Electrocatalytic Activity of Stainless Steel Substrate by Nickel Sulfides for Efficient Hydrogen Evolution. *Catalysts* **2020**, *10*, 1274. [CrossRef]
10. Kannah, R.Y.; Kavitha, S.; Preethi; Karthikeyan, O.P.; Kumar, G.; Dai-Viet, N.V.; Banu, J.R. Techno-economic assessment of various hydrogen production methods—A review. *Bioresour. Technol.* **2021**, *319*, 124175. [CrossRef] [PubMed]

11. Cifuentes, B.; Bustamante, F.; Cobo, M. Single and Dual Metal Oxides as Promising Supports for Carbon Monoxide Removal from an Actual Syngas: The Crucial Role of Support on the Selectivity of the Au–Cu System. *Catalysts* **2019**, *9*, 852. [CrossRef]
12. Bang, G.; Moon, D.-K.; Kang, J.-H.; Han, Y.-J.; Kim, K.-M.; Lee, C.-H. High-purity hydrogen production via a water-gas-shift reaction in a palladium-copper catalytic membrane reactor integrated with pressure swing adsorption. *Chem. Eng. J.* **2021**, *411*, 128473. [CrossRef]
13. Palma, V.; Gallucci, F.; Pullumbi, P.; Ruocco, C.; Meloni, E.; Martino, M. Pt/Re/CeO2 Based Catalysts for CO-Water–Gas Shift Reaction: From Powders to Structured Catalyst. *Catalysts* **2020**, *10*, 564. [CrossRef]
14. Du, Z.; Liu, C.; Zhai, J.; Guo, X.; Xiong, Y.; Su, W.; He, G. A Review of Hydrogen Purification Technologies for Fuel Cell Vehicles. *Catalysts* **2021**, *11*, 393. [CrossRef]