catalysts

MDPI

Editorial

Catalysts for Polymer Membrane Fuel Cells

William Mustain [1,*] and Bryan Pivovar [2,*]

[1] Department of Chemical Engineering, University of South Carolina, Columbia, SC 29016, USA
[2] National Renewable Energy Laboratory, Golden, CO 80401, USA
* Correspondence: MUSTAINW@mailbox.sc.edu (W.M.); Bryan.Pivovar@nrel.gov (B.P.)

Received: 20 December 2019; Accepted: 25 December 2019; Published: 7 January 2020

Low-temperature fuel cells with a polymer membrane electrolyte are at an exciting time in their development. State-of-the-art proton-exchange membrane fuel cells (PEMFCs) are able to achieve extremely high areal current density and high power density. Systems have been demonstrated with tens of thousands of hours of continuous lifetime. Despite this, these low-temperature fuel cells remain unable to achieve appreciable market penetration. In many cases (e.g., automotive) the main reason for limited commercial deployment is that the overall cost remains too high, and it is believed that further engineering of the existing system may not allow PEMFCs to meet government and industrial cost targets. Very similar arguments can be made for the limitations of existing low-temperature membrane-based electrolysis systems for producing H_2.

Two approaches with the potential to revolutionize the fuel cell market and allow for cost to be substantively decreased are: (1) the emergence of very-high-activity and highly performing catalysts that are platinum group metal (PGM)-free. PGM-free catalysts present a new learning curve from a catalysis perspective because of the uncertainty in the nature of the active site, generally low active site density, and often low turnover frequencies. Hence, many fuel cells deploying PGM-free catalysts have high catalyst loadings and thick catalyst layers, which can impart mass transport limitations into the system; and (2) rethinking the chemistry of the system. Anion-exchange membrane fuel cells (AEMFCs) and electrolyzers are rapidly increasing in popularity. It is thought that AEMFCs will allow for lower-cost catalysts, bipolar plates, and balance of plant than PEMFCs. However, from a catalysis perspective, AEMFCs suffer from sluggish kinetics at the anode and the cathode, and the choices for catalysts outside of the PGM family are limited.

This focus of this special issue of *Catalysts* is to show several examples of state-of-the-art approaches to reduce the cost of these polymer electrolyte membrane systems. In putting together this special issue, we purposely targeted a breadth of perspectives, approaches, and problems instead of focusing on one very specific area. Hopefully, this gives the reader a holistic view of the state of the field. A common approach to reducing the cost of polymer electrolyte systems is to reduce the Pt loading in the system, which can be done through either a change in catalyst or a change in architecture. On the catalyst side, Co–Pt bronzes were shown to have very good activity and stability whilst significantly reducing the amount of Pt in the catalyst layer [1]. Related to the electrode architecture, two papers explored fundamentally different methods for manipulating the pore structure of the support. Remy et al. [2] used an interesting approach to reduce the dimensionality of the repeating unit of the carbon support material by replacing traditional carbon black with graphene and carbon nanotubes. Kamitaka and coworkers [3] uniquely explored a sacrificial nanostructured metal-oxide template to create the support architecture, which was then deployed successfully in a PEMFC.

Other authors explored the design space of PGM-free catalysts. Li et al. [4] reported Fe–N–C-type oxygen reduction reaction cathodes with FeN_x. Although FeN_4 catalysts show the best activity in acid media, this paper also showed that there are several structures that show interesting activity in alkaline media, including some that are intrinsically unstable in acid. This does give some interesting life to the possibility of very-high-activity catalysts for AEMFCs with totally different structures than PEMFCs, which was also explored in this special issue by Peng et al. [5] and Sharma et al. [6]. Peng's work not only supports Li's work, showing that chemistries that are unstable in acid media may be reasonable for alkaline media; Peng's work also shows the importance of material structure on electrode performance. In that paper, the intrinsic activity of the cobalt ferrite catalyst was not as high as others in the literature, but its performance in an operating AEMFC was among the best reported in the world to date. Sharma showed that non-PGM catalysts, Pr_6O_{11} specifically, can be active not only for the oxygen reduction, but for oxygen evolution and hydrogen evolution. Speaking of hydrogen reactions, Davydova and coworkers [7] used three-electrode rotating disc electrode experiments to show that Fe, Co, and Cu-doped Ni can have very high hydrogen oxidation reaction activity in alkaline media. Finalizing the discussion on catalysts is a thorough review by Sun et al. [8], which discussed state-of-the-art PGM-free catalysts for PEM electrolyzers, giving an important perspective on activity, cost, and stability. This review is extremely fundamental and thorough, and it provides an excellent starting point for new researchers in this field to understand what was done and what can be done in the future.

The final two articles in this collection are meant to encourage the reader to have extremely broad interpretations of "catalyst"-relevant approaches to reduce cost. In one of these articles, Kang and Chen [9] explored electrodes of different composition and their response to the presence of impurities, which provided some interesting findings that can be applied to possible low-Pt electrode designs in the future. Lastly, Pollet reminded us that cost is also related to the manufacture of the individual components, not just their chemistry and composition [10].

In closing, we would like to express our sincerest thanks to all authors for their high-quality contributions. It takes a lot of time, energy, and passion to bring these ideas to life and then to share them with the scientific community. Without all of you, this special issue simply would not have been possible.

Author Contributions: W.M. and B.P. contributed equally to the writing of this article. All authors have read and agreed to the published version of the manuscript.

Funding: No external funding was used for the writing of this article.

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

References

1. Kamitaka, Y.; Taguchi, N.; Morimoto, Y. Assessing the Potential of Co-Pt Bronze for Electrocatalysis in Acidic Media. *Catalysts* **2018**, *8*, 258. [CrossRef]
2. Remy, E.; Thomas, Y.R.J.; Guetaz, L.; Fouda-Onana, F.; Jacques, P.; Heitzmann, M. Optimization and Tunability of 2D Graphene and 1D Carbon Nanotube Electrocatalysts, Structure for PEM Fuel Cells. *Catalysts* **2018**, *8*, 377. [CrossRef]
3. Kamitaka, Y.; Takeshita, T.; Morimoto, Y. MgO-Templated Mesoporous Carbon as a Catalyst Support for Polymer Electrolyte Fuel Cells. *Catalysts* **2018**, *8*, 230. [CrossRef]
4. Li, J.; Jia, Q.; Mukerjee, S.; Sougrati, M.; Drazic, G.; Zitolo, A.; Jaouen, F. The Challenge of Achieving a High Density of Fe-Based Active Sites in a Highly Graphitic Carbon Matrix. *Catalysts* **2019**, *9*, 144. [CrossRef]
5. Peng, X.; Kashyap, V.; Ng, B.; Kurungot, S.; Wang, L.; Varcoe, J.R.; Mustain, W.E. High-Performing PGM-Free AEMFC Cathodes from Carbon-Supported Cobalt Ferrite Nanoparticles. *Catalysts* **2019**, *9*, 264. [CrossRef]
6. Sharma, R.K.; Müller, V.; Chatenet, M.; Djurado, E. Oxygen Reduction Reaction Electrocatalysis in Alkaline Electrolyte on Glassy-Carbon-Supported Nanostructured Pr_6O_{11} Thin-Films. *Catalysts* **2018**, *8*, 461. [CrossRef]
7. Davydova, E.S.; Zaffran, J.; Dhaka, K.; Toroker, M.C.; Dekel, D.R. Hydrogen Oxidation on Ni-Based Electrocatalysts: The Effect of Metal Doping. *Catalysts* **2018**, *8*, 454. [CrossRef]

8. Sun, X.; Xu, K.; Fleischer, C.; Liu, X.; Grandcolas, M.; Strandbakke, R.; Bjørheim, T.S.; Norby, T.; Chatzitakis, A. Earth-Abundant Electrocatalysts in Proton Exchange Membrane Electrolyzers. *Catalysts* **2018**, *8*, 657. [CrossRef]
9. Kang, R.; Chen, Y. Experimental Study on the Effect of Hydrogen Sulfide on High-Temperature Proton Exchange Membrane Fuel Cells by Using Electrochemical Impedance Spectroscopy. *Catalysts* **2018**, *8*, 441. [CrossRef]
10. Pollet, B.G. The Use of Power Ultrasound for the Production of PEMFC and PEMWE Catalysts and Low-Pt Loading and High-Performing Electrodes. *Catalysts* **2019**, *9*, 246. [CrossRef]