

Bryan S. Pivovar

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Education and Training:

B.S. Chemical Engineering, University of Wisconsin-Madison, 1994
Ph.D. Chemical Engineering, University of Minnesota-Twin Cities, 2000
Advisors: Edward L. Cussler and William H. Smyrl

*Employment History***National Renewable Energy Laboratory**

Director H2NEW (10/20-present), Senior Research Fellow (9/19-present), Group Manager (1/10-present), Senior Scientist (6/08-9/19)

Responsible for building and maintaining an R&D program based on fuel cells and electrolyzers, and contributing to research in other areas of energy efficiency and renewable energy. Responsible for establishing labs, research competencies, setting research direction, staffing, budget oversight, and research oversight (technical staff members, technicians, post-docs and graduate students). Technical areas of contribution focused on novel membranes/ionomers, extended surface electrocatalysts, novel electrode/MEA development and advanced diagnostics in areas that include fuel cells, electrolyzers, and electrochemical hydrogen compression, as well as leadership in membranes/separations.

Colorado School of Mines

Associate Research Professor (2/2011-present), Dept of Chemistry, Colorado School of Mines
Served on thesis committee of several PhD candidates, co-advised PhD Students.

Los Alamos National Laboratory

Fuel Cell Team Leader (2/05-5/08), Acting Program Manager Fuel Cells (2/08-5/08), Technical Staff Member (4/01-2/05), Post-doctoral Researcher (3/00-4/01)

Responsible for setting research direction, staffing, budget oversight, and research oversight (technical staff members, technicians, post-docs and graduate students). Projects were focused at the MEA level and included: electrode supports, impurities, fundamental science for cost and durability, freezing effects, non-precious catalysis, direct methanol fuel cells, hydroxide conductors, non-Nafion MEAs and high temperature membranes.

University of Minnesota

Research/ Teaching Assistant (9/94-2/00)

Thesis research centered on direct methanol fuel cell electrolytes with emphasis on methanol permeability, proton conductivity and electro-osmotic drag. Involved with the establishment of a fuel cell test facility.

Honors and Appointments

- '22 Chair 3rd International Conference on Electrolysis (ICE 2021)
- '22 Co-Chair Advanced Materials for PEM Electrolysis Workshop (H2-AMP)
- '22 Co-Chair Liquid Alkaline Water Electrolysis Workshop (H2-LAWE)
- '21 US DOE Secretary's Honor Award

'21 Electrochemical Society Energy Technology Division Research Award
 '20 Director Hydrogen from Next-generation Electrolyzers of Water (H2NEW) Consortium
 '19 NREL Senior Research Fellow
 '18 NREL Chairman's Award
 '18 DOE Hydrogen and Fuel Cells Program Special Recognition Award (For exceptional efforts and visionary leadership on the groundbreaking H2@Scale initiative)
 '16 NREL Presidents Award
 '16 DOE Hydrogen and Fuel Cells Program Special Recognition Award (for Outstanding dedication and contributions to the Hydrogen at Scale National Lab-wide Big Idea)
 '16 Organizer DOE/FCTO Alkaline Membrane Fuel Cell Workshop
 '12 Charles Tobias Young Investigator Award (Electrochemical Society)
 '11 Organizer/Chair DOE/ARO Alkaline Membrane Fuel Cell Workshop
 '09 RASEI Fellow (Founding) – Joint NREL-University of Colorado Energy Institute
 '17, '12, '10, '08 International Science Steering Committee– Progress MEA (CARISMA)
 '17, Organizing Committee– International Conference on Electrolysis (ICE 2017)
 '15, '13, '11, '09 International Science Steering Committee – Advances in Materials for Polymer Electrolyte Fuel Cells (ACS – Polymer Division)
 '07 co-Chair Gordon Research Conference – Fuel Cells
 '06 Organizer/Chair Army Research Office Alkaline Membrane Fuel Cell Workshop
 '04 Organizer DOE/LANL Workshop for Sub-Freezing Effects in Fuel Cells
 '02 Distinguished Performance Award – Los Alamos National Laboratory
 '01 Richard A. Glenn Award - American Chemical Society

Publications

1. C He, AC Yang-Neyerlin, B Pivovar, “Water limiting current measurements in anion exchange membrane fuel cells (AEMFCs); part 1: Water limiting current method development,” *Journal of Power Sources* 539, 231534C, 2022.
2. Sarah F Zaccarine, Shaun M Alia, W Wilson McNeary, Raphaël Chattot, Michael J Dzara, Isaac Martens, Scott A Mauger, Alan W Weimer, Jakub Drnec, Bryan S Pivovar, Svitlana Pylypenko, “Optimization of Extended-Surface PtNi Nanowire Oxygen Reduction Electrocatalysts Produced via Atomic Layer Deposition,” *ACS Appl. Energy Mater.* 2022, 5, 4, 4587–4602. <https://doi.org/10.1021/acsaem.2c00016>
3. Yao Yang, Cheyenne R Peltier, Rui Zeng, Roberto Schimmenti, Qihao Li, Xin Huang, Zhifei Yan, Georgia Potsi, Ryan Selhorst, Xinyao Lu, Weixuan Xu, Mariel Tader, Alexander V Soudackov, Hanguang Zhang, Mihail Krumov, Ellen Murray, Pengtao Xu, Jeremy Hitt, Linxi Xu, Hsin-Yu Ko, Brian G Ernst, Colin Bundschu, Aileen Luo, Danielle Markovich, Meixue Hu, Cheng He, Hongsen Wang, Jiye Fang, Robert A DiStasio Jr, Lena F Kourkoutis, Andrej Singer, Kevin JT Noonan, Li Xiao, Lin Zhuang, Bryan S Pivovar, Piotr Zelenay, Enrique Herrero, Juan M Feliu, Jin Suntivich, Emmanuel P Giannelis, Sharon Hammes-Schiffer, Tomás Arias, Manos Mavrikakis, Thomas E Mallouk, Joel D Brock, David A Muller, Francis J DiSalvo, Geoffrey W Coates, Héctor D Abruña, “Electrocatalysis in alkaline media and alkaline membrane-based energy technologies,” *Chem. Rev.* 2022, 122, 6, 6117–632. <https://doi.org/10.1021/acs.chemrev.1c00331>
4. C He, AC Yang-Neyerlin, B Pivovar, “Probing Anion Exchange Membrane Fuel Cell Cathodes by Varying Electrocatalysts and Electrode Processing,” *J. Electrochem. Soc.* 169 024507, 2022.

5. Ashutosh G Divekar, Michael R Gerhardt, Christopher M Antunes, Luigi Osmieri, Ami C Yang-Neyerlin, Adam Z Weber, Bryan S Pivovar, Guido Bender, Andrew M Herring, "Spatially Resolved Performance and Degradation in a Perfluorinated Anion Exchange Membrane Fuel Cell," *Electrochimica Acta*, 406, 139812, 2022. <https://doi.org/10.1016/j.electacta.2021.139812>
6. Zhenye Kang, Yingying Chen, Hao Wang, Shaun M Alia, Bryan S Pivovar, Guido Bender, "Discovering and Demonstrating a Novel High-Performing 2D-Patterned Electrode for Proton-Exchange Membrane Water Electrolysis Devices," *ACS Appl. Mater. Interfaces* 2022, 14, 1, 2335–2342. <https://doi.org/10.1021/acsami.1c20525>
7. Alex Badgett, Mark Ruth, Bryan Pivovar, "Economic considerations for hydrogen production with a focus on polymer electrolyte membrane electrolysis," *Electrochemical Power Sources: Fundamentals, Systems, and Applications*, 2022, 327-364. <https://doi.org/10.1016/B978-0-12-819424-9.00005-7>
8. Saheed Bukola, Ashlee Vise, Yuanshun Li, Gabriel Goenaga, Thomas A Zawodzinski, Jeffrey L Blackburn, Bryan Pivovar, "Membrane-Induced Vanadium Crossover-Blocking Polybenzimidazole Copolymer with Exceptional Proton Selectivity," *ACS Appl. Polym. Mater.* 2022, 4, 1, 381–393. <https://doi.org/10.1021/acsapm.1c01318>
9. Bryan S Pivovar, Mark F Ruth, Akihiro Nakano, Hirohide Furutani, Christopher Hebling, Tom Smolinka, "Getting Hydrogen to the Gigaton Scale," *Electrochem. Soc. Interface*, 30, 85, 2021. DOI: 10.1149.2/2.F19214IF
10. Bryan S Pivovar, Mark F Ruth, Deborah J Myers, Huyen N Dinh, "Hydrogen: Targeting \$1/kg in 1 Decade," *Electrochem. Soc. Interface*, 30, 6, 2021. DOI: 10.1149.2/2.F15214IF
11. Editor's Choice - A. C. Yang-Neyerlin, S. Medina, K. M. Meek, D. J. Strasser, C. He, D. M. Knauss, W. E. Mustain, S. Pylypenko, and B. S. Pivovar, "Examining Performance and Durability of Anion Exchange Membrane Fuel Cells with Novel Spirocyclic Anion Exchange Membranes." *J. Electrochem. Soc.*, 168, 044525 (2021). DOI: 10.1149/1945-7111/abf77f
12. A Badgett, M Ruth, B James, B Pivovar, "Methods identifying cost reduction potential for water electrolysis systems," *Current Opinion in Chemical Engineering* 33, 100714, 2021.
13. S Ghoshal, BS Pivovar, SM Alia, "Evaluating the effect of membrane-ionomer combinations and supporting electrolytes on the performance of cobalt nanoparticle anodes in anion exchange membrane electrolyzers," *Journal of Power Sources* 488, 229433, 2021.
14. S Bukola, Z Li, J Zack, C Antunes, C Korzeniewski, G Teeter, J Blackburn, Bryan Pivovar, "Single-layer graphene as a highly selective barrier for vanadium crossover with high proton selectivity," *Journal of Energy Chemistry* 59, 419-430, 2021.
15. C Liu, M Shviro, AS Gago, SF Zaccarine, G Bender, P Gazdzicki, T Morawietz, I Biswas, M Rasinski, A Everwand, R Schierholz, J Pfeilsticker, M Müller, P Lopes, R Eichel, B Pivovar, S Pylypenko, K Friedrich, W Lehnert, M Carmo, "Exploring the Interface of Skin-Layered Titanium Fibers for Electrochemical Water Splitting," *Advanced Energy Materials*, 2002926, 2021.
16. S Kole, G Venugopalan, D Bhattacharya, L Zhang, JH Cheng, B Pivovar, C Arges, "Bipolar membrane polarization behavior with systematically varied interfacial areas in the junction region," *Journal of Materials Chemistry A*, 9 (4), 2223-2238, 2021.
17. Kelly M. Meek, Carly M. Reed, Bryan Pivovar, Klaus-Dieter Kreuer, John R. Varcoe and Rachida Bance-Soualhi, "The alkali degradation of LDPE-based radiation grafted anion-exchange membranes studied using different ex situ methods," *RSC Advances*, 2020, 10, 36467 – 36477.

18. J Mo, G Yang, Y Li, Z Kang, G Bender, BS Pivovar, JB Green Jr, FY Zhang, "Experimental studies on the effects of sheet resistance and wettability of catalyst layer on electro-catalytic activities for oxygen evolution reaction in proton exchange membrane electrolysis cells," *International Journal of Hydrogen Energy*, *International Journal of Hydrogen Energy* 45 (51), 26595-26603, 2020. <https://doi.org/10.1016/j.ijhydene.2020.07.087>
19. Israel Zadok, Hai Long, Bryan Pivovar, Aleksandra Roznowska, Artur Michalak, Dario R Dekel, Simcha Srebnik, "Unexpected hydroxide ion structure and properties at low hydration," *Journal of Molecular Liquids*, 313, 113485, 2020. <https://doi.org/10.1016/j.molliq.2020.113485>
20. Gaoqiang Yang, Shule Yu, Zhenye Kang, Yifan Li, Guido Bender, Bryan S Pivovar, Johny B Green Jr, David A Cullen, Feng-Yuan Zhang, "Electrocatalysts: Building Electron/Proton Nanohighways for Full Utilization of Water Splitting Catalysts," *Advanced Energy Materials*, vol. 10, 16, 2070075, 2020. <https://doi.org/10.1002/aenm.202070075>
21. Gaoqiang Yang, Shule Yu, Zhenye Kang, Yifan Li, Guido Bender, Bryan S Pivovar, Johny B Green Jr, David A Cullen, Feng-Yuan Zhang, "Building Electron/Proton Nanohighways for Full Utilization of Water Splitting Catalysts," *Advanced Energy Materials*, vol. 10, 16, 1903871, 2020. <https://doi.org/10.1002/aenm.201903871>
22. GC Anderson, BS Pivovar, SM Alia, Establishing Performance Baselines for the Oxygen Evolution Reaction in Alkaline Electrolytes, *Journal of The Electrochemical Society* 167 (4), 044503, 2020. DOI: 10.1149/1945-7111/ab7090
23. Gaoqiang Yang, Shule Yu, Jingke Mo, Yifan Li, Zhenye Kang, Guido Bender, Bryan S Pivovar, Johny B Green Jr, David A Cullen, Feng-Yuan Zhang, "Impacts of catalyst nanolayers on water permeation and swelling of polymer electrolyte membranes," *Journal of Power Sources*, 448, 227582, 2020. <https://doi.org/10.1016/j.jpowsour.2019.227582>
24. W Mustain, B Pivovar, "Catalysts for Polymer Membrane Fuel Cells," *Catalysts* 10 (1), 86, 2020. <https://doi.org/10.3390/catal10010086>
25. Ashutosh G Divekar, Ami C Yang-Neyerlin, Christopher M Antunes, Derek J Strasser, Andrew R Motz, Soenke S Seifert, Xiaobing Zuo, Bryan S Pivovar, Andrew M Herring, "In-depth understanding of the CO₂ limitation of air fed anion exchange membrane fuel cells," *Sustainable Energy & Fuels*, 4 (4), 1801-1811, 2020. DOI: 10.1039/C9SE01212E
26. Garrett Huang, Mrinmay Mandal, Xiong Peng, Ami C. Yang-Neyerlin, Bryan S. Pivovar, William E. Mustain, and Paul A. Kohl, "Composite Poly(norbornene) Anion Conducting Membranes for Achieving Durability, Water Management and High Power (3.4 W/cm²) in Hydrogen/Oxygen Alkaline Fuel Cells," *Journal of The Electrochemical Society*, 166 (10) F637-F644 (2019). DOI: 10.1149/2.1301910jes
27. Kelly M Meek, Christopher M Antunes, Derek Strasser, Zbyslaw R. Owczarczyk, Ami Neyerlin and Bryan S. Pivovar, "High-Throughput Anion Exchange Membrane Characterization at NREL," *ECS Trans.* 2019, volume 92, issue 8, 723-731. doi: 10.1149/09208.0723ecst
28. Ashutosh G Divekar, Nora C Buggy, Peter J Dudenas, Ahmet Kusoglu, Soenke Seifert, Bryan S Pivovar, Andrew M Herring, "Thin Film Morphological Characteristics of a Perfluorinated Anion Exchange Membrane," *ECS Trans.* 2019, volume 92, issue 8, 715-722.
29. Yiwei Zheng, Travis J. Omasta, Xiong Peng, Lianqin Wang, John R. Varcoe, Bryan S. Pivovar and William E. Mustain, "Quantifying and elucidating the effect of CO₂ on the thermodynamics, kinetics and charge transport of AEMFCs," *Energy Environ. Sci.*, 2019, 12, 2806. DOI: 10.1039/c9ee01334b
30. Zhenye Kang, Shule Yu, Gaoqiang Yang, Yifan Li, Guido Bender, Bryan S. Pivovar, Johny B. Green Jr., Feng-Yuan Zhang, "Performance improvement of proton exchange membrane

- electrolyzer cells by introducing in-plane transport enhancement layers,” *Electrochimica Acta*, 316, 43-51, 2019. DOI: 10.1016/j.electacta.2019.05.096
31. AT Mayyas, MF Ruth, BS Pivovar, G Bender, KB Wipke, “Manufacturing Cost Analysis for Proton Exchange Membrane Water Electrolyzers,” NREL/TP-6A20-72740. <https://www.nrel.gov/docs/fy19osti/72740.pdf>
 32. Ruth, Mark, Bryan Pivovar, Josh Eichman. “Hydrogen’s Expanding Role in the Energy System.” *Chemical Engineering Progress*, 115(8), 33-40, 2019. <https://www.aiche.org/resources/publications/cep/2019/august/hydrogens-expanding-role-energy-system>
 33. Catalysts for fuel cell transportation and hydrogen related uses, B. Pivovar, *Nature Catalysis*, 2(7), 562-565, 2019. <https://doi.org/10.1038/s41929-019-0320-9>
 34. Perspectives on Low-Temperature Electrolysis and Potential for Renewable Hydrogen at Scale, Katherine Ayers, Nemanja Danilovic, Ryan Ouimet, Marcelo Carmo, Bryan Pivovar, and Marius Bornstein, *Ann. Rev. of Chem and Biomolecular Engr.*, 10, 219-219, 2019. <https://doi.org/10.1146/annurev-chembioeng-060718-030241>
 35. The impact of alkyl tri-methyl ammonium side chains on perfluorinated ionic membranes for electrochemical applications, Ashutosh G. Divekar, Mei-Chen Kuo, Andrew M. Park, Andrew R. Motz, Zachary S. Page-Belknap, Zbyslaw Owczarczyk, Hai Long, Soenke Seifert, Christopher Mark Maupin, Michael A. Yandrasits, Yuan Yang, Bryan S. Pivovar, Andrew M. Herring, *JOURNAL OF POLYMER SCIENCE, PART B: POLYMER PHYSICS* 2019, 57, 700–712. <https://doi.org/10.1002/polb.24825>
 36. ZIF 67 Based Electrocatalysts As Highly Active Oxygen Electrodes for Water Electrolysis, S. Ghoshal, S. Zaccarine, G. C. Anderson, M. B. Martinez, K. E. Hurst, S. Pylypenko, B. S. Pivovar, S. M. Alia *ACS Appl. Energy Mater.* 2019 2 (8), 5568-5576. DOI: 10.1021/acsaem.9b00733
 37. Initial approaches in benchmarking and round robin testing for proton exchange membrane water electrolyzers, G. Bender, M. Carmo, T. Smolinka, A. Gago, N. Danilovic, M. Mueller, F. Ganci, A. Fallisch, P. Lettenmeier, K.A. Friedrich, K. Ayers, B. Pivovar, J. Mergel, D. Stolten, *International Journal of Hydrogen Energy* 44(18), pp. 9174-9187. <https://doi.org/10.1016/j.ijhydene.2019.02.074>
 38. A novel PEMEC with 3D printed non-conductive bipolar plate for low-cost hydrogen production from water electrolysis, Gaoqiang Yang, Shule Yu, Zhenye Kang, Yeshi Dohrmann, Guido Bender, Bryan S. Pivovar, Johny B. Green Jr, Scott T. Retterer, David A. Cullen, Feng-Yuan Zhang, *Energy Conversion and Management* 182, pp. 108-116, 2019. <https://doi.org/10.1016/j.enconman.2018.12.046>
 39. A Roadmap to Low-Cost Hydrogen with Hydroxide Exchange Membrane Electrolyzers, Reza Abbasi, Brian P. Setzler, Saisai Lin, Junhua Wang, Yun Zhao, Hui Xu, Bryan Pivovar, Boyuan Tian, Xi Chen, Gang Wu, and Yushan Yan, *Adv. Mater.* 2019, 31, 1805876. DOI: 10.1002/adma.201805876
 40. Self-Supported Hydrous Iridium–Nickel Oxide Two-Dimensional Nanoframes for High Activity Oxygen Evolution Electrocatalysts, Fernando Godínez-Salomón, Luis Albiter, Shaun M. Alia, Bryan S. Pivovar, Luis E. Camacho-Forero, Perla B. Balbuena, Rubén Mendoza-Cruz, M. Josefina Arellano-Jimenez, and Christopher P. Rhodes, *ACS Catal.* 2018, 8, 11, 10498-10520. <https://doi.org/10.1021/acscatal.8b02171>
 41. Developing titanium micro/nano porous layers on planar thin/tunable LGDLs for high-efficiency hydrogen production, Zhenye Kang, Gaoqiang Yang, Jingke Mo, Shule Yu, David A. Cullen, Scott T. Retterer, Todd J. Toops, Michael P. Brady, Guido Bender, Bryan S.

- Pivovar, John B. Green Jr., Feng-Yuan Zhang, *International Journal of Hydrogen Energy* 43(31), pp. 14618-14628, 2018. <https://doi.org/10.1016/j.ijhydene.2018.05.139>
42. Novel thin/tunable gas diffusion electrodes with ultra-low catalyst loading for hydrogen evolution reactions in proton exchange membrane electrolyzer cells, Zhenye Kang, Gaoqiang Yang, Jingke Mo, Yifan Li, Shule Yu, David A. Cullen, Scott T. Retterer, Todd J. Toops, Guido Bender, Bryan S. Pivovar, John B. Green Jr, Feng-Yuan Zhang, *Nano Energy* 47, pp. 434-441, 2018. <https://doi.org/10.1016/j.nanoen.2018.03.015>
 43. Chemical Stability via Radical Decomposition Using Silicotungstic Acid Moieties for Polymer Electrolyte Fuel Cells, Andrew R. Motz, Mei-Chen Kuo, Guido Bender, Bryan S. Pivovar and Andrew M. Herring, *Journal of The Electrochemical Society*, 165 (14) F1264-F1269 (2018). DOI: 10.1149/2.1361814jes
 44. Kinetic equilibrium study of CO₂ poisoning observed in Anion exchange membranes when exposed to ambient air and varying levels of CO₂ ppm, Divekar, A.G., Pivovar, B.S., Herring, A.M., *ECS Transactions*, 86(13), pp. 643-648, 2018. DOI: 10.1149/2.1361814jes
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 46. Strategies for reducing the PGM loading in high power AEMFC anodes, Travis J Omasta, Yufeng Zhang, Andrew Michael Park, Xiong Peng, Bryan S. Pivovar. John R. Varcoe and William E Mustain, *ECS Trans.* 2018 volume 85, issue 13, 873-887. doi: 10.1149/08513.0873ecst
 47. Strategies for reducing the PGM loading in high power AEMFC anodes, Travis J Omasta, Yufeng Zhang, Andrew Michael Park, Xiong Peng, Bryan S. Pivovar. John R. Varcoe and William E Mustain, *J. Electrochem. Soc.* 2018 volume 165, issue 9, F710-F717. doi: 10.1149/2.1401809jes
 48. Relating alkaline stability to the structure of quaternary phosphonium cations, Bingzi Zhang, Hai Long, Robert B. Kaspar, Junhua Wang, Shuang Gu, Zhongbin Zhuang, Bryan Pivovar and Yushan Yan, *RSC Adv.*, 2018, 8, 26640. DOI: 10.1039/c8ra03440k
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 50. 2D and 3D Characterization of PtNi Nanowire Electrode Composition and Structure, S. Shulda, J.N. Weker, C. Ngo, S.M. Alia, S.A. Mauger, K.C. Neyerlin, B.S. Pivovar, S. Pylypenko, *ACS Appl. Nano Mater.* 2019, 2, 1, 525-534. <https://doi.org/10.1021/acsnm.8b02097>
 51. Extended Thin Film Electrocatalyst Structures via Atomic Layer Deposition, W.W. McNeary, C. Ngo, A.E. Linico, J.W. Zack, K.M. Hurst, A.M. Roman, S.M. Alia, J.W. Medlin, S. Pylypenko, B.S. Pivovar, A.W. Weimer, *ACS Applied Nano Materials*, 1 (11), 6150-6158, 2018. <https://doi.org/10.1021/acsnm.8b01369>
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- and Bryan S. Pivovar, *J. Electrochem. Soc.* 2018 165(3): F238-F245; doi:10.1149/2.1061803jes
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 58. A Study of Carbonate Formation Kinetics and Morphological Effects Observed on OH- Form of Pfaem When Exposed to Air Containing CO₂ Ashutosh G Divekar, Andrew Michael Park, Zbyslaw R. Owczarczyk, Soenke Seifert, Bryan S Pivovar, and Andrew M Herring, *ECS Trans.* 2017 80(8): 1005-1011; doi:10.1149/08008.1005ecst
 59. Synthesis and Characterization of Perfluorinated Anion Exchange Membranes Andrew Michael Park, Zbyslaw R. Owczarczyk, L. E. Garner, Ami C. Yang-Neyerlin, Hai Long, C. M. Antunes, Matthew R Sturgeon, M. J. Lindell, Steven J Hamrock, Michael Yandrasits, and Bryan S Pivovar, *ECS Trans.* 2017 80(8): 957-966; doi:10.1149/08008.0957ecst
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Patents 3 granted,

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Member of the Electrochemical Society.

Member American Chemical Society (Polymer Division).