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Guest Editorial

Special Issue on Anion Exchange Membranes and AEM-Based Systems

The idea for this special issue was born when two of us (Dirk Henkensmeier and Alexander Dyck) planned the 4th EMEA workshop, which was held on June 27–29, 2016. The Workshop on Ion Exchange Membranes for Energy Applications (EMEA) started as a small workshop with 29 participants in 2013 and grew steadily since that time, reaching over 70 participants in 2016 (Fig. 1). Since the focus of this workshop series is set traditionally on anion exchange membranes (AEMs), we considered it to be the right time to collect contributions for a JEECS "Special Issue on Anion Exchange Membranes and AEM-Based Systems."

While the focus on AEMs and their systems appears to be quite narrow at first glance, it actually has a very large scope: Anion exchange membranes are vital components for the next generation of fuel cells, electrolyzers, metal–air batteries, redox flow batteries, actuators, reverse electrodialysis (RED), and carbon capture by electrochemical CO_2 pumps, as just some examples. The number of new publications per year is growing: In 2013, when the first EMEA workshop was held, 457 papers were published on "anion exchange membranes," according to Web of Science. On average, each paper published in that year has been cited 16 times. In 2016, 551 papers were published and have already averaged 1.7 citations per item. Clearly, AEM research is a growing, hot field of research. Power densities of $>1\,W\,cm^{-2}$ at $60\,^{\circ}C$ have now been achieved (*Green Chemistry*, 2017, **19**, pp. 831–843).

The main motivation for development of AEM-based fuel cells is that expensive and rare platinum-group-metal catalysts can potentially be substituted by cheaper and more abundant types like silver or nickel catalysts. The big challenge is the low alkaline stability of currently available commercial AEMs. A giant step toward improved alkaline stability was the finding that the 1,3-dimethyl, 2-mesityl imidazolium motif is remarkably stable, because the mesityl methyl groups sterically hinder the attack of hydroxide ions on the C2 position of imidazolium ions (*JACS*, 2012, **134**, pp. 10753–10756).

Fig. 1 Participants of the EMEA 2016 workshop, held on June 27-29, in Bad Zwischenahn, Germany

In alkaline water electrolyzers, a thin hydroxide conducting membrane would reduce the resistance of the currently used porous membranes. Because dense membranes show low gas crossover, the use of AEMs would also allow a more dynamic operation of alkaline water electrolyzers, which is important for connecting electrolyzers with renewable power sources like solar or wind energy.

For vanadium redox flow batteries, AEMs offer the great advantage that they, per definition, should not conduct cations. Therefore, AEMs show a very low vanadium ion crossover in comparison to commonly used cation exchange membranes like Nafion. This dramatically reduces the self-discharge and, if the conductivity is high enough to compete with Nafion, will also enhance the overall energy efficiency.

We are very happy with the exciting manuscripts we have received, which are inspiring and cover a broad spectrum:

- Ryuji Kikuchi's work focuses on the development of catalysts for the oxygen reduction reaction (ORR) in an environment where the catalyst is in contact with both air and an alkaline liquid phase—a situation which is found, for example, in metal–air batteries.
- Marta Hatzell's paper describes the development of a thermodynamic model to investigate the hydrogen and electricity generation of a RED stack. RED systems harvest the mixing enthalpy which derives from the salinity gradient between fresh water (e.g., river water) and saline water (e.g., industrial brine or sea water).
- William Mustain reports an electrochemical CO_2 pump. This is a system which is structurally similar to a fuel cell, but CO_2 (along with some oxygen) is transported as carbonate from the cathode to the anode gas stream. While this system is far from mature (this paper is one of the first three to five papers on this subject), the authors' persuasively predict that further development could lead to a system which allows to separate CO_2 for \$22 per tonne CO_2—cheaper than the U.S. DOE target of \$30 for 2035.

Even if electrochemical CO_2 pumps would never be implemented into a coal power plant, we can easily imagine other applications. Currently, 580 Dutch greenhouses are supplied with the CO_2 off-gas from an oil refinery, to enhance plant growth. The length of the transport pipeline is 85 km, and every year about 400,000 tons of CO_2 are brought to the greenhouses through a 300 km long distribution grid.[1] If solar power is used to power an electrochemical CO_2 pump, CO_2 from air could be enriched in the greenhouse atmosphere when photosynthesis is at its peak.

Another vision would be true CO_2 neutral driving. For example, as demonstrated on a technical scale in Audi's e-gas concept, it is possible to react hydrogen and CO_2 to methane, use the gas grid to deliver the methane to gas stations, and then to fill the tanks of

[1] http://www.the-linde-group.com/en/clean_technology/clean_technology_portfolio/co2_applications/greenhouse_supply/index.html

cars. If electrochemical CO_2 pumps are developed further to a point where they can concentrate CO_2 from air by using renewable energy, then we can envisage the following julesvernesque scenario: Methane could be produced anyplace in the world where there is access to water, air, and wind or sun. Methane could even be farmed on the ocean.

We would like to warmly thank ASME for their support of the EMEA 2016 workshop and express our gratitude to Wilson Chiu, the editor of the ASME *Journal of Electrochemical Energy Conversion and Storage*, for his continuous support of this special issue, also at the point when it was clear that it will not be a full special issue but rather contain a section dedicated to AEM and AEM-based systems. Finally, we would like to thank the reviewers who helped us to keep up a stringent review process and all the authors who submitted their work.

If you are interested in AEMs or AEM-based systems, we would like to take this opportunity to invite you to join us at the EMEA 2017 workshop, which will be held on June 26–28, again in Bad Zwischenahn, Germany.[2]

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[2] www.next-energy.de/EMEA2017.htm