JOHNSON MATTHEY
TECHNOLOGY REVIEW

www.technology.matthey.com

Guest Editorial

Electrochemistry at Johnson Matthey

Historically, Johnson Matthey has had a long association with electrochemistry, and perhaps this was inevitable because of the importance of the platinum group metals (pgm) to Johnson Matthey's early development. Platinum, in particular, has been incredibly useful in the field, because of its exceptional electrocatalytic activity and impressive inertness in most environments. Famously, Johnson Matthey supplied the platinum for Grove's 1839 experiment that demonstrated the fuel cell effect (1, 2). After a rather long incubation period, this is now paying dividends: Johnson Matthey has a business unit designing and manufacturing membrane electrode assemblies for proton exchange membrane (PEM) fuel cells, including direct methanol fuel cells, and electrodes for phosphoric acid fuel cells. Recently, applications for electrochemistry have been undergoing something of a renaissance and Johnson Matthey is active in a diverse range of areas where electrochemistry plays a part, a number of which are covered in this issue of *Johnson Matthey Technology Review*.

Batteries

The scope of electrochemical activities within Johnson Matthey is now much broader than fuel cells, with lithium-ion batteries the focus of intense research, development and investment, motivated by the prospect of a very large market for electric vehicles. The drive for increased energy density, safety, charging rate and resilience to capacity loss during charge and discharge has led to multiple research strands for each component of these batteries. The size of the market means that workers are already looking at extraction of lithium from new sources and at routes to recycle the lithium, and many of the other elements within the cells, especially those such as cobalt that show price-sensitivity as volumes ramp up. Alternative chemistries are also in the frame for transport applications, where they hold promise of higher volumetric or mass-specific energy density. Metal-air cells are attractive here, because there is no need for a material to store charge at the cathode, which contributes mass and volume to the cell; rather the charge is supplied by the reduction of oxygen from the air on an electrocatalyst, as in a fuel cell (known as an air, or oxygen, de-polarised electrode). One of the key challenges for metal-air cells is coping with direct contact between the electrolyte and the air, as this can lead to evaporation, oxidative degradation or, in the case of alkaline electrolytes, loss of conductivity by carbonation. The latter effect has tended to limit the application of zinc-air cells to single-discharge applications. New solid electrolytes will be needed for the development of compact, robust metal-air systems.

Fuel Cells Without Platinum

Following the pioneering work of researchers such as Jean-Pol Dodelet, oxygen reduction catalysts for fuel cells have been developed that contain no pgms. Whilst many problems remain to be solved for these (typically) transition metal-doped carbon materials, application in real products is starting to take place. Johnson Matthey is active in this field, working with a strong team in a European project called CRESCENDO and members of this team have reviewed the field in this issue (3). Lower cost is an obvious attraction for non-pgm catalysts, but care is needed here; in 2015 a US Department of Energy (DOE)-sponsored cost analysis for an automotive system showed that expensive precursors, processing costs and the need for two stacks made the non-pgm system 28% more expensive than the platinum-based system (4). Higher active site density, to give thinner catalyst layers with reduced mass transport losses, and improved stability are two of the main ambitions for these types of catalyst, but the insensitivity to certain gas-phase contaminants is also of interest.

Power to Chemicals and Storage

Fuel cells and batteries represent the conversion of chemical energy to electrical energy, but the prospect of increasing quantities of electrons from renewable electricity sources such as wind and solar power is fuelling interest in the reverse process, to produce useful chemicals. Alternatively, electrochemical systems can be used to store this energy until it is needed.

For storage, lithium-ion batteries can be used *en masse* to provide highly dynamic capacity for buffering electricity grids over short time periods. Advocates of redox flow batteries point to the capacity fade of lithium-ion and suggest that over, say, 20 years, a flow battery is a better investment. A summary of a recent conference is in this issue (5) as is an article describing a fuel cell that uses the same type of redox technology, as a route to a pgm-free cathode (6).

For conversion of power to chemicals, in the simplest case, water can be electrolysed to form oxygen and hydrogen, with the hydrogen used to power fuel cells, feed into gas grids or for established applications. PEM electrolysers are growing in abundance because of their robustness to intermittent operation and ability to ramp up quickly to high current densities, compared to traditional liquid, alkaline systems. Better oxygen evolution reaction (OER) electrocatalysts than iridium oxide are desirable and Johnson Matthey recently completed a European funded project on PEM electrolysers that encompassed this challenge. More active catalysts were developed, but they had lower stability in the very harsh, high potential, oxidising environment of the electrolyser anode. Good progress was made however, by significantly reducing hydrogen crossover in thin, reinforced membranes.

Synthesis of other chemicals *via* electrochemical methods is also being investigated. For example, Johnson Matthey has just started an ambitious European project on the electrochemical conversion of gaseous carbon dioxide to methanol. Success requires selective, efficient conversion of course, and the design and synthesis of new electrocatalysts is the key. A few millivolts matter greatly in electrochemical conversions. For power to chemicals, each extra millivolt required adds to the cost of generation, as do parasitic side reactions. Efficiency is vital in industrial electrochemistry, as it has a direct bearing on cost. A recent example of this is the deployment of gas diffusion electrodes (GDE) for the chlor-alkali process, one of the largest, best-established industrial electrochemical processes, which makes chlorine and caustic soda from salt water and electricity (7). The use of GDEs as oxygen-depolarised electrodes for chlor-alkali saves hundreds of millivolts, leading to 30% lower energy costs, and avoids the need to deal with hydrogen gas that is the normal byproduct. When it comes to consumer products however, efficiency is a less certain guide and convenience and other factors matter; the current domination of the transportation market by the internal combustion engine has not come about because these engines are efficient.

It is an exciting time to be working in industrial electrochemistry, not least because of the linkages with the growth of renewable energy. Electrochemistry is inherently multi-disciplinary, bringing in aspects of chemistry, physics, materials science, electrical engineering and chemical engineering, and Johnson Matthey, with its diverse technical workforce and network of business units, is well placed to act on many of the developments and opportunities covered in this issue. Watch out for progress updates in future issues of *Johnson Matthey Technology Review*.

JONATHAN SHARMAN
Johnson Matthey, Blounts Court, Sonning Common, Reading, RG4 9NH, UK
Email: jonathan.sharman@matthey.com

References

1. C. F. Schœnbein, *Phil. Mag*., 1839, **14**, (85), 43
2. W. R. Grove, *Phil. Mag*., 1839, **14**, (86–87), 127
3. F. Jaouen, D. Jones, N. Coutard, V. Artero, P. Strasser and A. Kucernak, *Johnson Matthey Technol. Rev*., 2018, **62**, (2), 231
4. B. D. James, '2015 DOE Hydrogen and Fuel Cells Program Review: Fuel Cell Vehicle and Bus Cost Analysis', Strategic Analysis Inc, Arlington, Virginia, USA, 10th June, 2015
5. M. van Dalen and J. O'Farrelly, *Johnson Matthey Technol. Rev*., 2018, **62**, (2), 185
6. D. B. Ward and T. J. Davies, *Johnson Matthey Technol. Rev*., 2018, **62**, (2), 189
7. J. Kintrup, M. Millaruelo, V. Trieu, A. Bulan and E. S. Mojica, *Electrochem. Soc. Interface*, 2017, **26**, (2), 73

