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Scientia

RENEWABLE ENERGY GETS A BOOST FROM SODIUM BATTERY TECHNOLOGY

Professor Maria Forsyth and Dr Patrick Howlett are leading a project funded by the Australian Research Council to develop sodium-based energy storage technologies to bolster a future renewable energy landscape. Sodium-based batteries will give renewable energy a much needed boost in the replacement of fossil fuels.

Lithium gives way to a sodium revolution

Renewable energy is steadily replacing the world's entrenched reliance on fossil fuels, which continue to release carbon into the Earth's atmosphere. Renewable energy plants composed of arrays of wind turbines or solar panels, for instance, are clean and sustainable alternatives, but they have a downside – they cannot function continuously because they rely on favourable climate and weather conditions. This is where battery technology comes in to work with renewable energy sources. As a wind turbine produces more energy in windier conditions, that energy can then be stored in batteries. The energy can then be supplied to the grid when needed, when weather conditions are not windy or sunny enough to meet the energy demand.

The last few decades have seen concentrated developments in lithium-ion battery technology, but lithium is by no means the only element that can be used for electrical energy storage. Sodium has been identified as a successor to lithium for important reasons. One reason is that sodium is orders of magnitude (hundreds or even thousands of times) more abundant than lithium. In addition, more than 70% of the world's lithium ore comes from only a few locations in South America. These factors lead to instability in the lithium market and have already caused problems with availability and supply. With sodium also being a safer substance, sodium-based battery technologies are regarded to be a supporting pillar for future energy systems.

Professor Maria Forsyth and Dr Patrick Howlett at the Institute for Frontier Materials (IFM), Deakin University are leading researchers in battery technology and electrochemical devices. Their work focuses on studying the dynamics of charge transport in electrolytes and metal-electrolyte interfaces. The team are currently conducting research into sodium-ion conducting electrolytes for battery technology, funded by the Australian Research Council (ARC). The IFM can facilitate the highest quality energy storage and materials research due to its Nuclear Magnetic Resonance (NMR) Facility, Microscopy and Characterisation Suite, and electrochemistry laboratories. These facilities attract an outstanding calibre of researchers that are well placed to perform research at the highest level.

The current state of the art in sodium-based research focuses on developing and testing sodium electrolytes required in batteries. Presently, sodium-based batteries are limited by high operation temperatures, roughly 300 °C, and short lifetimes, making them insufficient for mainstream use. Professor Forsyth and Dr Patrick Howlett, along with Michel Armand from CIC Energigune (with funding from the ARC) are developing high conductivity, ambient temperature sodium electrolytes in order to push past these limitations, towards making batteries that are viable for integration with the future renewable energy grid.

The initial goal of the project is to diligently design experiments and devices, which will set the stage for a successful outcome. Research and development will include the characterisation of sodium electrolytes to probe their properties and electrochemical performance. A parallel goal is to study the molecular properties of sodium electrolytes in order to better understand sodium ion dynamics and chemical speciation. These goals will precede the production of battery prototypes that fall into three main categories: ambient temperature sodium metal batteries (necessary for environmental conditions that the batteries will ultimately operate in), sodium-ion batteries with improved performance, and sodium-based hybrid supercapacitors (capacitors that can store a lot of energy).

Sodium-based batteries

A simple battery is made up of two electrical terminals called an anode and a cathode, between which an electric current flows through a liquid electrolyte from cathode to anode. Cutting edge sodium technology usually adopts a molten sodium anode and a molten sulphur cathode. Another battery type, called a ZEBRA battery, comprises a beta-alumina ceramic electrolyte and a nickel chloride cathode. Two of the main reasons that sodium technology is still in its infancy are that these types of batteries experience substantial manufacturing problems, and in terms of application are only suitable for large devices that are used continuously. This shows why lithium-based technology initially took off rather than sodium-based technology, in spite of its previously mentioned drawbacks.

The research group at Deakin, together with Professor Doug Macfarlane (from the School

BatTRI-Hub director Prof Maria Forsyth and Assoc Prof Patrick Howlett

of Chemistry at Monash University) and his team, have investigated the use of ionic liquids as electrolytes and their application in lithium devices. An ionic liquid is a salt that exists in a liquid phase at room temperature, and it has a high conductivity that is ideal for many real world applications. An ionic liquid is entirely made up of ions, but not all of its ions contribute to the specific charge transport required for a given device. The team has pioneered the development of new classes of ionic liquid electrolytes. The fruits of this research are implemented into devices such as batteries, solar cells and capacitors, and these new classes of ionic liquid electrolytes are now the subject of research throughout the field. New studies have shown that sodium metal ionic liquids can support an electrical potential that competes with what has been achieved using lithium metal. This work has revealed that sodium-based batteries can indeed compete with lithium-based batteries.

Professor Forsyth brings her considerable knowledge and expertise in lithium technology to the development of sodium technologies. In her work she has shown that lithium ionic liquids can meet safety standards and can operate reliably. One reason for this is that a protective solid interface can be formed when using suitable lithium ionic liquids. Recently, she has conducted lithium metal speciation studies which characterise the organisation of metal ions and anions in the electrolyte, using computational techniques such as Molecular Dynamics as well as NMR experiments. Further to this research, her group has also studied polymer electrolytes and plastic crystals as potential safe electrolytes for energy storage.

The research project

Many institutions and governments across the globe are now investing in renewable energy and embarking on the deconstruction of the fossil fuel economy. This is a global imperative with the aim of minimising anthropogenic climate change. Renewable energy plants that use solar, wind or tidal power, cannot operate in step with energy demands. This is where electrical energy storage devices come in. They will be an essential component of the grid to ensure that electricity can be provided when it is needed. Energy storage devices, batteries in particular, will then function to allow energy modulation, and increase the reliability of the future energy grid, giving renewables greater application. Lithium-based technology will not be able to meet all of the challenges faced by an emerging renewable energy system in the long term, due to the aforementioned obstacles of its economy and availability.

The main goals of Professor Forsyth and Dr Howlett's sodium-based technology project are diligent design, research and development, and necessary

A battery scientist begins long-term performance testing on a sodium coin cell

characterisation. In more detail, there are two devices that are to be developed. One is called a shuttle battery, where ions move from one electrode terminal to the other, in charge and discharge cycles. In this sense, the ions are shuttled across the battery between the electrode terminals. The other device is a hybrid capacitor which functions by releasing ions from both electrodes during the discharge process. In this case, the ions are released into the electrolyte, changing its composition as a result. The key difference between these two devices is the charge transport within the electrolyte. In the shuttle battery the sodium ion transport is the dominant process to be optimised, while in the hybrid capacitor both sodium ion and anion transport are required for device operation. Moreover, the electrochemical and physical adsorption processes at the electrodes differ and so this means that the electrolyte may need to have different chemical properties.

Controlling metal ion speciation, particularly at an electrode interface, is essential to the development of high efficiency and long term cycling stability of ionic liquid electrolytes; the precise chemistry and the component cation and anions in an ionic liquid, as well as other complexing agents that may be added to electrolyte, strongly determine the efficiency and stability of the system. In this phase of the project, ionic liquids and polymer ionic liquid gel systems are optimised for sodium ion transport.

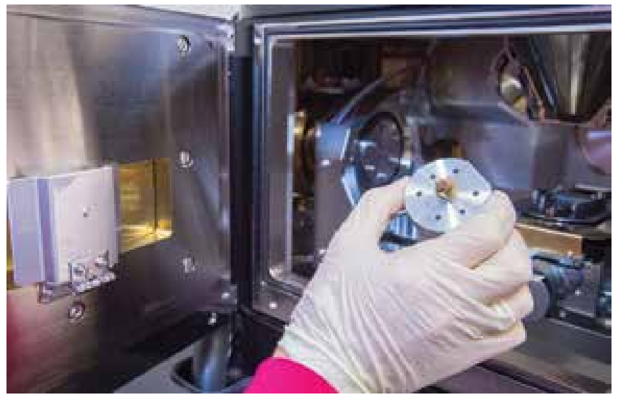
Sodium ionic liquid mixtures, where more than half of the cations in the electrolyte are in fact sodium, as opposed to typical concentrations of 5-20%, are a viable alternative that have been shown to be successful in the lithium technology sector. These mixtures offer an alternative design approach where the mixtures can be customised and optimised for ion transport, stability, electrolyte behaviour with reactive metals, viscosity, and melting point. With all these variables it is possible to finely tune an ionic liquid with the best properties for meeting the aims of the project.

The characterisation of an ionic liquid involves determining the transport dynamics and electrochemical properties of the system. The transport properties are determined by measuring the ionic conductivity at variable temperature, and measuring the viscosity and diffusion of the chemicals using advanced NMR techniques. The anions, cations and molecular solvents contain nuclei which are amenable to NMR measurements with and without an external electric field. Chemical speciation will be measured using methods that have been very useful in previous work, such as multi-nuclear NMR spectroscopy and vibrational spectroscopy. These results will be compared with measurements of the sodium chemistry, and with measurements of the ionicity – the degree to which the material exhibits ionic behaviour. Computational modelling will play a big role in development and understanding of the ion transport within the electrolytes as well as the interfacial properties of the ionic liquid at the electrode, which surely determine the electrochemical behaviour and thus ultimately the performance of the battery. Professor Forsyth's team includes a number of computational researchers who will contribute to this work.

Once a candidate electrolyte system is developed through the stages of design, development and characterisation, functional devices will be built in collaboration with Professor Michel Armand's team at the CIC Energigune from the Basque Country in Spain, for performance testing. For example, an optimised shuttle battery could be composed of a sodium metal anode with a cathode based on a sodium iron phosphate mineral (NaFePO4), other layered oxide cathodes or indeed organic cathodes being developed at the CIC Energigune. Within this phase of the project, the team at the CIC will be working closely with the Deakin team to optimise the combination of electrolyte and electrode to achieve the best performing sodium battery. A cell based on the hybrid supercapacitor design would most likely have a conducting polymer or functionalised carbon cathodes newly developed by the ARC Centre of Excellence for Electromaterials Science (ACES), and a sodium anode. These devices will then undergo standard performance testing for batteries and capacitors.

Widespread benefits

This project involves a collaborative effort with institutions all over the world and will help establish Australian research on the international stage. Strong links will be forged with researchers in other fields of related research, such as electrode material science and theoretical modelling. PhD students will have the opportunity to visit leading academic centres in Europe and the United States, opening up avenues for their future careers.



Gold sputtered separator material used in fundamental studies of battery

The team at Deakin University have also had the opportunity to apply their vast knowledge of energy storage systems to a project in collaboration with AusNet Services, a major energy infrastructure company in Victoria. This initiative involved the development of a powerful lithium battery energy bank that has been attached to the mains grid for a two-year trial period. The Deakin part of the project, led by Professor Howlett, selected the batteries and advised on aspects such as safety, service lifetime, design, experience and performance management. Just recently, the team was successful in securing an Australian Indian Strategic Research Fund grant for over $1M which will incorporate some of the outcomes from the ARC funded project, to develop prototype devices for lithium and sodium batteries. The success of this collaborative project, comprising a team of Australian and Indian based researchers, is likely to have significant impact in areas such as remote or stand-alone renewable energy installations, for example in isolated communities or rural dwellings areas of major importance to both Australia and India.

As we reduce our reliance on fossil fuels and move towards a sustainable future, efficient energy storage systems are essential. This transition is crucial in order to lessen the catastrophic effects of global climate change and environmental pollution. Supplanting fossil fuel plants in Australia with renewable energy sources alongside sodium-based energy storage technology, which would be harmoniously integrated with the electrical grid, would place Australia in a leading position in the mitigation of climate change.

Professor Forsyth and her group are poised to produce breakthrough research and bring sodium-based energy storage devices to a position where they can complement renewable energy plants in a future energy system. The synergy offered by this system can reliably meet the continuous demands of the grid and surpass our unsustainable use of fossil fuels. Sodium-based energy storage devices are therefore an essential and intelligent path forwards.

Meet the researchers

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Dr Patrick Howlett received his PhD from Monash University in Australia in 2004. Soon after, he began a postdoctoral fellowship at the same university, and went on to become a senior research fellow in 2007. In 2010, he moved to Deakin University, where he currently holds a Senior Lecturer position. Dr Howlett's research focuses on the development of new electromaterials by applying novel materials science principles, design and methodology. He has authored over 100 publications and 4 patents, which have been cited more than 4000 times.

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FOCUS ON BATTERY RESEARCH

The development of safe, efficient, rechargeable batteries is key to achieving sustainable future energy supplies. This area of research will receive a major boost with the opening of a new battery technology research and innovation centre (BatTRI-Hub) at Deakin University in 2016. A major component of this centre will be the establishment of a battery prototyping facility in collaboration with CSIRO. About $1.5M has been committed to set up a facility to produce moderate sized battery pouch devices. It will also allow upscaling of materials manufacture to prepare 10-20kg batches as opposed to a few grams of electrode materials. 'The prototyping facility will be a platform for us to test our novel materials and new technologies in a more realistic format (compared to coin cells) which will be a core component for future applied research projects and future industry partnerships (both locally and internationally)', explains Professor Forsyth. 'One focus of this research will be prototyping of sodium metal batteries.' Researchers at the hub will also explore innovations in functionality, such as the development of flexible and wearable batteries, light weighting and system integration. Battri-Hub will be a centre for engagement with industry, from chemical companies through to battery manufacturers and energy providers.

Professor Maria Forsyth earned her PhD at Monash University, Australia in 1989. Since then she has held positions in the USA, UK and Australia. She is an Australian Laureate Fellow and Alfred Deakin Professorial Fellow at Deakin University. She is also Associate Director in the ARC Centre for Excellence in Electromaterials Science and Deputy Director of the Institute for Frontier Materials. Her work focuses on charge transport in electrolytes and metal-electrolyte interfaces, including ionic liquids, polymer electrolytes and plastic crystals. She leads collaborative projects in lithium and sodium battery technologies with funding from ARC. She has co-authored over 400 publications that have received over 11,000 citations in total.

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