https://doi.org/10.1595/205651319X15653548389641 *Johnson Matthey Technol. Rev.*, 2020, **64**, (1), 16–18

JOHNSON MATTHEY
TECHNOLOGY REVIEW

www.technology.matthey.com

In the Lab

Alternative Recycling Process for Lithium-ion Batteries: Molten Salt Approach

***Johnson Matthey Technology Review* features new laboratory research**

Ruth Carvajal-Ortiz's current research is centred around innovation in energy storage. She has a special focus on the characterisation of materials, molten salts and their potential applications to several industrial processes, such as metal production and recovery. Currently a research fellow at Coventry University, UK, Ruth is in charge of the molten salts recycling work package of the Custom Automotive Lithium Ion Battery REcycling (CALIBRE) consortium, a circular economy project for automotive lithium-ion batteries (LIBs) funded by Innovate UK and led by Johnson Matthey.

Ruth's academic and industrial background includes electrochemical characterisation techniques (such as voltammetry), corrosion in metals under hydrothermal conditions and synthesis and characterisation of catalysts. She obtained her doctoral degree from the University of Manchester, UK, where she worked designing and testing an *in situ* molten salt electrochemical oxidation cell to measure hydrogen diffusion in zirconium alloys (1). Prior to her doctoral studies, Ruth worked with corrosion in metals involved in nuclear applications, during her MSc and as a research chemist at Trent University in Peterborough, Canada. The main project at Trent University's supercritical water laboratory was part of generation IV (GEN-IV) nuclear reactor investigations. The aim of the project was to understand the corrosion behaviour of stainless steel in hydrothermal and supercritical conditions (2–4). The project included collaborations with the Canadian Nuclear Society in Chalk River, Ontario. Ruth's background also includes synthesis and characterisation of catalysts such as titania, used in biofuels.

Ruth Carvajal-Ortiz

- **Position:** Research Fellow in Electrochemical Engineering
- **Department:** Institute for Future Transport and Cities (IFTC) Centre for Advanced Low-Carbon Propulsion Systems (C-ALPS)
- **University:** Coventry University
- **Address:** Puma Way, Coventry
- **Post Code:** CV1 2TL
- **Country:** UK
- **Email:** ruth.carvajalortiz@coventry.ac.uk

About the Research

The demand for LIBs has substantially increased during recent years and is forecast to grow almost 66% globally by 2025 for electric vehicles alone (5). This increases the need for an efficient and sustainable recycling process and circular economy system (6). Coventry University and several battery and automotive companies are working together on a project to provide an achievable and effective way to recycle LIBs. CALIBRE is a new consortium that covers several stages (**Figure 1**), from ageing and end-of-life (EoL) assessment to chemical or molten salt recycling and materials regeneration. Additionally,

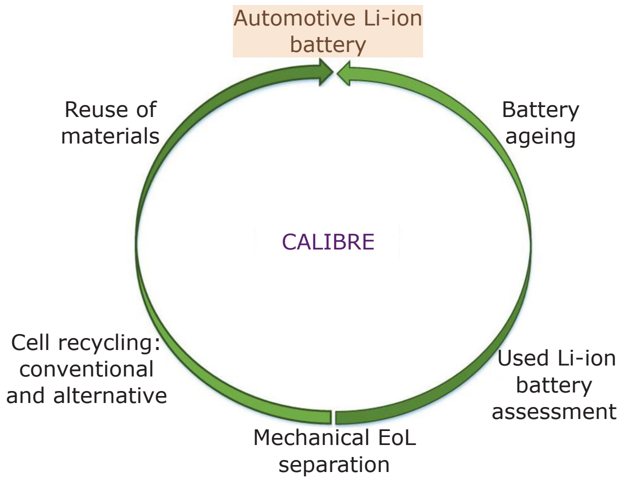

Fig. 1. LIB recycling circular economy project, CALIBRE scheme

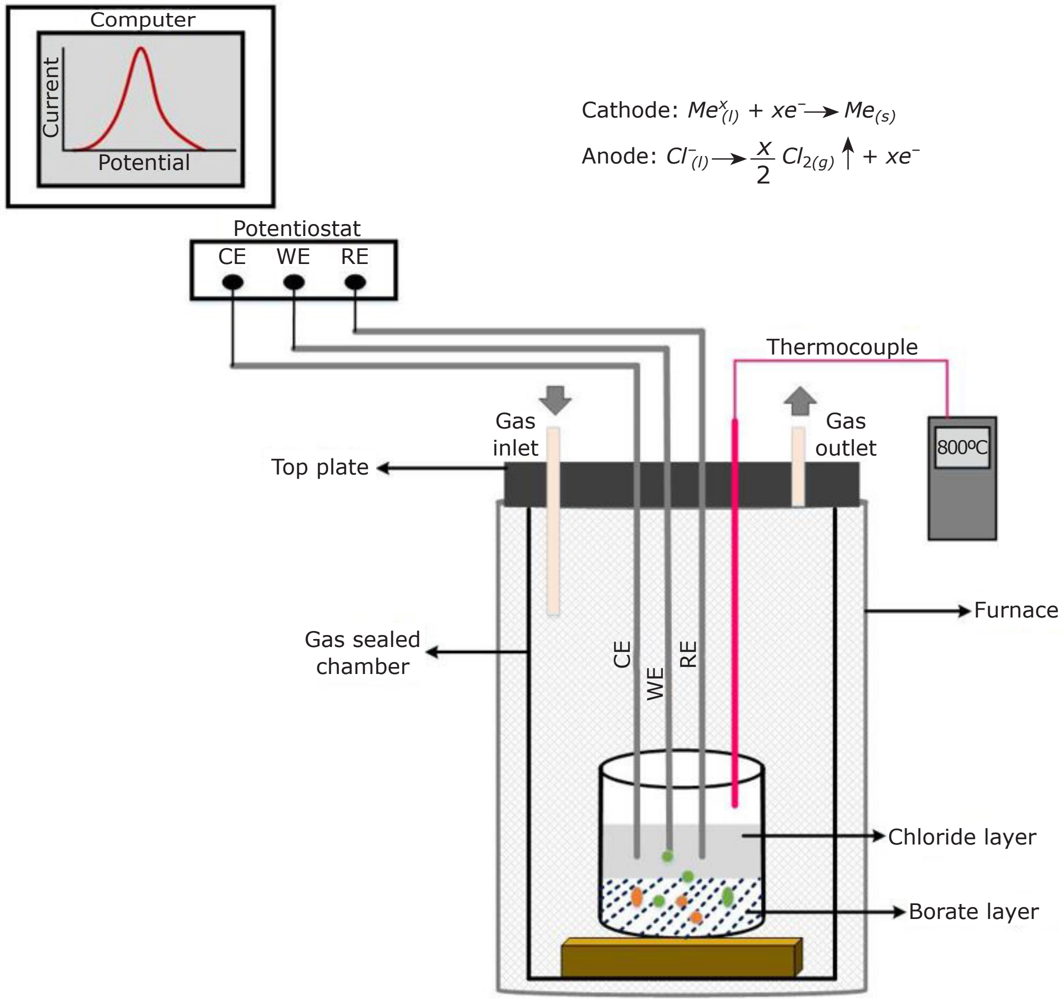

Fig. 2. Molten salt electrochemical cell scheme showing cathode and anode reactions during the process of metal deposition. Working electrode (WE) = half-cell where reaction occurs = cathode. Reference electrode (RE) = evolution of chlorine (oxidation) = anode

the project includes a mechanical separation and material recovery process at pilot scale, reuse and life cycle assessment.

A molten salt recycling process is part of the chemical recycling package. This process provides a novel approach that uses common molten salts as electrolytes and reaction media. The main advantage of the molten salts is their performance versatility which, given the multiple choices of battery electrode chemistries that are presently in the market, provide an improvement over current methods.

For the study, different eutectic mixtures of molten salts (7, 8) (for example sodium, potassium, lithium and calcium borates and chlorides, sodium and potassium carbonates) are tested to provide an optimised alternative or a shortcut to the hydrometallurgical, pyrometallurgical or even biometallurgical recovery of metals (such as cobalt, nickel and manganese). This approach takes advantage of the salts' electrochemical and solubility properties. Initially, a two-phase molten salt system composed of sodium borate and sodium chloride was employed to evaluate the feasibility of metal recovery from mixed feeds of oxides of cobalt, manganese, copper and nickel mixtures and virgin cathode materials (for example nickel manganese cobalt (NMC) 111) by electrodeposition. The process operates within a temperature range of 800–900°C, where both salts are in liquid state. Amietszajew *et al*. reported 98–99% metal purity for single metal oxides deposited using the process described (**Figure 2**) (9, 10).

The system has demonstrated stability and could be used together with other metal recycling sources and processes. Additional insight into the environmental impact of the pilot scale process such as its carbon footprint and its efficiency are also being assessed. The new method might solve some of the issues related to the hydrometallurgical methods currently used by the recycling industry, including significant water waste, sulfate byproducts and toxic acids that are detrimental to the environment. Furthermore, the method developed is inclusive of a range of metals, which is of high importance considering the growing and future complexity of the battery waste stream and the need for the world to recycle essential materials, while at the same time reducing pollutants and greenhouse gas emissions.

References

1. R. A. Carvajal-Ortiz, S. B. Lyon, M. Preuss and A. Ambard, *ECS Trans.*, 2017, **80**, (10), 1019
2. I. M. Svishchev, R. A. Carvajal-Ortiz, K. I. Choudhry and D. A. Guzonas, *Corros. Sci.*, 2013, **72**, 20
3. R. A. Carvajal-Ortiz, A. Plugatyr and I. M. Svishchev, *Nucl. Eng. Des.*, 2012, **248**, 340
4. R. A. Carvajal-Ortiz and I. M. Svishchev, *J. Mol. Liq.*, 2014, **190**, 30
5. B. Swain, *Sep. Purif. Technol.*, 2017, **172**, 388
6. J. Heelan, E. Gratz, Z. Zheng, Q. Wang, M. Chen, D. Apelian and Y. Wang, *J. Miner. Metals Mater. Soc.*, 2016, **68**, (10), 2632
7. E. B. Freidina and D. J. Fray, *Thermochim. Acta*, 2000, **356**, (1–2), 97
8. K. Zheng, X. Cheng, Y. Dou, H. Zhu and D. Wang, *J. Electrochem. Soc.*, 2017, **164**, (13), E422
9. T. Amietszajew, S. Seetharaman and R. Bhagat, *J. Am. Ceram. Soc.*, 2015, **98**, (10), 2984
10. T. Amietszajew, S. Sridhar and R. Bhagat, *J. Electrochem. Soc.*, 2016, **163**, (9), D515

