2024_87_Materials_RR: Developing electrochemical technologies to convert biomass waste to low-cost green hydrogen and value added products

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Using renewable energy to produce green hydrogen and chemicals is key for decarbonising the power generation, transport, and chemical industries, and enabling a zero-pollution future. The current state-of-the-art technology to generate green hydrogen is based on low-temperature water electrolysis [1]. However, these technologies have several drawbacks including large thermodynamic barriers, the use of scarce elements as catalysts and the low economic value of oxygen that is produced. Replacing the water oxidation reaction at the anode with biomass substrates such as glycerol not only eliminates these key bottlenecks associated with water electrolysis, but also enables conversion of waste to high-value products that are of relevance to the chemical industry [2]. For example, partial oxidation of glycerol can yield lactic acid and dihydroxyacetone. Lactic acid is a building block for the production of sustainable biopolymers, is a feedstock for production of green solvents and has widespread uses in the pharmaceutical, food and detergent sectors, with an estimated market size of $5.02 bn by 2028. Dihydroxyacetone is also highly desired for its use in cosmetics and has a large profit margin for the chemical sector [2].

Current catalysts for biomass electro-valorisation are based on precious metals such as platinum [3]. Non-precious metal oxides offer an exciting alternative to Pt due to their low-cost, chemical and structural tunability and ease of manufacture. However, the development of metal oxide-based materials remains in its infancy. This project will focus on:

Fabrication of multi-metallic metal oxides and establishing activity and selectivity trends for glycerol oxidation

Operando spectroscopy (surface enhanced infrared absorption spectroscopy, X-ray absorption spectroscopy) to establish the reaction pathway

Testing the most efficient catalyst in a proof-of-concept electrochemical device

Lifecycle and technoeconomic analysis for the scale-up of this technology based on the obtained performance metrics; including identification of areas for further improvement.

References:

[1] Wei, C., Rao, R.R., Peng, J., Huang, B., Stephens, I.E., Risch, M., Xu, Z.J. and Shaoâ Horn, Y., 2019. Recommended practices and benchmark activity for hydrogen and oxygen electrocatalysis in water splitting and fuel cells. Advanced Materials, 31(31), p.1806296.

[2] Luo, H., Barrio, J., Sunny, N., Li, A., Steier, L., Shah, N., Stephens, I.E. and Titirici, M.M., 2021. Progress and perspectives in photoâ€□and electrochemicalâ€□oxidation of biomass for sustainable chemicals and hydrogen production. Advanced energy materials, 11(43), p.2101180.

[3] Luo, H., Yukuhiro, V.Y., FernÃ¡ndez, P.S., Feng, J., Thompson, P., Rao, R.R., Cai, R., Favero, S., Haigh, S.J., Durrant, J.R. and Stephens, I.E., 2022. Role of Ni in PtNi Bimetallic Electrocatalysts for Hydrogen and Value-Added Chemicals Coproduction via Glycerol Electrooxidation. ACS catalysis, 12(23), pp.14492-14506.