Development of bio-electrochemical fuel cells.

Dr. Paul Kavanagh
Biomolecular Electronic Research Laboratory, School of Chemistry, NUI Galway, Galway, Ireland

Electrochemical energy storage and conversion systems include batteries, capacitors and fuel cells. Fuel cells transform chemical reactivity into electricity by oxidising fuel at the anode and reducing oxidant at the cathode using noble metal catalysts, providing electrical power output for as long as sufficient fuel and oxidant are available. Bio-electrochemical fuel cells (BFCs) are low-temperature fuel cells that harness biological catalytic reactions, in place of metal catalysts in traditional low-temperature fuel cells, to generate electricity from electrolysis of fuel and oxidant (Figure 1A). Due to nature's versatility, BFCs are not limited to use of hydrogen or methanol as a fuel, and can derive electrical power from a wide range of organic substrates. BFCs can be classified into those which utilise living cells (bacteria, algae)[1,2] and those which utilise catalysts extracted from cells (enzymes, enzyme cascades and, more recently, mitochondria)[3-6] as biological catalysts. Biofilms of electro-active bacteria can facilitate proficient organic carbon removal from wastewater while producing biological renewable energy in the form of electricity.[2] Similarly, the utilisation of redox enzymes (*oxidoreductases*) as biocatalysts for the electro-catalytic oxidation (or reduction) of specific redox reactions at miniaturised electrodes permit *in vivo* power generation with the long-term objective of providing self-powered subcutaneously implantable biosensors.[6]

In this presentation, an overview of BFC development within the Biomolecular Electronic Research Laboratory, NUI Galway will be presented. Specific approaches to improve electrode current densities, cell voltages and operational stability of BFCs through various combinations of electrode materials, biocatalysts and redox mediators will be discussed. For example, loading of electroactive bacteria within three dimensional carbon nanotube-based scaffolds (Figure 1B) results in substantial current generation for oxidation of acetate, with electrodes producing a current density of 19 kA m^{-3} representing one of the highest volumetric current densities in microbial electrochemical systems reported to date. In addition, modification of electrode surfaces with chemical functional groups provides a route for increased stability of biofilms through greater retention of biocatalytic components at the electrode surface. Improvements in the design of the redox mediating species in terms of structure and redox potential can help to increase the biocatalytic output of BFCs, and our approach for preparation and screening of libraries of mediators from a theoretical and practical point of view will be included.

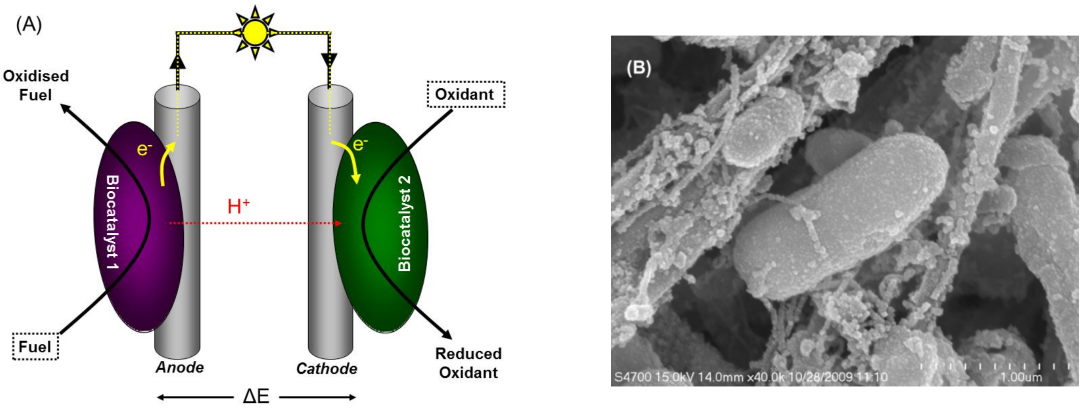

Figure 1. A) Simplified schematic of bio-electrochemical fuel cell operation. B) Scanning electrochemical microscopic image of electroactive bacteria on nanostructured electrodes.

References
1. K. P. Katuri, P. Kavanagh, R. Saravanan, D. Leech, *Chem. Comm*. 2010, 46, 4758-4760.
2. T. Catal, P. Kavanagh, V. O'Flaherty, D. Leech, *J. Power Sources* 2011, 196, 2676-2681.
3. F. Barrière, P. Kavanagh, D. Leech, *Electrochimica Acta*, 2006, 51, 5187-5192.
4. P. Kavanagh, S. Boland, P. Jenkins, D. Leech, *Fuel Cells* 2009, 9, 79-84.
5. D. MacAodha, P. Ó Conghaile, B. Egan, P. Kavanagh, D. Leech, *ChemPhysChem* 2013 14, 2302-2307.
6. P. Kavanagh, D. Leech, *Phys. Chem. Chem. Phys.* 2013, 15, 4859-4869.