**Institution: University of Bedfordshire**

**Unit of Assessment: 7- Earth Systems & Environmental Sciences**

**Title of case study: Biosensor technologies for improved environmental monitoring**

## 1. Summary of the impact

Reliable and timely measurements are vital for innovation, trade, environmental protection and quality of life. University of Bedfordshire work with measurement systems was already established in 1993 with commercially sponsored work to develop and patent sensors for rapid toxicity assessment in the water industry. Biosensor technologies provide approaches to development and application of cost effective devices for measurement at the point of need in many fields of application and the university's Sensor Research Group has continued to work with industry to develop robust (bio)sensor systems to address business and society needs – particularly with respect to environmental protection, health and wellbeing.

## 2. Underpinning research

*Research context*

(Bio)Chemical measurement is a significant aspect of global economy and disposable sensor manufacture is a significant contributor to knowledge based bioeconomy. Professor Tony Turner ('Mr Biosensor') estimated the global biosensor market in 2010 to be US$13billion growing to US$17billion by 2018 (Turner, A.P.F. *Chem. Soc. Rev.* **42**, 3184-3196, 2013). Disposable sensor systems are attractive both to manufacturers and to users. Environmental biosensors were predicted to take about 14% of the market - compared to 20% for home testing and 45% for point of care testing (Thusu, R. www.sensorsmag.com/specialty-markets/medical/strong-growth-predicted-biosensors-market-7640).

Demonstrating sensors in-principle is easy (the academic literature is awash with reports). However, developing commercially viable sensor systems is tough. Experience showed that maximum benefit was obtained by both industrial sponsor(s) and by the research group by embedding post-doctoral staff in the sponsor(s)' research and development teams. This facilitated communication between the parties and ensured that the academic input was optimally focused. In cases where the research was carried out 'at arm's length', the feedback times between parties were (much) longer and it was less easy to ensure that the academic effort was optimally aligned with the customer needs.

*What research was undertaken, when and by whom*

The concept of using immobilised biological whole cells for environmental monitoring was developed with sponsorship (1993-2004) from (amongst others) Astra Zeneca, ICI, Severn Trent Water and Shell and support from the Environment Agency (ongoing) due to their interest in toxicity assessment (ref 3.4, 3.5). This research and development programme arose from early work of David Rawson sponsored by the Water Research Centre and the recruitment of Barry Haggett with physicochemical expertise. The technology was licensed (1997) to Primera and commercialised as CellSense™. This work highlighted the challenges in cryopreserving immobilised biological whole cells and resulted in the formation of a world-class Cryobiology Research Group led by Professor Rawson and Professor Zhang at the University of Bedfordshire in parallel with a Sensor Research Group with expertise in the development of disposable sensor systems headed by Dr Barry Haggett with Professor Brian Birch as new business manager. Funding was obtained to develop sensor systems and components from DEFRA (2004 – 2006, ref 3.6), EU Framework (1999 – 2002), Johnson & Johnson (2006 – 2011), Kodak (1995 - 2002), Oxley (1998 – 2001), Oxoid, Unilever (2000 – 2008), Unipath (1995 – 2006), Yorkshire Water (1995 – 2000) and others. The emphasis in this work was to generate intellectual property that could be commercially exploited.

*Names of the key researchers and the positions they held at the institution at the time of the research*

David Rawson, Professor of Applied Cell Biology (1989 – 2010; continuing as Emeritus Professor)
Brian Birch, Visiting Professor/Professor of Analytical Sciences (1995 – 2010)
Barry Haggett, Senior/Principal Research Fellow (1989 – 2011; currently Senior Lecturer)

## 3. References to the research


3.1. Redha, Z. M., Baldock, S. J., Fielden, P. R., Goddard, N. J., Treves Brown, B. J., Haggett, B. G. D., Andres, R. and Birch, B. J. (2009). Hybrid microfluidic sensors fabricated by screen printing and injection moulding for electrochemical and electrochemiluminescence detection. *Electroanalysis* 21, 422-430. dx.doi.org/10.1002/elan.200804415 (2013 impact factor 2.817; ISI Journal Citation Reports 9/26 (electrochemistry), 22/75 (chemistry analytical).)

3.2. Jezek, J., Dilleen, J. W., Haggett, B. G. D., Fogg, A. G. and Birch, B. J. (2007). Hexacyanoferrate(III) as a mediator in the determination of total iron in potable waters as iron(II)-1,10-phenanthroline at a single-use screen-printed carbon sensor device. *Talanta* 71, 202-207. dx.doi.org/10.1016/j.talanta.2006.03.051 (Impact factor 3.498; 5 year impact factor 3.733) ***

3.3. Kang, J., Hussain, A. T., Catt, M., Trenell, M., Haggett, B. and Yu, E. H. (2014) Electrochemical detection of non-esterified fatty acid by layer-by-layer assembled enzyme electrodes. *Sensors and Actuators B: Chemical* 190, 535-541. dx.doi.org/10.1016/j.snb.2013.09.011 (Impact factor 3.535; 5 year impact factor 3.668)

3.4. Daniel, M., Sharpe, A., Driver, J., Knight, A. W., Keenan, P. O., Walmsley, R. M., Robinson, A., Zhang, T. and Rawson, D. (2004). Results of a technology demonstration project to compare rapid aquatic toxicity screening tests in the analysis of industrial effluents. *Journal of Environmental Monitoring* 11, 855-865. dx.doi.org/10.1039/B408939A (Impact factor 2.085) ***

3.5. Polak, M. E., Rawson, D. M. and Haggett, B. G. D. (1996). Redox mediated biosensors incorporating cultured fish cells for toxicity assessment. *Biosensors and Bioelectronics* 11, 1253-1257. dx.doi.org/10.1016/0956-5663(96)88090-0 (Impact factor 5.437; 5 year impact factor 5.389) ***

3.6. Kadara, R. O., Haggett, B. G. D. and Birch, B. J. (2006). Disposable sensor for measurement of vitamin B2 in nutritional premix, cereal and milk powder. *Journal of Agricultural and Food Chemistry* 54, 4921-4924. dx.doi.org/10.1021/jf0603376 (2012 Impact factor 2.906).


*** Indicates those references that best indicate the quality of the underpinning research.

## 4. Details of the impact

*How the research underpinned the impact*

The Sensor Research Group was equipped with manufacturing and test equipment – mostly supplied by commercial sponsors over an extended period of years. Members of staff were able to undertake industrially sponsored contract research on a full-time basis without teaching commitments or the requirement to publish in the academic literature. This context, together with experience of manufacturability, commercial and end-user issues related to developing 'real' sensor systems was attractive to sponsors looking to undertake development work outside the scope or capacity of their in-house staff and too commercially sensitive to be undertaken within a 'conventional' academic environment.

*The nature of the impact*

Three types of impact are claimed for the work undertaken by the University of Bedfordshire:

(1) Sensor systems produced by the group enabled sponsors to generate data (that was otherwise inaccessible or prohibitively expensive) enabling, supporting or facilitating manufacturing processes that, in turn, better satisfied their customer needs.

(2) Generation of intellectual property to enable sponsors to maintain and/or improve their products and/or services.

(3) A general impact on the wider community through the uptake of the redox-mediated whole cell biosensor approach to rapid toxicity assessment invented by Prof. Rawson (Pollutant detector. GB Patent 2189605A).

*Process or means through which the research led to the impact*

University of Bedfordshire staff were able to work for, with and in industry to: design and manufacture prototype sensor systems; work with sponsors to test prototypes under 'real' conditions; and, where necessary, work with third parties to transfer technology and facilitate scale-

up from laboratory (thousands) to manufacturing (tens of thousands) prototype production.

*Details of the beneficiaries*

Work carried out by the University of Bedfordshire on behalf of Johnson & Johnson led to the generation of intellectual property. Although it is difficult to quantify the economic value, it has enabled the company to protect and enhance its significant share of the billion dollar market for blood glucose measurement systems. This is a market in which the company is determined to remain a leading player which is why it continues to push for the widest possible protection of the intellectual property generated on its behalf by the University (Dr Saini, 5.1).

The association between Unilever Corporate Research and the sensor research group at the University of Bedfordshire extended over many years covering (amongst others) the technology programme at Unipath Diagnostics and the Healthy Ageing programme (2005-2009) managed by Michael Catt (5.2). A fundamental objective of the research programme was to examine the feasibility of analysing biological fluids for vitamin C levels as a surrogate indicator for fruit and vegetable intake. This work was initiated in light of the associations found in the EPIC study (*Int J Epidemiology* **37** 2008 978-987). Vitamin C is routinely added to foodstuffs and beverages and the sensors developed were deployed for material quality assessment within the business, both in the UK and elsewhere in the EU. Exploratory product concepts were well received in qualitative professional and consumer research. The programme included exploration of other relevant biomarkers that informed the Healthy Ageing programme and, although the sensors have yet to be commercialised, there is still considerable potential for rapid assessment of markers of dietary intake and Professor Catt continues to collaborate with the University of Bedfordshire (*e.g.* ref 3.3).

*Indicators of the extent of the impact*

The extent of the impact of the University of Bedfordshire work on Johnson & Johnson's business is reflected by the international scope of the patent applications (China, US and IPO agencies; section 5). The position is similar with respect to the work for Unipath/Unilever (US and IPO patents). Although the CellSense™ instrumentation is no longer available in the UK, it is manufactured and distributed in China ("ToxTell"; *Biosensors and Bioelectronics* 41 2013 557-562) and the patented redox-mediated biosensor approach to rapid toxicity assessment continues to be exploited in the UK (e.g. Rothamsted Research, 5.3; and Environment Agency, 5.4) and across the world.

*Dates of when these impacts occurred*

2008 to present.

**5. Sources to corroborate the impact**

Much of the work carried out by the Sensor Research Group was funded by industrial research contracts rather than research grants and the University is not at liberty to use business information other than for the purpose of the contracts. Patent applications submitted by sponsors encapsulate those parts of the work considered (by the sponsors) to be significant to the company and worth protecting. People representing the following the organisations are willing to corroborate the impact of the Sensor Research Group's work in their areas:

5.1 Johnson & Johnson (Concepts and New Product Technologies) for research impact in biomarkers for health and wellbeing with respect to Chinese Patent Application CN 101680875(A), US Patent Application 2009/0325307, US Patent Application 2009/0325307, US Patent Application 2009/0302872 and International Patent Application WO 2009/034284.

5.2 Alere International: Derwent House, University Way, Cranfield Technology Park, Cranfield, MK43 0AZ for research impact in biomarkers for health and wellbeing with respect to World Intellectual Property Organisation Patent Applications WO 2009/021908 and WO 2009/021907, and US Patent 7198708 for the work with Unilever Corporate Research and Unipath Diagnostics

5.3 Rothamsted Research with respect to sensors for rapid toxicity assessment in environmental

applications and protection particularly for use with soils.

5.4 Environment Agency with respect to sensors for rapid toxicity assessment and more generally for environmental monitoring and protection.