Institution: Loughborough University

Unit of Assessment: B8 Chemistry

Title of case study: Intelligent Energy: A $500M Loughborough spin out company

1. Summary of the impact (indicative maximum 100 words)

Electrochemistry research in the Department of Chemistry (and associated research in Aeronautical and Automotive Engineering) at Loughborough University (LU) since 1993 has led directly to the development of a new generation of clean power systems based on advanced fuel cell technology. This resulted in **the creation of a spinout company** based on a license awarded by LU: Advanced Power Sources Limited (APS) in 1995. Intelligent Energy (IE) Limited (founded in 2001 upon the acquisition of APS), has a global presence: a workforce of over 350 highly skilled employees, significantly advanced technology, and investment in R&D. Environment improvements have been achieved through introduction of zero-emission fuel cell systems.

2. Underpinning research (indicative maximum 500 words)

The Fuel Cell Group at Loughborough University was formed in 1988 to focus on research in fuel cell technology in the Department of Chemistry in collaboration with Aeronautical and Automotive Engineering. This led to the construction of the first 1 kW proton exchange membrane fuel cell in 1995, when the spin out company Advanced Power Sources Limited (APS) was formed to work on the pre-commercial development of prototype fuel cells. Intelligent Energy was formed in 2001 to acquire APS and attract private capital investment. Initially a 25 person strong company based in Loughborough and London offices, it secured an irrevocable, worldwide license to exploit all of both APS's and the University group's fuel cell related IP. Key research staff from Loughborough University were involved in setting up both companies, including Dr Phil Mitchell and Dr Paul Adcock. Dr Mitchell, a lecturer in the Department of Chemistry at the beginning of the project, is now Chief Technology Officer and Executive Director of Intelligent Energy, is an electrochemist with over 20 years of experience in fuel cell and related fields who obtained his BSc and PhD at Loughborough University and was a co-leader of fuel cell research at Loughborough University. Dr Adcock is Director of Research and Technology, heading up teams at Intelligent Energy developing PEM (proton exchange membrane) fuel cell stacks and systems, and was also part of the Fuel Cell Group at Loughborough University. Additionally, Jon Moore was a researcher in the Chemistry Department during this period. He contributed to key research findings, and is now the Communications Director for Intelligent Energy.

The research carried out at Loughborough University contributed directly to knowledge in the area of fuel cell development at the time. These studies were carried out and published in the period 1997-2001. Operating pressure has a direct effect on fuel stack efficiency since it increases the cell potential. Research at Loughborough showed that a 33% efficiency gain was achieved at an operating pressure of 4 bar **[3.1]**. Solid polymer fuel cells are suitable sources for short duration, high power pulses, but this requires the cell design, component materials and membrane assemblies to be tested. Loughborough research showed that best performance was achieved with low equivalent weight, thin membranes with high catalyst utilization and optimized flow designs **[3.2]**. This also required new techniques for the fabrication of the electrodes **[3.3]** The effects of contamination of the fuel cell were assessed for common pollutants such as carbon monoxide, sulfur monoxide, nitrogen dioxide, hydrocarbons, as well as chemical weapons that may be present in a battlefield environment **[3.4]**. At normal concentrations, little effect was found for the first class of contaminants, but the chemical weapons class had serious effect on performance. These studies were carried out in the period 1995-2001. The research also discovered advanced humidification techniques that obviate the need for external humidification, a major saving in space and weight for the fuel cell system package; an extremely important factor in transportation applications in 2000.**[3.5]**

The papers [3.1-3.4] are in peer reviewed journals or invited contributions and [3.5] is an international patent. This meets the requirement that the underpinning research is at least of 2* quality. In addition, the underpinning grant income outlined below, which led to these papers was peer reviewed in competitive responsive mode.

Key researchers for LU contributing to this project were: Dr. Phil Mitchell (PhD and lecturer 1980 until 1998, now Chief Technology Officer at IE), Dr Paul Adcock (PhD and Senior Lecturer 1984 until 2001, now Director of Research at IE), Dr. Jon Moore (PhD and Research Associate 1992 until 2001, now Communications Director at IE), Dr. Simon Foster (PhD and Research Associate 1993 until 1995, now Technology Specialist at IE), Dr. Chris Dudfield (PhD and Research Associate 1993 until 2001, now Technical Director: Corporate Development at IE)

3. References to the research (indicative maximum of six references)

3.1 Effect of operating pressure on the system efficiency of a Methane-fuelled solid polymer fuel cell power source, Virji, MBV; Adcock, PL; Mitchell, PJ; Cooley, G. Journal of Power Sources, 71 (1-2):337-347 1998. DOI:10.1016/S0378-7753(97)02764-X

3.2 Solid polymer fuel cells for pulse power delivery, Lakeman, JB; Mepsted, GO; Adcock, PL; Mitchell, PJ; Moore, JM. Journal of Power Sources, 65 (1-2):179-185 1997. http://dx.doi.org/10.1016/S0378-7753(96)02616-X

3.3 Development and characterisation of a novel electrode fabrication technique for use in solid polymer fuel cells Foster, SE; Mitchell, PJ; Mortimer, RJ; Adcock, PL Editor(s) Attewell, A; Keily, T. Power Sources, 15 15407-418 1995. ISBN: 0951232045. ISSN: 0743-7137

3.4 The effects of battlefield contaminants on PEMFC performance, Jon M. Moore, Paul L. Adcock, J. Barry Lakeman, Gary O. Mepsted, Journal of Power Sources 85, 254–260, 2000. http://dx.doi.org/10.1016/S0378-7753(99)00341-9

3.5 PL Adcock, PJ Mitchell, SE Foster, Electrolytic and fuel cell arrangements, US Patent 6,040,075, Loughborough University, 2000

Research funding
EPSRC Grant GR/L60074/01; Carbonaceous bipolar plates for solid polymer fuel cells; M. Turpin and P. Mitchell; £233K; 1998-99.
EPSRC Grant GR/K59507/01; Computer modelling of solid polymer fuel cells, P. Adcock, P. Mitchell and J McGuirk, £218K, 1996-98.
EPSRC Grant GR/K87524/01; Low cost component design for solid polymer fuel cells; P. Mitchell and P. Adcock, £96K, 1996-1998.
EPSRC Grant GR/H16575/01; Design and construction of a solid polymer fuel cell based power source and associated processing unit.; P. Adcock and P. Mitchell, £183K, 1991-1995.

Technology Strategy Board funding: Project #210008, (H2Origin); project partners: Intelligent Energy Ltd, Prodrive, PSA Peugeot Citroën and Robert Bosch GmbH; Technology Strategy Board investment: £1,717,600, Total project investment: £4,090,500.
http://www.innovateuk.org/content/case-study/results/ultra-low-emission-vans-of-the-future.ashx

4. Details of the impact (indicative maximum 750 words)

A spin out company has been established and a new technology sector has been created: There is a clear link between research at Loughborough University in electrochemistry and methane and hydrogen-based fuel cell power sources. This is evidenced through the involvement of Dr. Phil Mitchell, a lecturer in the Department of Chemistry, in the underpinning research and his departure from Loughborough University to form the spinout company Advanced Power Sources Limited, and subsequently Intelligent Energy in 2001. Dr. Jon Moore, was a researcher in the Department of Chemistry and is now also with Intelligent Energy. Professor Roger Mortimer is a co-author on some of the publications cited in Section 3 and is still in the Department of Chemistry. Section 3 lists supporting evidence in the form of refereed papers, research funding (e.g. EPSRC and TSB) and patents. Research in related areas of electrochemistry is on-going in the Department of Chemistry (in collaboration with Aeronautical & Automotive Engineering) at Loughborough

University (LU), funded in part by EPSRC.

Intelligent Energy (IE) has strong links to LU, commencing in the late 1980s when researchers in the Department of Chemistry collaborated with the Department of Aeronautical and Automotive Engineering to create one of Europe's first research and development teams working on the development of proton exchange membrane (PEM) fuel cell technology. The UK's first kilowatt-level PEM fuel cell stack was constructed by the Loughborough Univeristy team in 1995, and the commercial implications of the work became apparent. A University spin-out company was formed called Advanced Power Sources (APS) Ltd. APS was the first company established in the UK to specifically address the development and commercialisation of PEM fuel cells.

With respect to the REF Impact timeline, and impact in period since 2008, in addition to its head quarters in Loughborough and office in London and its operation in the US, Intelligent Energy has representation in Japan and in the emerging markets of India. It has been ranked 27th in The Times 100 Fastest Growing Technology Companies **[5.1]** and 15th in the Deloitte 2013 Fast 50 list of companies ranked by revenue growth driven by technology innovation **[5.2].**

Economic Impacts: jobs created, investment raised, evidenced by business performance measures: IE currently employs some 350 personnel **[5.3] [5.4]** and it is anticipated by the company that this will rise to 400. The majority are in the UK (Loughborough), with other bases in the US, Japan and India. In 2011/12, shareholder investment was in excess of £100M since incorporation. It had a 269% revenue growth, 150 patents granted and 298 others pending in 76 patent families filed around the world **[5.3] [5.4]**. The company was valued at $0.5B in 2012. R&D expenditure accounted for more than 30% of total turnover **[5.3] [5.4]**. Strong links and collaboration exist between LU and IE on fluid transport, fuel cell control and system integration, materials and reliability **[5.3]**. The company has conducted numerous projects with LU and fully expects such collaborative agreements to continue in the future **[5.3]**.

Intelligent Energy has collaborated with many high profile partners in the development of mobile fuel cell power sources, including Peugeot Citroën, Suzuki, Boeing, Airbus, Lotus and others. These collaborations have led to the development of the world's first purpose-built motorbike with a fuel cell power source, fuel cell aircraft and zero emission road vehicles. Technology Strategy Board support for several of these collaborations is a measure of the strategic importance of fuel cell development to the UK.

A collaboration with PSA Peugeot Citroën (one of the world's biggest producers of electric vehicles), Prodrive, and Robert Bosch GmbH, funded by TSB (H2Origin project), led to the integration of fuel cell technology in a standard Peugeot Partner electric van **[5.5]**. Intelligent Energy has worked with LTI Vehicles, Lotus and TRW Conekt to develop a zero emission fuel cell hybrid London taxi (also supported by TSB). The first vehicle was unveiled in 2010 and a fleet of 100 vehicles were available for the 2012 Olympics **[5.6]**. Collaboration with Boeing resulted in the inaugural flight of the world's first manned fuel cell aircraft, powered by an IE power source in 2008. **[5.7]**

A major collaboration with Suzuki has led to the incorporation of an IE fuel cell power source in the world's first fuel cell motorcycle, the Burgman Fuel-cell Scooter, which was announced at the 2009 Tokyo motor show. The show also previewed the Tokyo Preview: Suzuki SX4-FCV Hydrogen Fuel Cell concept car. The Burgman motor cycle was the first fuel cell vehicle to receive Whole vehicle Type Approval in the EU in 2011 **[5.8]**. This has led on to the first ready to scale fuel cell production line in Japan. **[5.9]**

The research from the Unit underpinned these impacts. In turn these have had demonstrable economic impacts through the creation of a new company in a growing business sector, employing hundreds of people and creating new business partnerships and markets. In addition, the use of fuel cells has an environmental impact through reduction of pollution and emissions.

5. Sources to corroborate the impact (indicative maximum of 10 references)

The following sources of corroboration can be made available at request:

5.1 2013 Tech Track 100 league table
http://www.fasttrack.co.uk/fasttrack/leagues/tech100leaguetable.asp?siteID=3&searchName=&yr=2013&sort=num&area1=99

5.2 Deloitte2013UK Fast 50 winners
http://www.deloitte.co.uk/fast50/winners/2013-winners/index.cfm

5.3 Letter of Support from Intelligent Energy.

5.4 Intelligent Energy Annual Report 2012.

5.5 Ultra-low emission vans of the future, PSA project, joint research with Intelligent Energy,
http://www.intelligent-energy.com/automotive/case-studies/psa

5.6 Fuel Cell Black Cab prototype First Drive,
http://www.cleangreencars.co.uk/jsp/cgcmain.jsp?lnk=401&featureid=1170
London black taxi cabs to run on hydrogen by 2012 Olympics,
http://www.environmenttimes.co.uk/news_detail.aspx?news_id=668

5.7 Boeing project, joint research with Intelligent Energy, 70 kW fuel cell system in light aircraft.
http://www.wired.com/autopia/2008/04/in-an-aviation/

5.8 Suzuki Burgman project, joint research with Intelligent Energy, 1.6kW fuel cell system in Burgman motor bike.
http://www.which.co.uk/news/2011/03/suzuki-burgman-fuel-cell-scooter-gets-approval-247213/

5.9 Intelligent Energy and Suzuki Motor Corporation Announce Completion of Ready-to-Scale Fuel Cell Production Line in Japan, http://www.intelligent-energy.com/about-us/media-room/news/company-news/2013/02/20/intelligent-energy-and-suzuki-motor-corporation-announce-completion-of-ready-to-scale-fuel-cell-production-line-in-japan