Institution: Imperial College London

Unit of Assessment: B8 – Chemistry

Title of case study: B8-3 Bramble Energy – Exploiting Materials Chemistry to Manufacture Practical Hydrogen Fuel Cells

Period when the underpinning research was undertaken: September 2009-September 2018

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Professor Anthony R.J. Kucernak	Professor of Chemical Physics	7/1995 – present day

Period when the claimed impact occurred: 1st August 2013 – 31st December

Is this case study continued from a case study submitted in 2014? N

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

Building on seminal materials chemistry research at Imperial College London funded by EPSRC, Carbon Trust, InnovateUK, and Climate KIC, Bramble Energy Ltd (BE), formed in 2015. BE develops, and currently sells and profits from, a unique, patent protected, high volume manufacturable hydrogen fuel cell - the PCBFC™. BE recently secured £5M series A funding from BGF, IP Group, Parkwalk Advisors and UCL Tech fund. The company partners with Linde (BOC) to sell a fuel cell power generator, and with Taylor Construction Plant to provide portable LED lighting towers for industrial sites. BE is negotiating with automotive companies [redacted] about the use of its technology in passenger vehicles and with industrial portable power suppliers [redacted]. BE has successfully demonstrated its technology with a major medical device company [redacted] and met all requirements (including cost) for the required device. This led to development of an oxygen sensor for use in ventilator applications for treatment of Covid patients. BE currently employs fourteen FTEs with Kucernak as CSO and chair of the Scientific Advisory Board and commercial sales [redacted] in 2020.

2. Underpinning research (indicative maximum 500 words)

Background: after many years, hydrogen powered fuel cells are becoming a reality through their use in cars and a wide range of portable applications. In realising a carbon free future, the UK and rest of the world will need to rely on these classes of devices to convert green hydrogen into electrical energy and hence we are now seeing a rapid deployment of fuel cells (see below).

The industry wide "Fuel Cell review" presents that in 2019 1200MW of fuel cells were delivered, showing an annual average 42% rate of growth over the last five years. Even with a more moderate forward-looking growth rate of 17% (2018-2025), the fuel cell market is expected to reach $25bn in 2025 (source: Grand View Research: Fuel Cell Market Size, Share & Trends Analysis Report, 2019 – 2025. September 2019).

Research Accomplishments: work on the underpinning materials chemistry, which lead to BE, took place within an EPSRC project "The Flexible Fuel Cell**" [i]**, leading to a patent application by Brett and Kucernak **[1]**. It became obvious that was a good opportunity to drastically reduce the manufacturing costs of current fuel cells by producing them on available printed circuit board manufacturing lines. Subsequently a proposal to the Carbon Trust was successful and the Kucernak team obtained a first tranche of funds **[ii]** associated with de-risking the technology and establishing the ultimate possibilities of cost reduction. From this work, Kucernak developed ideas which went into the 2nd patent **[2]**. A further grant from the Carbon Trust[iii] along with Impact acceleration funds at Imperial **[iv]** allowed much more extensive testing of the fuel cells, and

development of a new corrosion protection layer for the copper used in printed circuit boards leading to a key enabling technology based on new chemistries for corrosion protection and a third patent **[3]** and three papers **[4-6]**. Following these promising results, a TSB grant was obtained **[v]** which allowed the group to go to a PCB toll manufacturer, ZOT Engineering Ltd, and start producing systems on their production line **[C]**. A benefit of the PCB technology is that it is very robust compared to current fuel cell hardware (link to video comparing contemporary fuel cell plate to BE hardware). In 2015, BE was formed (named after the Kucernak's family cat) with Kucernak as an Executive Board Member and CSO, and the three patents were licensed to it. At the same time funding was obtained from the Climate KIC **[vi]**. BE was initially angel funded and subsequently obtained significant investment from the IP Group as part of their Investment Accelerator Pilot.

BE relies on a model wherein manufacturing takes place within industry standard printed circuit board (PCB) manufacturing plants, and hence there is no need to have its own manufacturing facilities. To put BEs technology in context, a single existing PCB factory could be used to manufacture >5 GW of fuel cell modules per year using BE's patented technology, representing a fourfold increase over the entire worlds fuel cell production in 2019. Currently worldwide there are more than 200 PCB factories of this size with 40 new factories coming on-line in China alone (Source: The 2018 NTI-100 Top Global PCB Fabricators", PCB007 Magazine).

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

[1] PCT/EP2012/053479, Brett, D.J.L.; Kucernak, A.R.J., "Fuel Cell Comprising at least two Stacked Printed Circuit Boards with a Plurality of Interconnected Fuel Cell Units", Priority patent application date 29/2/2012. Assignees: Imperial Innovations Limited and UCL Business PLC. Licensed to BE. Status (20/7/2020): Granted in China, US, Japan, South Korea and South Africa. Prosecution in Canada, EPO, India in progress. Divisionals filed in major jurisdictions and awaiting examiners' reports.

[2] PCT/GB2013/051162, Kucernak, A.R.J., "Fuel Cell", Priority patent application date 3/5/2013. Assignees: Imperial Innovations Limited. Licensed to BE. Status (20/7/2020): Granted in EPO, Japan, USA, South Africa China. Prosecution in Canada, India, South Korea in progress. Divisionals filed an major jurisdictions and awaiting examiners' reports.

[3] PCT/GB2017/051697, Kucernak, A.R.J.; Lapinski, J. "Corrosion Protection Coating", Priority patent application date 10/6/2016. Assignees: Imperial Innovations Limited. Licensed to BE. Status (20/7/2020): National phase (PCT) in Canada, China, Hong Kong, EPO, India, Japan, South Korea, USA, South Africa, UK.

[4] O.A. Obeisun, Q. Meyer, J. Robinson, C.W. Gibbs, A.R. Kucernak, P.R. Shearing, D.J.L. Brett, Development of open-cathode polymer electrolyte fuel cells using printed circuit board flow-field plates: Flow geometry characterisation, International Journal of Hydrogen Energy, 39 (2014) 18326-18336., DOI: 10.1016/j.ijhydene.2014.08.106. Times Cited: 36 (as of 14/1/2021)

[5] F.A. Daniels, C. Attingre, A.R. Kucernak, D.J.L. Brett, Current collector design for closed-plenum polymer electrolyte membrane fuel cells, Journal of Power Sources, 249 (2014) 247-262. DOI: 10.1016/j.jpowsour.2013.10.075. Times Cited: 12 (as of 14/1/2021)

[6] Obeisun, O. A., Meyer, Q. P.-G., Robinson, J., Gibbs, C., Kucernak, A. R. J., Shearing, P. R., & Brett, D. J. L. Advanced Diagnostics Applied to a Self-Breathing Fuel Cell. *ECS Transactions, 61*(27)(2014), 249-258. doi:10.1149/06127.0249ecst Times Cited: 12 (as of 14/1/2021)

External Funding (Grants):
[i] Kucernak, EP/G041792/1 – "The Flexible Fuel Cell**",** EPSRC, Oct 2009-March 2013, £217k.

[ii] Kucernak, URN02, Phase 0 accelerator grant**,** Carbon Trust, April 2011-October 2012, £198k.

[iii] Kucernak, URN02, Phase 2 accelerator grant**,** Carbon Trust, November 2012-October 2014, £322k.

[iv] Kucernak, EP/K503733/1 [Imperial College Impact accelerator grant] – Pathways to Impact - Development of a demonstrator for "The flexible Fuel Cell"**,** EPSRC, Feb 2013-Jan 2014, £67k.

[v] Kucernak, 39036-279170, "Flexi-planar fuel cell manufacturing"**,** Technology Strategy Board, Aug 2014-July 2017, £170k.

[vi] Kucernak, "Bramble Energy Fuel Cells", Climate-KIC UK Accelerator Programme, June 2015-May 2016, €20k.

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

Economic benefits are four-fold:

(i) **The formation of a company, Bramble Energy Ltd (BE) [A],** which employs fourteen FTEs (Kucernak – founder and CSO, Dr Tom Mason – CEO, Dr. Erik Engebretsen – Head of Engineering, Dr. Vidal Bharath Head of Operations, Prof. Dan Brett - Director of Innovation) and manages the development of the underlying technology. This has led to wealth creation and employment within the UK. BE has received Series A investment of £5M **[A]**, an event noted in the Daily Telegraph **[B]**. In 2020 BE first had initial sales [redacted]. BE additionally supports down-stream job creation in a number of suppliers including ZOT Engineering, GGM Engineering, Air Engineering Group, and PDR.

(ii) **BE supports a number of other "downstream" companies** as its model is to outsource manufacture to a number of sub-companies, such as ZOT printed circuit boards **[C]**. ZOT employs 220 people at their site in Inveresk Mills Industrial Park, Musselburgh. BE also uses components manufactured from important UK industrial producers such as Johnson Matthey Fuel Cells, who manufacture catalysts and electrodes for fuel cells. BE partners with users in a wide range of areas. Examples include BOC (Linde) who are using BE fuel cells in their products **[D]**, and companies such as Taylor Construction Plant Ltd (TCP) who are using the BOC systems (containing BE fuel cells) to power a wide range of devices such as industrial lighting towers **[D, E]**.

(iii) **From an investor perspective**, BE is one of a range of companies allowing the rapid growth of the Clean Technology sector in the UK **[B]**. The Office of National Statistics has estimated that turnover in the UK low carbon and renewable energy economy (LCREE) has increased to £46.7 billion in 2018, compared to £40.4 billion in 2015[D]. In the recent business section of the Sunday Times [27 December 2020, "HOPE BLOOMS FOR 2021"], Entrepreneurs were asked to list the start-ups they see thriving in the new Britain of 2021. In the article Stephen Welton wrote that "*To achieve the UK's target of net zero greenhouse-gas emissions by 2050 will require revolutionary changes in energy use, and that can't be done without innovative start-ups. BE makes hydrogen fuel cells, which generate power from an electrochemical reaction rather than combustion. The technology can use existing manufacturing facilities, cutting the time and investment needed to bring the products to market.*" **[B]**.

(iv) Contribution to the emerging "Green Industrial Revolution" energy sector. BE is a start-up working in the area supported by the UK government push towards the use of hydrogen in the governments "The Ten Point Plan for a Green Industrial Revolution" in which point 2 is "Driving the growth of low carbon hydrogen", an area which could deliver support for up to 8,000 jobs by 2030, potentially unlocking up to 100,000 jobs by 2050 in a high hydrogen net zero scenario with over £4 billion of private investment in the period up to 2030 leading to savings of 41 MtCO2e between 2023 and 2032, or 9% of 2018 UK emissions. This area is associated with £350 million worth of funding to help decarbonise industry, including dedicated funding for green hydrogen.

George Mills Technology, Investor **at the major investment fund BGF wrote** "*Bramble has created a world-first in the production of hydrogen fuel cells, with the potential to transform a global and growing market. Critically, Bramble has inherent scale-up potential with fuel cells that can be made in PCB factories around the world. BGF is backing a pioneering team with significant commercial acumen. As the UK advances towards its greener future, the cleantech industry is one of increasing interest to BGF, with our capital and financial firepower designed to help accelerate growth and provide long-term partnerships*." **[E]**

Neil Cameron, Investment Director at the major investment fund Parkwalk wrote "*The fuel cell market appears to have finally reached a tipping point within which Bramble's highly scalable technology can enable widescale adoption.*" **[E, G]**

Societal benefits. BE is involved in bringing the concepts of lower carbon footprint and energy usage to the general society. DEFRAs recent CLEAN AIR STRATEGY 2019 states that the long-term exposure to man-made air pollution in the UK has an annual impact on shortening lifespans, equivalent to 28,000 to 36,000 deaths with the majority of those deaths associated with transport emissions. This has resulted in the Department of transport to mandate the shift to electric vehicles (including Hydrogen Fuel Cell vehicles) by 2030 (Government takes historic step towards net-zero with end of sale of new petrol and diesel cars by 2030). BE has already demonstrated the use of its fuel cells in transport **[D, G, H]** and is working with a number of automotive providers [redacted] to implement their fuel cells in passenger vehicles.

Public policy or services benefits. BE and specifically Kucernak have been involved in a number of Governmental and industrial workshops and contributed to the major Royal Society policy briefing document "Options for producing low-carbon hydrogen at scale" associated with scoping out the future pathways towards rapidly accelerating decarbonisation of society.

Positive health impacts and environmental benefits. The systems that BE are working on will contribute to a cleaner environment with reduced emissions of harmful gaseous pollutants which are estimated to cause an extra 4.2 million yearly deaths worldwide (source: WHO) or an extra to 28,000 to 36,000 deaths per year in the UK (source: European Heart Journal) . Reduction in emissions associated with particulates and NOx from diesel emissions will contribute to a less polluted urban environment through the use of BE hydrogen fuel cells in electric vehicles (see below). Furthermore, BE is working with a portable industrial electricity generator company [redacted] on portable fuel cell generators to reduce air pollution on industrial sites **[D]**: a 5kW diesel generator produces as much carbon monoxide as 450 cars (Source: US consumer product safety commission)! By working with BOC, TCO and others [redacted], BE is developing replacements for these generators with clean, quiet fuel cell systems which only produce water as their exhaust **[D, E]**. (2) The longer-term goal is to put BE fuel cells in vehicles, as these will be able to drastically decrease the emissions and improve the energy efficiency of transport. To that goal, BE is already negotiating with vehicle manufacturers about the use of fuel cells in their vehicles and have demonstrated a project in which BE fuel cells operate efficiently in transportation **[D, G, H]**, The company is in discussion with various other manufacturers and centres: Advanced propulsion centre, and major automobile manufacturers [redacted]. As fuel cells demonstrate a much higher energy efficiency than internal combustion engines, the shift to hydrogen powered fuel cells will allow a reduction in UK emissions of carbon dioxide, and also provide a path towards a sustainable economy in which the storage of renewable energy is facilitated through water electrolysis to hydrogen and when required the energy stored within the hydrogen is converted back to electricity in a fuel cell.

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

[A] Letter from CEO and CTO of Bramble Energy.

[B] Coverage by The Telegraph (Monday 3 August 2020), The Telegraph (19 October 2019) and Sunday Times (27 December 2020). (Archived here)

[C] ZOT printed circuit boards, "FUEL CELL MANUFACTURING", http://www.zot.co.uk/newsitem.php?id=54 (Archived here)

[D] Multiple articles in Fuel Cells Bulletin 2018. (Archived here)

- Aberdeen construction site uses BOC Hymera in TCP lighting tower
- Bramble Energy H20 prototypes in testing
- Bramble Energy makes progress on 5kW air-cooled PCBFC stack
- Revolve unveils van-range-extended with Bramble PCB fuel cell

[E] "Bramble Energy – significant new capital to accelerate its unique fuel cell deployment" Parkwalk Investments, August 2020. (Archived here)

[F] "Low carbon and renewable energy economy, UK: 2018", Office of National Statistics, January 2020. (Archived here)

[G] Letter from Parkwalk Advisors

[H] Letter from Head of Cleantech, IP Group PLC.