Institution: University of the West of England, Bristol

Unit of Assessment: 12

Title of case study: Pee Power – microbial fuel cell electricity generation for safe sanitation

Period when the underpinning research was undertaken: 2002 – 2019

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:
Ioannis Ieropoulos	Professor of Bioenergy	2002 – present
John Greenman	Professor of Microbiology	2002 – 2016
Chris Melhuish	Professor of Robotics	2002 – present
Jonathan Winfield	Lecturer in Bioenergy	2008 – present
Alexis Walter	Senior Research Fellow	2012 – present
Iwona Gajda	Senior Research Fellow	2011 – present
Jiseon You	Research Fellow	2015 – present

Period when the claimed impact occurred: 2014 – 2020

Is this case study continued from a case study submitted in 2014? No

1. Summary of the impact

Over 2 billion people globally lack basic sanitation facilities, and over a billion are also without electricity. Researchers at the University of the West of England (UWE) have developed an inexpensive Microbial Fuel Cell (MFC) technology, Pee Power®, which addresses both these challenges. Pee Power urinals use unprocessed urine to generate sufficient electricity to light cubicles. With funding from the Bill and Melinda Gates Foundation, this technology has been developed to the point of practical application. Units have been installed in schools in Uganda and Kenya, and in an informal settlement in South Africa. They have helped several thousand students and local residents feel safer while using toilet facilities at night. In addition, Pee Power toilets have changed awareness, knowledge and public attitudes through three years of installations at Glastonbury Festivals. The technology has also been evaluated by humanitarian organisation, Oxfam, who see it having major potential for future provision of sanitation in disaster zones.

2. Underpinning research

Microbial fuel cells (MFCs) generate power using wastewater as fuel. Bacteria inside the MFCs break down organic matter, releasing electrons and cleaning the liquid. MFC research at UWE began in 2002, with Professor Ieropoulos developing the world's first autonomous MFC-powered robots (EcoBots) (**R1**). Realising the potential of MFC technology to change lives, the Bristol Bioenergy Centre (BBiC) at UWE focused on developing MFC technology for wider societal implementation. This meant working with higher energy density and lower-cost materials (**R2**). Such a consideration was rare amongst other laboratory-based groups internationally, who use expensive and unsustainable materials (such as noble metals) for research. BBiC projects began to focus on optimising MFC components for wastewater treatment, and in 2011 the group reported for the first time that unprocessed urine works extremely well as fuel for MFCs (**R2**). This finding was instrumental in Ieropoulos securing both an EPSRC Fellowship (**G1**) and a follow-up EPSRC commercialisation grant (**G2**), and

also obtaining a linked series of grants from the Bill and Melinda Gates Foundation (**G3**, **G4**, **G5**, **G6**).

In 2012-13, work by Winfield *et al.* led to the development of ceramic MFCs (**R3**). This has been crucial for implementing the technology in remote and/or poor areas, where clay can be sourced locally at very little cost. Research by Gajda *et al.* focused on improving the design of ceramic MFCs by developing cylindrical reactors (**R3**). These novel MFCs produce three times as much power. The cylindrical stacks also produce a by-product with antimicrobial properties that can be used as a disinfectant (**R3**).

With a focus on size and power scale-up, BBiC developed expertise on how best to configure multiple MFCs into three-dimensional stacks. This opened up opportunities for new applications of MFC technology, including its potential in the development of smart 'living architecture' (**R4**). MFCs were integrated into three different kinds of conventional house bricks (from Europe and Uganda) to test their ability to produce usable power (e.g. to operate motorised windows) whilst cleaning the property's wastewater (**G7**). The research demonstrated that the conversion of existing and future buildings into micro-power stations and micro-treatment plants was achievable using MFC technology.

BBiC have developed a range of designs, configurations and patents for MFCs (**R5**) with the power output now orders of magnitude higher than a decade ago. In 2003, original BBiC MFCs produced nine nanowatts of power. BBiC MFCs now produce two million nanowatts, and are a fraction of the size. An important technological breakthrough in stack development came with the production of novel multi-electrode boxes, generating power measured in watts rather than microwatts. BBiC's systems today produce between two and three watts of power continuously.

3. References to the research

R1 Melhuish, C., Ieropoulos, I., Greenman, J. and Horsfield, I. (2006) Energetically Autonomous Robots: Food for Thought, *Autonomous Robots* 21:(3), pp 187-198. https://doi.org/10.1007/s10514-006-6574-5

R2 Ieropoulos, I., Greenman, J. and Melhuish, C. (2011) Urine utilization by microbial fuel cells: energy fuel for the future, *Physical Chemistry Chemical Physics* 14: (1), pp 94-98. http://dx.doi.org/10.1039/C1CP23213D

R3 Gajda, I., Greenman, J., Melhuish, C. and Ieropoulos, I. (2015) Simultaneous electricity generation and microbially-assisted electrosynthesis in ceramic MFCs, *Bioelectrochemistry* 104, pp 58-64. https://doi.org/10.1016/j.bioelechem.2015.03.001

R4 You, J., Rimbu, G., Wallis, L., Greenman, J. and Ieropoulos, I. (2019) Living Architecture: Toward Energy Generating Buildings Powered by Microbial Fuel Cells, *Frontiers in Energy Research* 7. https://doi.org/10.3389/fenrg.2019.00094

R5 Ieropoulos, I., Greenman, J. (2015) Patent: Microbial fuel cell, method of controlling and measuring the redox potential difference of the fuel cell, WO2016120641A1, WIPO (PCT).

R6 Ieropoulos, I., Stinchcombe, A., Gajda, I., Forbes, S., Merino-Jimenez, I., Pasternak, G., Sanchez-Herranz, D., Greenman, J. (2016) Pee Power urinal – microbial fuel cell technology field trials in the context of sanitation, *Environmental Science: Water research and technology*, 2, pp 336-343. https://doi.org/10.1039/C5EW00270B

Evidence of the quality of the underpinning research

G1 Ieropoulos, I. *Waste made useful by using Microbial Fuel Cells for energy generation*,

EPSRC, 2010 – 2014, £539,721.

G2 Ieropoulos, I. *New Directions: MFC Commercialisation through continued Research, Networking and Collaboration*, EPSRC, 2013 – 2015, £247,108.

G3 Ieropoulos, I. *Grand Challenges Explorations, Urine-tricity: Electricity from urine,* Bill and Melinda Gates Foundation, 2011 – 2013, £55,555.

G4 Ieropoulos, I. *Grand Challenges Explorations, Phase-II Urine-tricity ++: Electricity from urine*, Bill and Melinda Gates Foundation, 2014 – 2015, £499,701.

G5 Ieropoulos, I. *Urine-tricity III: Electricity from urine*, Bill and Melinda Gates Foundation, 2014 – 2015, £1,052,337.

G6 Ieropoulos, I. *Phase 4 Urine-tricity: Development of Microbial Fuel Cell Platform Technology and In-Field Testing and Support*, Bill and Melinda Gates Foundation, 2019 – 2021, £1,073,748.

G7 Adamatzky, A. *Living architecture*, European Commission, 2016 – 2019, £699,828.

4. Details of the impact

BBiC successfully translated their findings into a pee-powered urinal installation (named Pee Power), which used the urine to fuel the MFCs that generated power for the cubicle's lights. The first Pee Power urinal was installed at UWE's Frenchay campus in March 2015 and then scaled-up for testing in the field at the Glastonbury music festivals (2015-2019) (**R6**). The field trial demonstrated, for the first time, that it was feasible to use MFCs to generate power as well as treat urine.

Pee Power urinals are already having practical impact. Installations in Uganda, Kenya and South Africa have improved safety and sanitation for over 3,600 students and community members. Field trials at Glastonbury Festival raised significant public awareness of MFC technology and its potential for providing sustainable and safe sanitation solutions. These urinals have also offered a huge step forward for humanitarian organization, Oxfam, in their future provision of sanitation in disaster zones.

Improving safety and sanitation: Pee Power in the Global South

In July 2017, the first overseas Pee Power installation was commissioned at the Seseme girls' secondary boarding school in Kisoro, Uganda, funded by the Bill and Melinda Gates Foundation. The school serves 600 pupils, who have access to four toilets. Prior to the installation of the MFCs, these toilets had never been lit, with serious safety implications. In a video interview, the Headteacher commented that '*the girls used to fear to go to the latrines at night*' because of intruders getting into the school (**S1**).



A brick structure was constructed adjacent to the toilets to house the MFC modules. Urine from the first two cubicles in the toilet block flows down into the MFCs, powering lights in the

toilets and providing a safer environment for the girls at night. Following the Pee Power installation, the Headteacher noted that '*since we got this power*…[the girls] *can freely go to the latrines at night, and they are not scared at all, and those strangers no longer come into school*' (**S1**). The International Water Security Network's survey of the girls at the school who used the Pee Power system, highlighted that 86% of respondents found the toilets safer to use at night (**S2**).

In June 2018, a second Pee Power system was installed at the Brainhouse Academy, a mixed-sex primary and secondary academy in Mathare, Nairobi, Kenya. The Academy has around 500 pupils. New toilets at the school would have been unlit without the integration of Pee Power. One Brainhouse teacher commented that Pee Power had '*made the school secure*' and that '…*pupils feel much safer when they visit the toilet during night hours*' (**S3**). Another teacher at the school echoed this point, and also commented on the reduction of rodents in the toilets due to the lights (**S4**). The technology has also enhanced his teaching, as he refers to it when teaching related topics (**S4**).

A third Pee Power system was installed at an informal settlement community of about 2,500 people in Thandanani, Durban, South Africa. This was part of the Bill and Melinda Gates Foundation engineering field-testing platform, used to evaluate technologies sufficiently mature for potential commercialisation. As well as demonstrating feasibility in practice and at scale, at Thandanani, Pee Power has again enabled people to use the toilets at night without the need for torches. A community member at Thandanani commented '*we feel comfortable having lights – you don't have to carry your phone any more*' (**S5**). A Prototype Engineer in the Pollution Research Group at the local University of KwaZulu-Natal praised the Pee Power installation at Thandanani for its '*eco-friendly electricity provision and waste treatment*', noting that the system '*has positively surprised the community and visitors that we can use waste as an energy source*' (**S6**).

Field-testing and support with successive phases for funding from the Bill and Melinda Gates Foundation has supported development to the point where large-scale deployment is now practical in a humanitarian, not-for-profit-context. Early-stage industrial collaboration has also been undertaken (subject to confidentiality) to support commercial development of the technology in selected markets, in line with the terms of agreements with the Gates Foundation.

Pee Power shaping the future of sanitation in refugee camps

Humanitarian organization, Oxfam, became interested in the Pee Power urinals in March 2015. The prototype urinals offered an entirely new solution for Oxfam's delivery of sanitation in disaster zones. The Head of Water and Sanitation at Oxfam, identified Pee Power urinals as a potential '*game changer*' for refugee and displacement camps without lighting for toilet areas, where often '*women going to the toilet at night are facing abuse and being molested*' (**S7**). The Pee Power urinals have several advantages over, for example, solar panels, the performance of which deteriorates with time and which are often stolen. Oxfam are now aware of a viable solution which does not have these limitations (**S7**).

Pee Power enhances environmental profile of Glastonbury Festival and improves public understanding and confidence in sustainable toilets

Field trials at Glastonbury Festival have done much to spread knowledge and understanding of the technology and its potential with the broad-spectrum, developed-world festival audience. This resulted in increased media coverage and resulted in successively larger Pee Power installations, eventually accommodating up to *c*.5000 users per day. Pee Power urinals operated at all the Glastonbury Festivals from 2015 to 2019, with a five-year

memorandum of understanding being signed by Glastonbury and UWE. Glastonbury's sanitation manager commented:

> *'Since 2015, the Pee Power installations at the festival site have helped Glastonbury Festival to position itself as an environmentally and socially responsible event. The installations help raise awareness of environmental issues among festival-goers, in addition to awareness of the situation of the 2 billion people without access to basic sanitation and 1 billion without access to electricity'* (**S8**).

The 2019 Glastonbury installation improved confidence in sustainable toilets for 92% of the 4,745 users who responded using the 'FeedbackNow' pads located inside the urinal - quite an achievement for a music festival (**S9**)! A more detailed survey conducted by the Pee Power team, showed improved awareness among urinal users of the power of innovative technology to make all toilets sustainable, and to address the lack of electricity and sanitation in the developing world (97% of respondents, n=77). 84% of respondents also reported increased awareness of Glastonbury Festival's commitment to sustainability after using Pee Power (**S10**, pp 3-5).

5. Sources to corroborate the impact

S1 Video interview (and transcript) with Headmistress at Sesame Girls School, Kisoro, Uganda

S2 International Water Security Network Kisoro survey report

S3 Testimonial from Teacher A at Brainhouse Academy

S4 Testimonial from Teacher B at Brainhouse Academy

S5 Testimonial from member of the community at Thandanani, Durban

S6 Testimonial from member of the Pollution Research Group, University of KwaZulu-Natal

S7 Video interview (and transcript) with the Head of Water and Sanitation at Oxfam

S8 Testimonial from the Sanitation Manager, Glastonbury Festivals

S9 FeedbackNow Glastonbury survey report

S10 Pee Power at Glastonbury survey report